2006

Estimation of evapotranspiration using continuous soil moisture measurement

Mandana Seyed Rahgozar
University of South Florida

Scholar Commons Citation

Rahgozar, Mandana Seyed, "Estimation of evapotranspiration using continuous soil moisture measurement" (2006). *Graduate Theses and Dissertations.*
http://scholarcommons.usf.edu/etd/2667

Estimation of Evapotranspiration Using Continuous Soil Moisture Measurement

by

Mandana Seyed Rahgozar

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
Department of Civil and Environmental Engineering
College of Engineering
University of South Florida

Major Professor: Mark A. Ross, Ph.D.
Jeff Geurink, Ph.D.
Edward Mierzejewski, Ph.D.
Mahmood Nachabe, Ph.D.
Mark Stewart, Ph.D.
David Sumner, Ph.D.

Date of Approval:
November 6, 2006

Keywords: West Central Florida, Vadose Zone Hydrology, Shallow Water Table,
Potential ET, Groundwater ET

DEDICATION

This research is dedicated to my parents, Mahineh Tavakoli & Jallal Seyed Rahgozar, for the sacrifices they made and my beloved brother Albert whose exceptional strength, unwavering kindness and unique happy spirit were an inspiration to all who knew him. I love and miss you immensely. This is also dedicated to John and Lee Farrinacci, David and Virginia Close, Magnolia Burnett who became my extended family and Minoo and Havva my childhood friends. How I miss each one of you. A special thanks to my special friend Ron Norwood. This research is also dedicated to my major professor Dr. Mark A. Ross whom unwavering support and patience has been with me for many years and in his own right became a major contributor in my life. I also wish to include late Dr. Franques whom served on my master’s defense. Each one of you, in your own unique and gentle ways became an integral part of my life to a point that I simply cannot imagine my life without you. I cherished your values, integrity, kindness, support and understanding. How I wished everyone could have been as lucky as I have been. Napoleon Bonaparte once said “If throughout your life you have one true friend then you have had one more than your share.” I wish I knew what I have done to have deserved your friendships. I promise that I will cherish and uphold the legacy that you so instinctively and effortlessly demonstrated and demanded and simply could not help but to bestow upon those whom were in the enviable position of having your association. How honored I am that God permitted our path to not just cross but become a journey. Thank you again, all of you for everything. It simply would have been impossible without you.

ACKNOWLEGMENTS

The author hereby wishes to extend her sincere thanks to Dr. Mark Ross, P.E., Director of Center for Modeling Hydrologic and Aquatic System, for his unwavering support, extensive contribution and valuable input throughout this research. Also, Jeff Vomacka, P.E. for his field contribution and data collection efforts and Dr. Ahmed Said and Nirjhar Shah for contributing to Journal publications. Appreciation is also extended to Tampa Bay Water (TBW), University of South Florida (USF) and Southwest Florida Water Management District (SWFWMD) for financial assistance that made this research possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ESTIMATION OF EVAPOTRANSPIRATION USING CONTINOUS SOIL MOISTURE MEASUREMENT

Mandana Seyed Rahgozar

ABSTRACT

A new methodology is proposed for estimation of evapotranspiration (ET) flux at small spatial and temporal scales. The method involves simultaneous measurement of soil moisture (SM) profiles and water table heads along transects flow paths. The method has been applied in a shallow water table field site in West-Central Florida for data collected from January 2002 through June 2004. Capacitance shift type moisture sensors were used for this research, placed at variable depth intervals starting at approximately 4 in. (10 cm) below land surface and extending well below the seasonal low water table depth of 59 in. (1.5 m). Vegetation included grassland and wetland forested flatwoods. The approach includes the ability to resolve multiple ET components including shallow and deep vadose zone, surface interception capture and depression storage ET. Other components of the water budget including infiltration, total and saturation rainfall excess runoff, net runoff, changes in storage and lateral groundwater flows are also derived from the approach. One shortcoming of the method is the reliance on open pan or other potential ET estimation techniques when the water table is at or near land surface. Results are compared with values derived for the two vegetative covers from micrometeorological and Bowen ratio methods. Advantages of the SM method include resolving component ET.

CHAPTER ONE BACKGROUND

Introduction

Measurement of the temporal and spatial distribution of evapotranspiration (ET) is a challenge facing the engineering and scientific community. ET estimation is required to calibrate hydrologic models and to assess hydrologic budgets. Basinwide studies have demonstrated that ET is second only to precipitation in magnitude in terrestrial hydrologic budgets of Florida (Jones et al. 1984). ET in shallow water table environments is governed by vegetation cover, soil hydrologic processes and depth to water table (DTWT). Atmospheric potential ET (PET) is a physical and modeling concept controlled by meteorological stresses including solar radiation, relative humidity, wind speed and temperature. The actual ET (AET) from vegetative cover is controlled by PET, available moisture and plant physiology.

Hydrologic models have varying techniques to represent the role of soil moisture in limiting direct soil evaporation and plant transpiration, commonly treated together as evapotranspiration (ET). Evaporation from the soil surface decreases as the shallow soil dries, and this interaction between soil water storage and evaporative loss can be an important aspect of unsaturated zone hydrology (Hillel, 1982). The interaction is more complex when vegetated surfaces are involved because plant-mediated water fluxes depend significantly on physiological and morphological responses of plants to drought, root zone depths, moisture distribution among many other factors.

Despite the importance of ET in hydrologic studies, seasonal and diurnal distributions of particular plant communities, including spatial field-scale and short time-scale variability, remain relatively poorly quantified, and thus a topic deserving further investigation. In areas with pronounced wet and dry seasons and sandy soil, such as west-central Florida, a highly variable and seasonally shallow water table, combined with a wet vadose zone that transitions from very dry to very wet, controls the extent to which plants attain potential ET during the year. Knowledge of seasonal or monthly plant uptake is needed to refine and parameterize hydrologic models used for water supply investigation. A more reliable technique for measuring soil water-balance components, including ET and water table recharge, could lead to more reliable targets for simulation of the water table and thus runoff and groundwater processes.

Soil moisture (SM) is the critical variable that dynamically links plants to the overall water balance, thereby influencing feedbacks to the atmosphere. Below the land surface, plants utilize soil moisture by osmotic uptake. This interaction between soil water storage and evaporative loss is an important component of unsaturated zone hydrology (Hillel, 1982). Knowledge and measurement capabilities of SM within the root zone would be quite useful for estimation of hydrologic fluxes.

During the last decade an increasing number of studies have been focused on dynamic measurement of SM, considering to various degrees explicitly the spatio-temporal variations of this property (Crave and Gascuel-Odoux, 1977**;** Grayson and Western, 1998; Famiglietti et al., 1999). Many studies limit investigation of SM to the near surface (0-5 cm), and have been conducted at different spatial scales (1 m^2 to a few km^2), and temporal scales from days to years (Wilson, et al., 2003; Ladekart, 1998).

Many measurement techniques exist: gravimetric analysis of physical samples, dynamic in situ measured with Time Domain Reflectometry (TDR), Frequency Time Domain (FDR), Neutron Probes; and remote sensing (e.g., satellite approach) over a wide range of hydrologic and climatic conditions. Results from theses studies, have provided more insight into the spatio-temporal dynamics of SM in vegetative environments. Spatio-temporal variability is also influenced by topographic features such as soil surface slope angle (Hills and Reynolds, 1969**;** Moore et al., 1988**;** Nyberg, 1996) and slope orientation (Reid, 1973; Western et al., 1999a), soil (hydrodynamics) properties (Henninger et al,. 1976; Crave and Gascuel-Odoux, 1997), vegetation distribution (Bouten et al,. 1992; Mohanty et al., 2000a), landuse and in particular the agricultural practices (Famiglietti et al., 1999), and finally, by climatic variability (Hawley et al., 1983**).**

Available Models for Measurements of ET and Their Potential Strengths and Weaknesses

The simple fact is no prolonged direct and undisruptive measurement of ET at the field scale can be made. However indirect methods exist. All methods can be grouped in to the following distinct categories: 1) Atmospheric flux estimation 2) Energy balance approaches 3) Soil moisture monitoring (including weighing lysimeter studies) 4) Pan evaporation measurement 5) Water budget estimation and 6) Combined methods. Well known methods include Eddy correlation method (ECM); Energy Balance Bowen Ratio (EBBR); Energy-Balance Wind and Scalar Profile (EBWSP); Eddy Correlation Energy-Balance Residual (ECEBR); Penman (1948), Penman-Monteith (1965) and Modified Priestly-Taylor one-dimensional model (1972). A brief review of previously employed models and their potential weaknesses and strengths, pointed out by researchers employing the models, are presented here for comparison purposes:

Estimating ET by the EBBR, EBWSP and ECM are subject to many potential sources of error. Evaluating those sources and quantifying ET error are extremely difficult. First, applicability of the three meteorological techniques for a given site depends on the assumption of a steady-state atmospheric-boundary layer with negligible horizontal gradients of vertical fluxes. In some studies no attempt may be made to examine the assumption of a steady-state boundary layer; instead, the boundary layer is assumed to be at steady state for the relatively short averaging periods that are used for micrometeorological measurements (20 minutes). Also, attempts may not be made to test for horizontal gradients. The assumption of negligible horizontal gradients may be based on instrument height and fetch guidelines. Second, if atmospheric boundary–layer conditions are met, the problem remains that determining the appropriate time-averaged and space averaged values for the time-series variables needed to compute ET. Measured values of the time-series variables, such as net radiation, subsurface heat flux, vapor pressure difference, and covariance of vertical wind speed and vapor density, are subject both to random and systematic error. Random error can be random measurement error or the result of inadequate spatial or temporal sampling of the time-series variables. Systematic error, or bias, can be a serious source of error for many field measurements (Bidlake, et al., 1996).

Errors in estimating ET by the EBBR and ECM methods can occur if the nature of turbulent transport in the surface sub-layer where the measurements are made departs from the ideal conditions on which the methods are based. For example, assumptions on which the two methods are based are not valid if there are substantial horizontal gradients in vertical fluxes of momentum, heat, or water vapor (Bidlake et al., 1996).

Errors in estimating ET also can arise due to errors in measuring or estimating the variables that are necessary for the application of the EBBR or ECM. ECM is used to measure two components of the energy budget of the plant canopy; latent and sensible heat fluxes. A recurring problem with the ECM is a common discrepancy of the measured latent heat and sensible heat fluxes with energy budget equation. Both fluxes are transported by turbulent eddies in the air generated by a combination of frictional and convective forces. Researchers have shown ECM performs best in windy conditions (relatively high friction velocity). Measurement of the soil heat flux and storage terms of the available energy can be problematic, given the difficulty in making representative measurements of these terms. Assumptions can include the accuracy of measured available energy and that any error in the energy-budget closure is associated with errors in measurements of turbulent fluxes (Sumner 2001).

Measured time-series variables, such as net radiation, subsurface heat flux, vapor-pressure difference and covariance of vertical wind speed and vapor density are subject to random and systematic error. Random error can be random measurement error or the result of inadequate spatial or temporal sampling of the time-series variables (Bidlake and Boetcher 1996). Daily estimates of ET using EBBR, EBWSP and ECM have shown to have strong seasonal variability for each vegetation type. Maximum ET using these methods occurred during May-July for each vegetation type and minimum ET occurred during November-March, strongly driven by available energy and moisture. (Bidlake et al. 1996).

The Penman and Priestley-Taylor methods require less meteorological data and are less computationally demanding than the Penman-Monteith method. The Penman model ET has the potential to be a poor predictor of measured ET with little relation evident between Penman simulated ET and measured ET at a site (Sumner 1996). The discrepancy between model and measured values can be most extreme when canopy coverage and soil moisture are relatively low. However, daily ET rates, simulated by non-traditional Penman-Monteith and Priestley-Taylor models calibrated to a Bowen Ratio variant of the ECM demonstrated strong seasonal variability (Sumner 1996)**.** Upon calibration, ET models provided estimates of ET that were about 10% lower and higher depending upon the selected variant of the eddy correlation method (Sumner 1996). Within the framework of the Priestley-Taylor model, variations in daily ET were primarily the result of variations in surface cover, net radiation, photosynthetically active radiation (PAR), air temperature and water table depth (Sumner 2001).

Available Techniques for Soil Moisture Measurements Used for ET Estimation and Their Potential Strengths and Weaknesses

Direct and indirect methods are available for measuring SM in situ. As yet, there is no universally recognized standard method of measurement and no uniform way to compute and present the result of SM measurements. Investigators have described various problems with previously employed techniques. All methods can be grouped in to the following distinct categories for: Soil Profile Water Content Measurement Method using 1) Neutron Scattering (NS) 2) Gamma-ray Absorption 3) Double-probe Gamma-ray 4) Tensiometer 5) Remotely Sensed SM Monitoring 6) Lysimeter, 7) Time Domain

Reflectometers (TDR) and 8) Frequency Domain Reflectometers (FDR). The advantages and disadvantages of some of the widely used techniques are presented.

Neutron Scattering (NS) - First developed in the 1950s, the NS method has gained widespread acceptance as an efficient and reliable technique for monitoring SM in the field. The principal advantages of the NS are technical basis, non-destructive, robust rapid and simple installation. This method is practically independent of temperature and pressure. Its main disadvantages, however, are the high initial cost of instrument, low degree of spatial resolution, difficulty in measuring SM near the surface zone and the health hazard associated with exposure to neutron and gamma radiation. The NS method, no matter how well calibrated, does not give accurate measurement near land surface where most storage change occurs (Evett et al. 1993).

Gamma-ray Absorption - The gamma-ray absorption method is used mostly in the laboratory, where the dimensions and density of the soil sample, as well as the ambient temperature, can be precisely controlled. A high degree of spatial resolution (~2 mm) can be accomplished by collimation of the radiation. Because the absorption of radiation depends on the intervening mass between the source and the detector, the readings can be only related uniquely to SM if bulk density is constant or if its change is monitored simultaneously (Hillel, 1998).

Double-probe Gamma-ray -The double-probe gamma-ray method has also been adapted to field use and is manufactured commercially. In principal, this technique offers several advantages over the Neutron moisture meter in that it allows much better depth resolution when measuring the distribution of SM throughout the profile. A depth resolution of about 0.4 in. (1 cm) reportedly can be achieved. This resolution is sufficient to detect discontinuities between profile layers as well as movement of wetting fronts and conditions prevailing near the soil surface (Hillel, 1998). However, in some soils, difficulties are encountered in the accurate installation and alignment of two access tubes that must be strictly parallel, and the method requires the accurate determination of soil bulk density, providing problems as bulk density can vary in depth and time.

Problems of temperature sensitivity of the electronic device, which plagued early designs, can apparently be solved, but field calibration with the high degree of depth resolution required remains a difficulty (van Bavel et al., 1985). The health hazard associated with use of gamma-ray equipment is similar in principal to that of Neutron moisture meter. The equipment is considered safe only if strict attention is paid to all precautionary rules.

Tensiometer - The tensiometer is an instrument designed to provide a continuous indication of the soil's matric suction (soil-moisture tension) in situ. Suction measurements by tensiometry are generally limited to matric suction values below 1 atm (about 1 bar, or 100 kPa), mainly due to the fact that vacuum gauges or manometer measurements are limited to partial vacuum relative to the external atmospheric pressure. Soil suction and moisture variation are a unique soil property varying considerably with soil type and vertical layer. Using suction for soil moisture measurements require calibration curves for each soil type and horizon. Furthermore, because the ceramic material used in a tensiometer is generally made of permeable and porous material in the interest of promoting rapid equilibrium with SM, higher suction may cause the entry of air from the soil into the cup (Hillel, 1998)**.** Such air entry equalizes the internal tensiometric pressure to the atmospheric pressure. Consequently, soil suction may continue to increase even though the tensiometer fails to show it. In practice, the useful limit of most tensiometers is a maximal tension of about 0.8 atm (80 kPa).

Remote Sensing - This is the collection of information regarding an object of interest, conducted from some distance without actual contact with that object. It is usually accomplished by detecting and measuring various portions (or bands) of the electromagnetic spectrum, using airborne or satellite-born electronic scanning devices. Remote sensing of the earth's surface includes aerial photography, multi-spectral imagery, infrared imagery, radar, and microwave scanning. These techniques may be passive or active. Passive techniques measure signals emitted or reflected from the ground. Active sensing techniques consist of generating a signal that is sent to the ground, and of measuring its response (Hillel, 1998).

Research conducted in the last three decades on remote sensing technology has shown that SM may be assessed by a variety of methods using specific segments of electromagnetic spectrum, including gamma radiation, visible and infrared radiation, as well as radar and microwaves (Schmugge 1990; Engman, 1991).

Of the various techniques suggested for measuring SM, microwave technology appears to be the most promising at present. It can be used from a space platform (as well as from air-craft and truck mounted devices) and can provide quantitative data of SM in the soil's top layer (approximately the top 5 cm) under a variety of topographic and vegetative conditions (Lin et al., 1994). The aerial resolution of microwave remote sensing of SM is rather coarse. The passive systems currently used only can provide spatial resolutions down to several to tens of kilometers (Engman and Chauhan, 1995). This may be satisfactory for regional-scale and global-scale monitoring of the interactions of climate and terrain (including regional effects of climatic changes or fluctuations, and the assessment of expectable crop yields over large areas), but inadequate for landuse based resolution of urbanizing landscape and local water resources studies.

Active sensors have the capability to provide more detailed data, with a resolution of 66 to 98 ft (20-30 m) over a swath width of 100 km, but their sensitivity to SM is more strongly influenced by surface roughness, topographic features, and vegetation than the passive systems. Research in remote sensing of SM is fast progressing, and may well result in the development of improved techniques in the coming years.

Lysimeter - The most direct method for measuring the field water balance is by use of Lysimeters (van Bavel and Myers, 1962; Hanks and Shawcroft, 1965; Harrold, 1966; Phene et al., 1989). These are generally large containers of soil, set in the field to represent the prevailing soil, vegetation, and climatic conditions and allowing more accurate measurement of physical processes than can be carried out in the open field, Some lysimeters are equipped with a weighting device and a drainage system, which together permit continuous measurement of both ET and rainfall additions. Lysimeters may not provide a reliable measurement of the field water balance, when the soil or above ground conditions of the Lysimeter differ markedly from those of the field itself.

This method is destructive, presents concerns for representation analysis, and is not practical for large or well established vegetation such as natural vegetation landscape (Hillel, 1998).

Time Domain Reflectometers (TDR) – This is a relatively new method for measuring SM wetness, based on the unusually high dielectric constant of water. A dielectric, in general, is a nonconductor of electricity, that is, a substance that, when placed between two charged surfaces (a capacitor), allows no net flow of electric charge but only a displacement of charge. The dielectric constant is also called relative permittivity (or specific inductive capacity). At radio frequencies, the dielectric constant of pure water at 20˚ C and atmospheric pressure is relatively high, normally about 81, that of soil solids varies between 4 to 8 and that of air equals to 1 (Jackson and Schmugge, 1989). Therefore, the value of relative permittivity for a composite of soil body (consisting of the three phases in varying proportions) is largely determined by the fractional volume of water present. As more water becomes present in the soil, the dielectric constant of the mixture increases. The TDR method measures the velocity of propagation of a high-frequency signal reflected back from the end of a transmission line or wave guides in the soil. Wave guides (with two, three or more rods) may be installed in the soil profile vertically or horizontally.

Previous researches revealed TDR arrays showed markedly different soil wetness even when separated only by a 15.74 in. (40 cm) horizontal distance**.** Also, TDR overestimated ET following precipitation due to drainage flux out of the bottom of the 0 to 15.74 in. (0-40 cm) layer and underestimated ET during drying periods due to upward soil water flux into the same layer. TDR estimated changes in daily ET during drying periods showed that an average of 88% of daily total soil profile changes in storage occurred in the top approximately 12 in (30 cm) of soil (Evett et al. 1993).

The TDR method has been well documented by Topp et al. (1980) & Topp (1993). From laboratory experiments at frequencies from 1 MHz to 1 GHz, Topp et al., (1980) determined an empirical relationship between the dielectric constant and soil volume wetness with a standard error of estimate of about 1.3% for all mineral soils. Their data agree very well with results of other researchers working in frequency ranges of 20 MHz to 1 GHz using a wide range of soils and electrical techniques. Nevertheless, soils with high organic content and high clay content (75%) may require site specific calibrations (Herkelrath et al., 1991; Zegelin et al., 1992**;** Bridg et al., 1996) and TDR may not perform well. Various investigators claimed that the volume wetness of soils can be determined with an accuracy of ± 2% and a precision (or repeatability) of ± 1% . Topp and Davis (1985) deemed this accuracy to be sufficient for using the TDR technique for irrigation applications without having to carry out calibration for each soil or field. They recommended that the transmission rods, the typical in situ device, be spaced 2 in. (5 cm) apart.

A potential source of error in TDR measurements may arise from air gaps around each rod or across the pair of rods in the soil. Such gaps may occur during installation or subsequently as the soil tends to shrink upon drying. Installing the rods at an angle (rather than vertically) may help to minimize the formation of cylindrical gaps around the rods. Possible errors due to the temperature changes have been studied (Hillel, 1998).

TDR instrumentation tends to be quite expensive because they must produce a series of precisely-timed electrical pulses, and return voltages at intervals down to around 100 picoseconds. Measurements are typically made on a series of pulses, with the digitized delayed for a set interval on each succeeding pulse, so a complete reflectance trace is built up over perhaps 250 pulses. Because the speed of light in air is around 1 ft/sec (30 cm /sec) and probe lengths range from under approximately 4 to 12 in. (10 cm to perhaps 30 cm), precise electronics are required to resolve apparent probe length with reasonable accuracy. Therefore, the obvious disadvantage of this measurement technique is the expense of the equipment and the numerical challenges of properly analyzing each trace. The advantage, claimed by the manufacturer is that measurements are relatively insensitive to salinity, as long the salinity does not completely attenuate the reflected signal, and temperature. Although the velocity of propagation of the TDR pulse as it travels in the soil is evidently unaffected by the soil solution's electrical conductive, the intensity of the transmitted signal is affected. The attenuation of the signal amplitude (i.e., the reduced voltages) can therefore serve to indicate the soil's salinity (Dalton et al., 1984).

Frequency Domain Reflectometers (FDR) or Capacitance Sensors – Like TDR, FDR utilize the dielectric constant of the soil surrounding the sensors in order to measure the volumetric water content, which is an intrinsic characteristic of the soil-water-air mixture. The dielectric constant of soils can be measured by capacitance. Measurement of the capacitance gives the dielectric constant, hence the water content of the soil. In a straight forward method for measuring capacitance, the capacitor is arranged to be part of an oscillator circuit so that frequency of oscillation is a direct measure of the capacitance (Gardner et al., 1991).

During the last four decades, only a few capacitance probes have been designed and manufactured. Enviro-smart® is a new system that has been developed in South Australia, using semi-permanent multi-sensor capacitance probes. The probes have been widely implemented in the irrigated agricultural industry of Australia since 1991 (Buss, 1993) and have been introduced in the U.S. for over a decade. A water and salinity measurement version of this equipment is under U.S. patent (Watson et. al., 1995). The Enviro-smart® multisensor capacitance probe consists of a plastic extrusion approximately 2 to 59 in. (5 cm 150 cm or ore), datum setting handle, printed circuit board, and a 20-way ribbon cable with connectors for capacitance sensors placed approximately every 4 in. (10 cm) along its length. Each capacitance sensor consists of two brass rings approximately 2 to 1 in. (50.5 mm O.D. and 25 mm high) mounted on a plastic sensor body separated by a 0.47 in (12 mm) plastic ring. Plastic spring guides located on each end of the sensor keep it in the center of the PVC pipe. The conductive rings of the center form the plates of the capacitor. This capacitor is connected to an LC oscillator, consisting of an inductor (L) and a capacitor (C) connected to circuitry that oscillates at a frequency depending on the values of L and C. As the inductor is fixed (seven turns of 0.02 in. (0.5-mm) wire), the frequency of oscillation varies depending on variations of capacitance. The oscillating capacitance field generated between the two rings of the sensor extends beyond the PVC access pipe into the surrounding medium-soil (dielectric). The resonant frequency (F) can be measured using a general formula:

$$F = \left[2\pi\sqrt{(LC)}\right]^{-1} \tag{1}$$

Where L is the circuit inductance and C is the total capacitance, which includes the soil components together with some constants (Dean et al., 1987; Gardner et al., 1991; Whalley et al, 1992; Evett and Steiner 1995).

Since the area of the plates-rings and the distance between the plates rings are fixed on the sensor, the capacitance varies only with varying complex dielectric constant of the material surrounding the plates-rings. Theses sensors have been designed to oscillate in excess of 100 MHz (inside access tube in free air) so as to be essentially immune to conductivity (salinity and fertilizer effects) at levels typically found in agricultural soils. The frequency of oscillation of the Enviro-smart® sensor is divided by a factor of 2048, providing an output frequency proportional to the frequency of oscillation. The data logger powers the sensor up for 0.5 s, then records the pulses during another 0.5 s to provide a count equal to half the output. For example, if the sensor is oscillating at 150 MHz, the output of the sensors would be 73.242 kHz ($1.5 \times 10^8/2048$), so the logger would record a count of 36621 (73242/2). The data logger records the output of the sensor by counting the pulses during a fixed time (0.5 s), therefore the counts are proportional to the frequency of oscillation of the sensors.

The output (frequency) from the sensors primarily varies with variations in the air/water ratio and is measured by the data logger at user-input sampling intervals to obtain a frequency of the soil. Frequency readings of each sensor inside the PVC pipe, exposed to air and water (at room temperature, ~ 22° C), are registered separately before installing the probe in the soil. The frequencies in air, water, and soil are passed through a normalization equation to determine a normalized or scale frequency (SF), defined as:

$$SF = (F_a - F_S)(F_a - F_W)^{-1} \tag{2}$$

Where F_a is the frequency reading in the PVC access pipe while suspended in air; F_S is the reading in the PVC access pipe in soil; and F_W is the reading in the PVC access pipe in the water bath. The *SF* has also been called a *universal frequency*. Until a standard procedure is established and commonly recognized, *SF* is used.

The data logger is capable of reading and storing data from multiple sensors (≤ 32 sensors in two to eight probes) and two analog channels at pre-selected sampling intervals ranging from 1 to 9999 min. During the process of downloading data from the data logger, the *SF* is converted to θ_v percentage using either a default or user-specified calibration equation. The Envirosmart® software can then display the information as total water content in a profile (in millimeters) or at specified depths as a percentage (for this research we are using the latter). The downloaded data may also be converted to standard spreadsheet format for further analysis.

Due to reported accuracies of soil water measurements (Paltineanu et al. 1997), continuous monitoring capabilities, virtually no health related hazard associated with use of the equipment, the ability to set multiple sensors at varying depths from near surface to the zone of saturation, and the relatively affordable initial costs allowing purchase of multiple units, the FDR technique was the equipment of choice for this particular research.

Crop Coefficients

Due to the fact that there are so many factors affecting ET, simplified formulations are often based on limiting the number of parameters and making reference to a potential ET value, to formulate an equation that can produce estimates of ET for different sets of conditions. The idea of reference crop ET (ET_{ref}) was developed by researches interested in crop variability (Doorenbos et al., 1977 and Hargreaves et al., 1985). Reference crops are either grass or alfalfa surfaces whose biophysical characteristics have been studied extensively. Reference ET for a short crop having an approximate height of 0.12 m, e.g., from a standardized grass surface, is commonly denoted as ETo whereas reference ET for a tall crop having an approximate height of 1.64 ft (0.5m), e.g., from a standardized alfalfa surface, is denoted as ETr.

Many theoretical and empirical equations are used to estimate ETo. The choice of any one method depends on the accuracy of the equation under a given condition and the availability of required data. For reference surfaces with known biophysical properties, the main factors affecting ETo include solar radiation, relative humidity/vapor pressure, air temperature, and wind speed. For estimating ET_{ref}, a modified version of the Penman-Monteith equation (Allen et al., 1999) with some fixed parameters has been recommended (Walter et al., 2000 and Itenfisu et al., 2000). The equation is:

$$ET_{ref} = [0.408\,\Delta\,(R_n - G) + \gamma\,(C_n / T+273)U_2\,(e_S - e_a)\,]/\,\Delta + \gamma\,(1+C_d\,U_2) \qquad (3)$$

Where Δ is the slope of the saturation vapor pressure at mean air temperature (kPa $^\circ$ C^{-1}), Rn and G are the net radiation and soil heat flux density in MJ m^{-2} d^{-1} for daily or MJ m^{-2} h^{-1} for hourly data, γ is the psychrometric constant (kPa $^\circ$ C^{-1}), T is the daily or hourly mean temperature (˚ C), U_2 is the mean wind speed in m s^{-1}, and $e_S - e_a$ is the vapor pressure deficit (kPa). The coefficients in the numerator (C_n) and denominator (C_d) are given specific values depending on the calculation time step and the reference crop. The values for C_n vary because the aerodynamic resistance is different for the two reference crops and because of the conversion from energy to depth of water units.

For the hourly calculations, G is assumed equal to 10% of Rn when Rn ≥ 0 and G is assumed equal to 50% of Rn for Rn < 0. In addition, the surface (canopy) resistance is set equal to 50 s m^{-1} during daytime and to 200 s m^{-1} at night. This change accounts for nighttime stomatal closure and improves the daytime estimates as well.

While ET_{ref} accounts for variations in weather and offers a measure of the "evaporative demand" of the atmosphere, crop coefficients account for the difference between the crop ET (ETc) and ETo. The main factors affecting the difference between ETc and ETo are (1) light absorption by the canopy, (2) canopy roughness, which affects turbulence, (3) crop physiology, (4) leaf age, and (5) surface wetness. The ASCE committee on evapotransporation has recommended the use of Kco and Kcr for crop coefficients relative to ETos and ETrs, respectively, where "s" stands for standardized surface conditions.

The logic of the reference ET is to set up weather stations on standardized reference surfaces where most of the biophysical properties used in the ET equations are known. Using these known parameters and measured weather parameters, ET from these surfaces can be estimated. Then, crop factor (Kr), or crop coefficients (Kc), can be used to calculate the actual ET (Etc) for a specific crop in the same microclimate as the weather station site.

Crop coefficients (Kc) are used with ETo to estimate specific crop ET rates. The crop coefficient is a dimensionless number, usually between 0.1 and 1.2, that is multiplied by ETo value to arrive at a crop ET (ETc) estimates. The resulting ETc can be used for various purposes, including estimating ET demand and thus moisture availability.

Crop coefficients vary by crops, stage of growth of the crop, and by some cultural practices. Citrus trees have smaller coefficient than peach trees, when peach trees are at full cover. Coefficients for annual crops (row crops) will vary widely through the season, with a small coefficient in the early stages of the crop (when the crop is just a seed) to a large coefficient when the crop is at full cover (the soil completely shaded).

Smajstrla, 1990 obtained crops coefficients from the Agricultural Field Scale Irrigation Requirements Simulation (AFSIRS) Model developed by the Agricultural Engineering Department at the University of Florida. Updated values for 1995 are also available. The value of Kc ranges from 0.4 to 1.2 for most agricultural crops. The lower Kc values result early in the growing season when vegetative canopies are fragmented, or when other factors affect the normal maturity of healthy crop. The higher values occur during peak growth time and are characteristic of tall crops with cover that completely blankets the soil surface.

The equation used for the measurement of plant “crop” coefficient in this research is:

$$\text{Plant coefficients} = (\text{Monthly averaged TSM ET} + \text{DS ET}) / \text{GPET} \qquad (4)$$

Where plant coefficients = crop coefficients [Non-dimentional], TSM = total soil moisture [L], DS ET = depression storage ET [L] and GPET = ground potential ET [L]. TSM ET, DS ET and GPET are discussed in greater details in the following chapters. It is noted that the influence of Interception capture is not included in the numerator and ground potential ET is used, not PET, as the denominator.

Objectives

The objective of this research was to investigate a new methodology for measuring hydrologic fluxes (rainfall excess, infiltration and plant uptake) and specifically ET at high spatial and temporal resolution for different landuse covers.

This approach entails: 1) Installation of SM probes with multiple sensors at varying depths in close proximity to transect water table wells to derive SM storage changes through the unsaturated and saturated profile; 2) Coupling SM results from (1) & (2) with a one-dimensional (1D) transect flow model to solve for vertical and horizontal fluxes from the soil; 3) The resultant 1D transect model is solved to resolve vertical and horizontal fluxes (including ET) from different horizons for two vegetative covers selected for monitoring; a bahia ungrazed pasture grass and a slash pine flat woods forested wetland; 4) using the results to determine "plant" or crop coefficients for the two aforementioned landuse covers.

CHAPTER TWO METHODOLOGY, HYPOTHESIS & DEFINITIONS

Methodology

The approach is based on solving the following basic water budget equation:

$$I + \Delta q - ET - L = \Delta V/\Delta t\,, \tag{5}$$

where I = infiltration rate (L/T), Δq = net lateral flow(L/T),

ET = Evapotranspiration(L/T), L = deep leakage (L/T), ΔV = volume change in moisture (L/T), Δt = time step(T).

Volume change (ΔV) at a point $\Delta S(t)_i$ is based on numerically integrating the observed soil moisture data. SM measurements are made at high vertical resolution (e.g., every 10 cm vertically) through the entire SM profile from near land surface to a depth below the seasonal deep water table elevation 150 cm (59 inch). Observed SM changes are derived for each time step down below the deepest expected water table condition (zone of saturation), Z_0 . From the discrete SM observation, change in storage can be resolved as:

$$\Delta S(t)_i = \int_0^{Z_0} \left[\Delta\theta(z, t_i)\right] \cdot dz \tag{6}$$

where $\Delta S(t)_i$ = Change in storage (L/T), θ = Volumetric water content integrated from near surface to the fixed control depth, z_0, (L/T).

In the event of SM monitoring failures (data gaps), volume change (ΔS) is based on a simple variable specific yield (Sy) model as:

$$\Delta S(t)_i = S_y\left(h_i^{t+\Delta t} - h_i^t\right) \tag{7}$$

where Sy = dimensionless variable corresponding to change in storage per unit area per unit drop in water table, and $\left(h_i^{t+\Delta t} - h_i^t\right)$ is change in water table elevation between current and previous time step (L).

Following the approach of Ross et al. (2005) and findings of Said et al. (2004), a stepwise linear, but variable Sy model is used as follows and graphically depicted in Figure (1):

For depth-to-water table, d_{WT} (L), below the capillary fringe depth, ξ_{CF}, from land surface but above the soil capillary zone, $\xi_{CZ,}$ the specific yield is:

$$Sy_i = Sy\,\mathrm{min} + (Sy\,\mathrm{max} - Sy\,\mathrm{min}) \cdot \left(d_{WT} - \xi_{CF}\right) / [\xi_{CZ} - \xi_{CF}], \tag{8}$$

where the specific yield at any time, Sy_i, is a minimum value, *Sy min*, or maximum value, *Sy max*, depending on whether $d_{WT} < \xi_{CF}$ or $d_{WT} > \xi_{CF,}$ respectively (all Sy values are L/L), and linearly varying between the thresholds. Also, d_{WT} er table (L), ξ_{CF} = capillary fringe (L), and ξ_{CZ} = total capillary zone (L) as defined by Ross et al. (2005).

For the lateral flows, a simple node-centered Darcian computation is used. For each grid the averaged values of hydraulic conductivity $\overline{Kj}$ (L/T), selected grid dimension ΔX (L), averaged aquifer flow thickness $\overline{\tau}_i$ (L), and observed head $\left(h_i^{t+\Delta t} - h_i^t\right)$ (L) will be specified. It is noted that terms with over bar represent spatially averaged values. Mass balance for grid (i) requires that inflow (Q_i) from grid (i) (equation 9) minus the outflow

(Q_{i+1}) from grid (i-1) to grid (i+1) (equation 10), must equal the rate of change in storage $\left(\frac{\Delta V_i}{\Delta t}\right)$ in grid (i) (equation 11). The flow equation also incorporates the groundwater evapotranspiration rate.

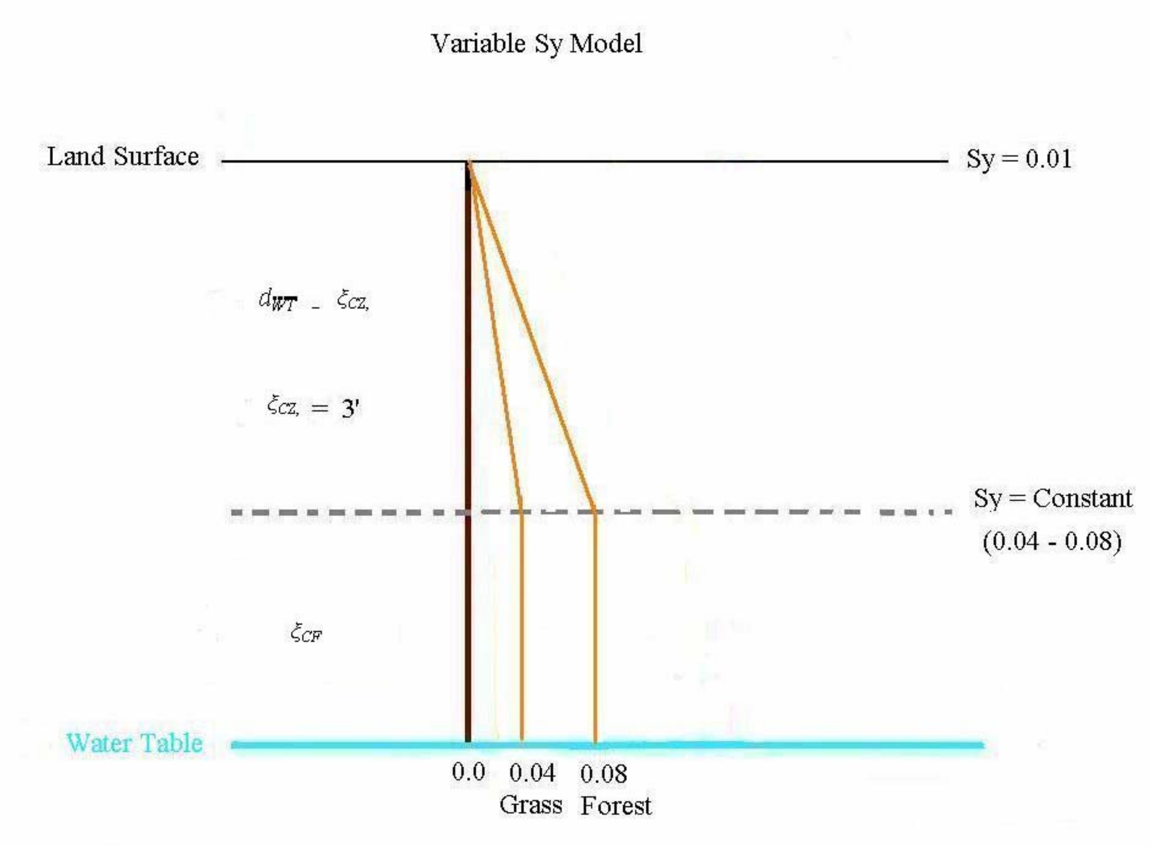

Figure 1. Variable Sy model used during brief periods of soil moisture measurement gaps.

Q_i here from grid (i-1) is:

$$Q_i = -\overline{K}_i \overline{\tau}_i \left[\frac{h_i^n - h_{i-1}^n}{\Delta X_i} \right] \tag{9}$$

where all terms were previously defined.

Flow from grid (i) to grid $(i+1)$ is:

$$Q_{i+1} = -\overline{K}_{i+1}\overline{\tau}_{i+1}\left[\frac{h^{\mathrm{n}}_{i+1} - h^{n}_{i}}{\Delta \mathrm{X}_{i+1}}\right]. \qquad (10)$$

where $Q_{\,\mathrm{i}+1} = \mathrm{L}^3/\mathrm{T}$ per unit width

The rate of change of storage of water in grid (*i*) for the time interval (Δt) is:

$$\frac{\Delta V_i}{\Delta \mathrm{t}} = \Delta S^n_i \Delta \overline{\mathrm{X}} / \Delta t \qquad (11)$$

where all terms were previously defined.

Rearranging eqn. (5) with measured and estimated flows placed on the LHS of the equation and derived fluxes on the RHS: The continuity for grid (*i*), including the groundwater evapotranspiration rate, is:

$$I + Q_i - Q_{i+1} = \frac{\Delta S_i}{\Delta \mathrm{t}} + ET + L \qquad (12)$$

$$\Delta S^n_i \,\Delta \overline{\mathrm{X}} - (\mathrm{Q}^{\mathrm{n}}_{\mathrm{i}} - \mathrm{Q}^{\mathrm{n}}_{\mathrm{i}+1})\Delta t = (I^n_i - ET^n_i - L^n_i)\Delta t \qquad (13)$$

$$IEL^n_i = (I^n_i - ET^n_i - L^n_i)\Delta t \qquad (14)$$

where *IEL* = combination of infiltration, evaporation and leakage (L), Δt = time step. All other terms previously defined.

Referring to equation (12) there are three unknowns I^n_i, ET^n_i and L^n_i that are combined into one term IEL^n_i which can be solved for each time step by substitution of equations (9), (10) and (11) and including infiltration (I).

The behavior of IEL_i^n is as follows: positive changes in IEL_i^n are primarily by infiltration in direct response to precipitation and negative changes result from net ET loss from the soil coupled with deep vertical leakage. Equation 13 can thus be reduced to:

$$IEL_i^n = \Delta S_i^n \Delta \overline{X_i} - (\Delta Q_i^n - Q_{i+1}^n)\Delta t \qquad (15)$$

where all terms were previously defined.

Hypothesis

Following the assumption of White et al. (1987) and Nachabe et al. (2005) that losses during the day are dominated by ET and those at night are primarily hill slope lateral and vertical leakage fluxes, some simple assumptions are made. If integrated SM indicates that losses have occurred $(IEL_i^n - IEL_i^{n-1} < 0)$, then the flux is assumed as a result of ET and L only. Conversely, if SM increases, then only I and L have occurred. Thus, it is assumed that ET is not occurring at the same time as rainfall (infiltration). Finally, to solve for ET, estimates for L must be made, using a simple e.g., a Darcian leakage method as:

$$L = (h_i^n - H_{DA}^n)l_i \qquad (16)$$

where L is leakage [L], l_i is a vertical leakance estimated from a confinement thickness (L), ξ,and confinement vertical hydraulic conductivity k_v , as $l_i = k_v / \xi$, for a deep aquifer head, H_{DA}^n (L), compared to the water table head $h_i^n[L]$.

The resultant data set is partitioned for the following two scenarios:

$$IEL_i^n > 0 \Rightarrow IEL_i^n = (I_i^n - L_i^n)\Delta t \quad \text{or} \quad IEL_i^n < 0 \Rightarrow IEL_i^n = (-ET_i^n - L_i^n)\Delta t \qquad (17)$$

where all terms were previously defined.

Since all observed negative cell values are believed to be associated with evapaotranspiration (ET) or evaporative losses, all observed positive fluctuations are believed to be associated with infiltration and are therefore checked against precipitation flux. Observed positive cell values greater than the precipitation are checked for occurrence of upslope runoff or delayed infiltration from local depression storage.

When water table is at or near land surface, a common occurrence during the wet seasons, the soil moisture change does not reflect all of the ET losses. Therefore, because the storage change is reflected in free surface storage change of water in surface depressions and plant uptake from the soil is readily replenished keeping the soil sensors at saturation. Since free surface conditions exist at the land surface an assumption is made that the ET rate then proceeds at potential ET (PET). Thus for this methodology to be applied to all periods it is essential to possess a good measure of on site PET. For these periods PET estimates can be derived by good local pan records or other meteorological methods.

For this particular application good pan measurements were not available and therefore another method was used. The PET values were estimated using the empirical equation of Jensen and Haise (1963).

$$ETP_{J\&H} = \left[\frac{R_S}{2450} * ((0.025 * T_{ave}) + 0.08)\right] \tag{18}$$

where $ETP_{\mathrm{J\&H}}$ = monthly mean of daily potential evapotranspiration (L/T); Rs = monthly mean of daily global solar radiation ($\mathrm{M/L^2/T}$); T_{ave} = monthly mean of daily air temperature ($^{\circ}$C).

Application of equation 18 was to estimate PET using hourly solar radiation and temperature. The solar radiation and temperature data were obtained from the Florida Automated Weather Network (FAWN) web site (http://fawn.ifas.ufl.edu/), stored in MINE data from the FAWN archived weather data. The data collected from the ONA site were utilized due to close proximity of this site to the research site. Resolution consistency was essential for proper comparison between J&H empirical model vs. research site SM ET. Although the J&H model does not incorporate the influence of relative humidity and wind speeds, but it does include the most influential parameters of solar radiation and temperature for PET, the results were considerably higher than typical PET range for the region which normally ranges close to 50 to 52 in. (1270 to 1321 mm). The model results demonstrated daily and seasonal variability in PET.

For this research, a correction pan factor of 0.7 is uniformly applied to the PET data to obtain estimates that average to known values of mean annual open water (lake) evaporation. The APET records were further adjusted to account for temporal and spatial variability in rainfall for the research site. This was achieved by comparing the APET records against the rainfall records for the research site. For any observed positive rainfall record the APET record was set to zero for the same time-step otherwise the APET data were used. The new set of record was termed Site PET. The Site PET records were further adjusted to account for interception capture (Ic) and the new set of records were referenced ground potential ET (GPET). This was achieved by running a 24 hr sum of Site PET and rainfall records for the previous 24 hrs. For the sum of rainfall records for the previous 24 hrs greater than or equal to the sum of Site PET records for the previous 24 hrs for any given time-step, the GPET is set to zero otherwise the Site PET values were used. GPET records were then used in the model when the water table was very close to land surface (DTWT ≤ 1ft or 0.3 m) for estimation of shallow water table ET. ET estimated during these periods was referred to as depression storage ET. (DS ET) corresponding to the primary contributions when visible water is standing on the surface.

The capacity of vegetated surfaces to intercept and store precipitation is of great practical importance for modeling. To hydrologists the most important aspect of interception relates to its effect on site and catchment water balances. Rainfall interception or Interception Capture (Ic) and its subsequent evaporation constitute a net loss to the system which may assume considerable values under certain conditions (Shuttleworth and Calder, 1979; Schellekens et al., 2000).

For this research, interception capture was estimated by plotting measured event precipitation (*P*) and corresponding estimated event infiltration (*I*) produced by the 1D transect model. These analyses were performed for each quarter and each station. Available quarterly data points were complied, as the period of study was abnormally wet, there were several quarters where insufficient data existed to formulate a basis quarterly *Ic* value. Therefore all quarterly data that were considered reliable were used to generate an annual interception capture (*Ic)* value. Recommended values for interception capture in the literature vary between bigger than these ranges. The *Ic* values, derived by this analysis were very close to literature values of 0.05 to 0.10 in./day (1.3 to 2.5 mm) (Viessman et al., 1977) corresponding to grass and forested land cover, respectively. Thus, this methodology was shown to yield comparable numbers to published values as well as the potential to resolve these threshold values to quarterly values or more. Traditionally, results of interception studies have been expressed mostly in relation to gross rainfall, either as a percentage or through various types of regression equations (Zinke, 1967; Jackson, 1975). Integrated soil moisture measurement along flow transects yields actual event by event losses due to interception capture for different land cover.

Infiltration Estimation -Event infiltration estimation was performed by summing observed positive changes in soil moisture following a precipitation event until ET commenced (negative changes occurred). This was accomplished by writing a simple algorithm in the model. Observed positive values were then stored in a separate column corresponding to each station and identified as “event infiltration”. Thus, each infiltration “event” included summing all observed positive cell values that occurred consecutively without interruption. Interestingly, on occasion and usually at night very small increases in soil moisture were observed in the absence of rainfall. They were mostly observed between the second and the third soil moisture sensors, for the grass land, but multiple sensors, excluding the top sensors, for the forested wetland cover. No explanations are offered for these occurrences other than nighttime dew, vapor pressure gradient, or plant root “hydraulic lift” (Dawson 1995). In the following summaries, total sum of infiltration represents total observed infiltration events that correspond to precipitation events only. Observed positive values of infiltration are summed in the same manner as ET for weekly, monthly, quarterly and annual accumulation timescales.

Total Rainfall Excess, Total Runoff, Saturation Excess Runoff, Net Runoff and Hortonian Runoff Estimation- various runoff mechanisms were examined with this method. First, estimated interception capture was removed for each precipitation event as the lesser of either the precipitation total or the I_C estimate for the station land cover. If the precipitation event, after removing the interception capture, was greater than the corresponding "event infiltration", then total runoff is the difference between the precipitation event minus interception capture minus the "event infiltration".

For estimation of saturation excess runoff from total runoff a simple algorithm was developed considering depth to water table (DTWT). Basically, an assumption was made for the capillary fringe thickness and when this thickness was close to ± 1 ft (0.3 m) below land surface or intercepted land surface then all runoff was assumed to be from saturation excess. Following soil studies on the site the thickness was found to be 1 ft (0.3 m), approximately the dimension of the capillary fringe). For deeper water table conditions the runoff was categorized as Hortonian runoff. Many events resulted in both mechanisms of runoff. This process is performed for each station and each quarter. The 1 ft (0.3 m) depth below land surface is used as the threshold in this research with the understanding that this is a simplistic assumption which may warrant future study.

For estimation of net runoff, a simple algorithm is included in the model for the difference between total rainfall excess and depression ET.

In order to ensure that a proper balance is achieved for each rainfall event, a balance check is performed considering interception capture, infiltration and net runoff.

SM ET, Adjusted ET, Deep water and shallow water and Depression Storage ET Estimation- Pursuant to the described methodology observed negative soil moisture changes and lateral flows were summed for SM ET estimation. Adjusted SM ET was estimated using the SM ET values while filtering the data such that observed SM ET values higher than the minimum GPET values with central moving in 24 hour period with a 1.1 multiplier will be substituted with GPET value averaged over 3 hour period. The 1.1 multiplier was used to account for acceptance of slightly observed higher hourly values of SM ET. Shallow water ET estimation was made by the taking the highest negative values of either adj. SM ET or GPET when DTWT was shallow (≤ 1' or o.3 m below land surface). For deep water table condition, > 1' (0.3 m) below land surface, observed and adj. SM ET is used. Depression storage ET is then estimated by taking the difference between shallow water ET and adj. SM ET.

Definitions

The following definitions are offered to understand the results presented in the quarterly tables in the following section;

(1) Interception Storage, Ic /Event [L]: Observed interception capture values generated by regression analysis grouped by land cover; e.g., grass and forested wetlands. Each value represents the maximum interception capture volume for any rainfall event for the specific vegetative cover.

(2) Total Interception Capture, EIc [L]: These values represent the total surface capture for the given period (e.g., quarterly or annual). This is a gross water budget accumulation.

(3) Saturated Rainfall Excess, SRE [L]: SRE represents the observed volume of rainfall available for runoff along the transect wells when depth to water table was ≤1 ft (0.3 m) below land surface (soil saturation was present). This volume is available to satisfy depression storage ET and runoff.

$$\text{If DTWT} \leq 1 \text{ ft below Land Surface} \Rightarrow SRE = (P - Ic) - (I) \quad (19)$$

where SRE = saturation rainfall excess.

(4) Total Rainfall Excess, TRE [L]: TRE represents the total observed volume of rainfall excess along the transect wells for any water table depth. This volume is available to satisfy depression storage ET and runoff. The following conditional constraints were observed:

$$\text{If } (P - Ic) > I \quad \Rightarrow \quad TRE = (P - Ic) - (I), \quad (20)$$

where P = Event Precipitation, Ic = Interception Capture, I = event infiltration and TRE = Total Rainfall Excess runoff.

(5) Net Runoff, NR [L]: The difference between TRE runoff and ET from depression storage.

(6) Infiltration, (I) [L]: I represent the total event infiltration volume observed following particular precipitation events.

(7) Total Precipitation, (P) [L]: P represents the total observed precipitation volume for a given reporting period (e.g., quarter).

(8) Total Lateral Flow, Q_{GW} [L]: Q_{GW} represents the net lateral flows along the transect wells that are summed quarterly.

(9) Total Change in Lateral Flow, ΔQ_{GW} [L]: Sum of Quarterly change in lateral flows along the transect wells. This is the change in flows between the down stream and the adjoining upstream well along the transect.

(10) Total Observed Soil Moisture ET [L]: The observed quarterly evaporative losses, from the soil only, along the transect wells.

(11) Adjusted SM ET [L]: The observed soil moisture ET adjusted with the GPET records.

(12) Difference between Observed and Adj. SM ET [L]: The difference between the observed soil moisture ET values and adjusted soil moisture ET.

(13) Deep Water SM ET (DTWT > 1 ft) [L]: The quarterly adjusted SM ET values when DTWT was greater than 1 ft (0.3 m)below land surface.

(14) Shallow Water SM ET+ ET from DS (DTWT ≤ 1 ft or 0.3 m) [L]: The quarterly magnitude, using the smallest values of the SM ET or the GPET when DTWT is equal to or less than 1 ft (0.3 m) below land surface.

(15) Depression Storage ET, DS ET [L]: The difference between the shallow water SM ET + ET from DS and total SM ET.

(16) Shallow Water SM ET- ET from DS (DTWT ≤ 1 ft or 0.3 m) [L]: The difference between shallow water SM ET + ET from DS - Depression Storage ET.

(17) Total ET (Adj. SM ET, DS ET& Ic) [L]: The total sum of adjusted SM ET, depression storage ET and interception capture ET.

(18) Total Change in Storage, ΔS [L]: ΔS represents the total quarterly change in storage.

(19) Upstream Runoff Infiltration (observed infiltration following a rainfall event up to several hours from the event) URI [L]: URI represents the total observed quarterly infiltration volumes in excess of the rainfall event minus the interception capture, during or within 24 hours of an event. On occasion when the balance between event interception capture, infiltration and total runoff did not balance event precipitation, excess infiltration was believed to be from up gradient runoff into the control section infiltrating in the vacuum of the stratum.

(20) Depression Storage Infiltration (DS/I, ET) [L]: Total observed quarterly infiltration /ET two hours after a rainfall event up to 24 hrs or the next rainfall event whichever is shorter.

(21) Soil Moisture Increase in the Absence of Rainfall Event ($SM_{wo}Rain$) [L]: Total observed quarterly infiltration volumes in the absence of any observed rainfall events. The exact origin of this small water-budget item may be from dew (increases in SM in the top sensor in the early hours) or unrecorded rainfall events.

(22) Soil Moisture Increase when Rainfall Event Not Recorded [L]: Observed quarterly infiltration volume in all stations when no rainfall event was recorded.

(23) Balance: (I+ΔQ_{WG}+ET(SM)-ΔS+(19)+(21)+(22) [L]: These values represent the total sum of the water budget balance equation based on the numerical model. The absence of closure, observed in some stations and some quarters, may be due to the substitution of the storage model and/or the physical hill-slope leakage to deep aquifer storage.

I, ΔQ_{WG}, ET(SM), ΔS, (19), (21) and (22): Terms previously explained.

(24) Avg. Depth to Water Table (ADTWT) [L]: These values represent the quarterly averaged depth to water.

CHAPTER THREE FIELD DATA COLLECTION

The study site is located near the Alafia River Watershed in West-Central Florida. A small catchment area of 184.38 acres was selected for the study. A small perennial stream, Long Flat Creek, runs through the catchment. An aerial view of the watershed site showing the watershed boundary is depicted in Figure 2. Two sets of transect wells were installed west of Long Flat Creek. They are designated as PS43, PS42, PS41, PS40 and PS39 and USF3 and USF1. Figures 3 and 4 depicts the 1-D flow section and nest of transect wells used in the model.

Vegetation in the upland area and near USF3 and USF1 was ungrazed Bahia grass. Vegetative communities close to and near the stream were dominated by alluvial mixed Slash Pine/hardwood forested trees typical of West-Central Florida. Green foliage density follows a seasonal pattern, reaching maximum coverage during summer wet periods and minimum coverage during winter dry periods.

Direct push drilling was performed near PS43, PS42, PS41, USF3 and USF1 to characterize the stratigraphy of the soil and collect samples from which laboratory evaluation of saturated hydraulic conductivity and porosity values could be derived. A sample of the result for station PS42 is graphically shown in Figure 5. Result for station USF3 is graphically shown in Figure 33 in Appendix A. Falling head permeability test was used to determine hydraulic conductivity. Due to the fact that hydraulic conductivity tests are a non-invasive process these tests were performed prior to texture analysis which is a rather invasive process. The hydraulic conductivity used in the model ranged from 1.152 ft/day (0.35 m/day) for most of the upland stations but for near the stream the hydraulic conductivity diminished by two order of magnitudes to about 0.014 ft/day (0.42 cm/day).

The textural analysis revealed a combination of sand and clay in the upland, PS43 and sand, sand/loamy sand and clay near PS41. Porosity tests were performed by measuring the mass of the soil sample before drying and after drying in the oven at 105 ºC for 24 hours. Porosity ranged from 0.24 to 0.43 in the upland, PS43, to about 0.34 to 0.58 near station PS41. The depth to clay layer (confinement) was also observed with direct push drilling measurement and ranged from 8.8 ft (2.68 m) below land surface near PS43 to 7.5 ft (2.29 m) near PS42. No significant variation in depth to clay layer was observed along the rest of the transect wells to near the stream region. The depth to clay layer for USF3 and USF1 were found near 5.4 ft and 4.375 ft (1.65 to 1.33m) respectively. Additional Details pertaining to the site data collection are available in the final report, Ross et al. (2005), prepared for the funding agencies Tampa Bay Water and Southwest Florida Water Management District.

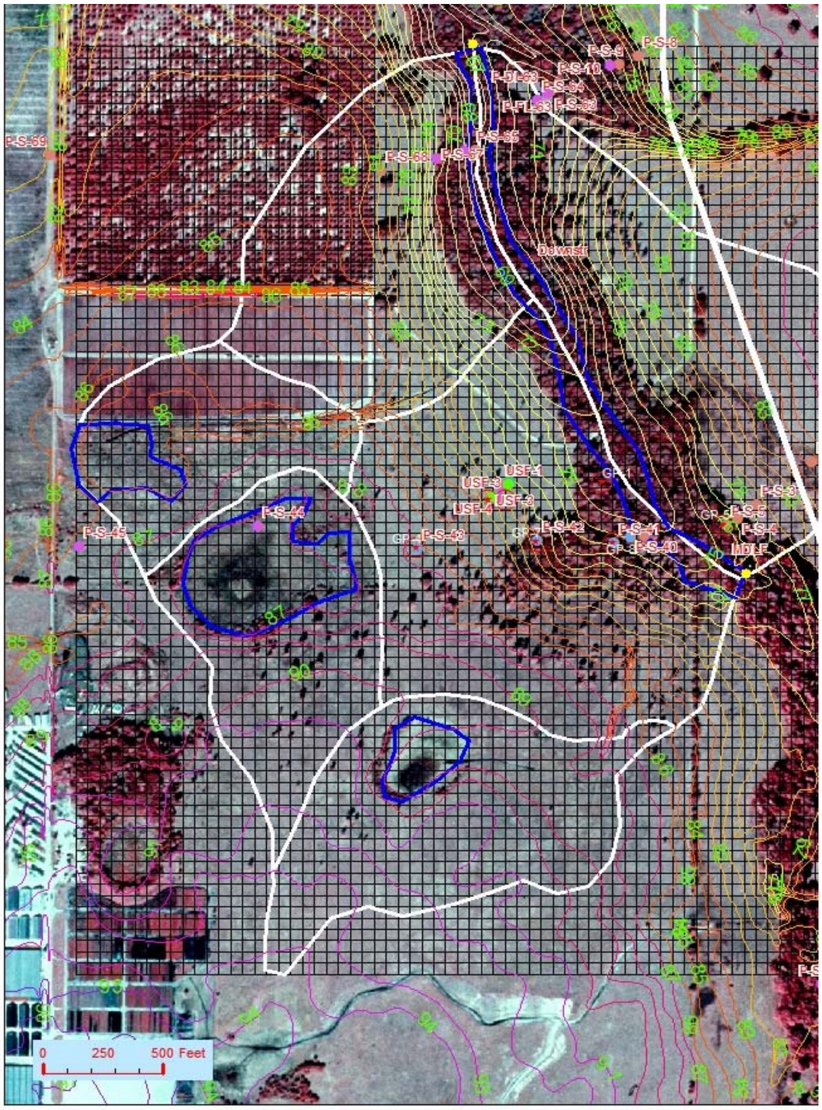

Figure 2. Aerial view of the Alafia river watershed showing the boundary and sub-basins delineation for the research site.

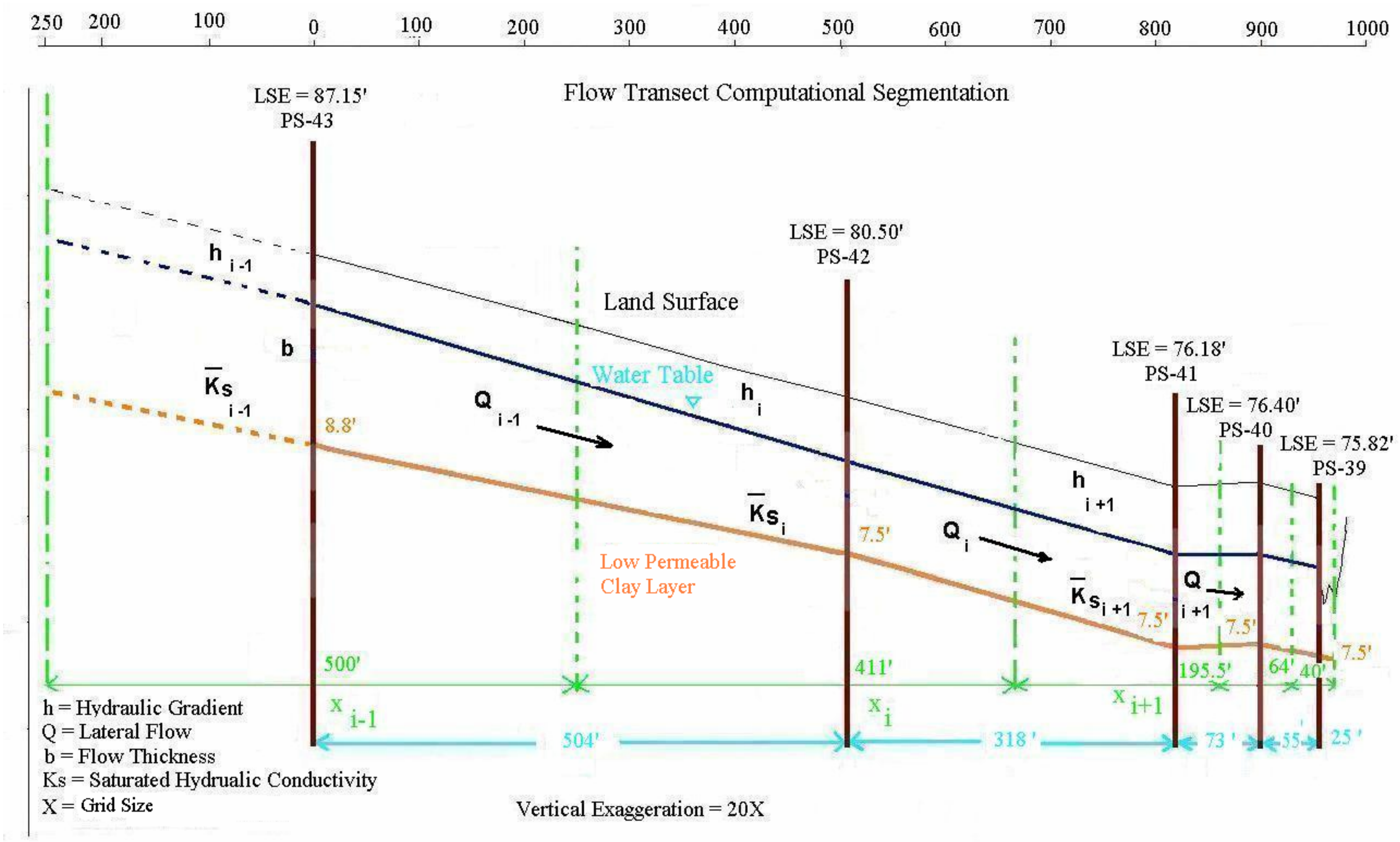

Figure 3. Graphical display of the 1-D flow model for the transect wells, PS43-PS39.

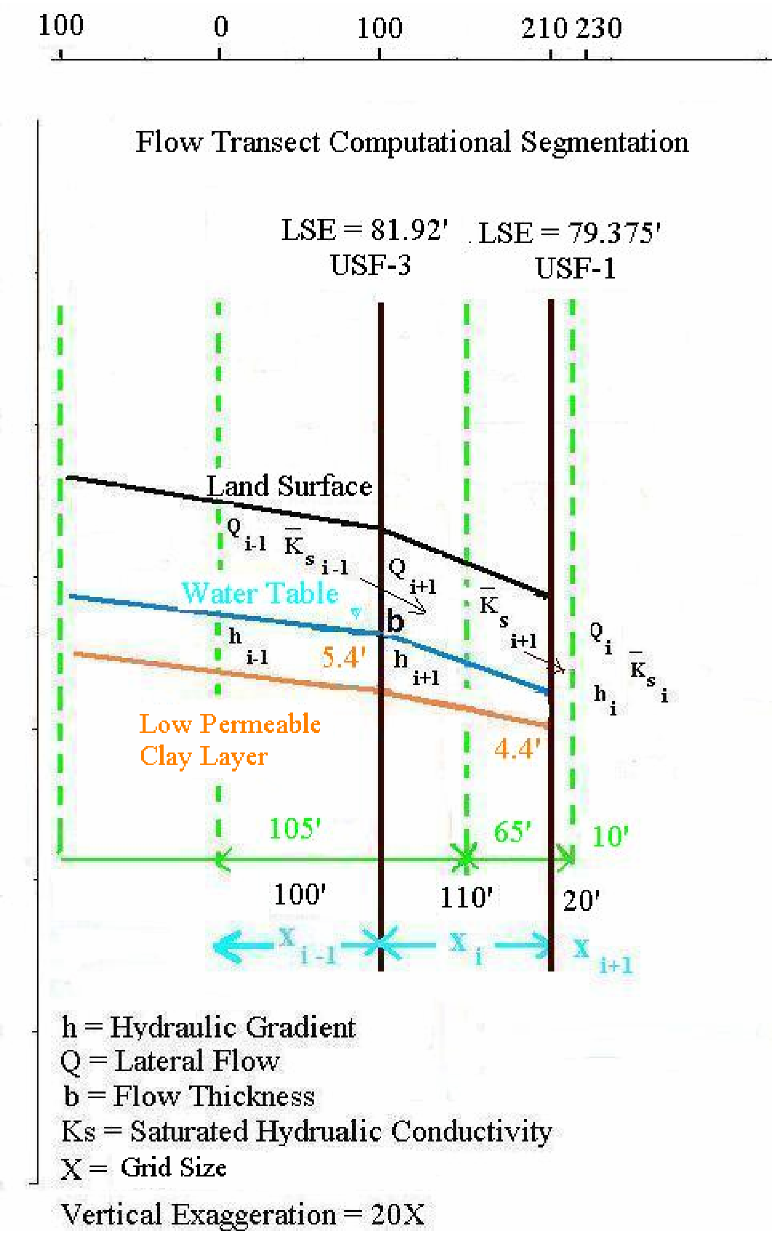

Figure 4. Graphical display of the 1-D flow model for the transect wells, USF3-USF1.

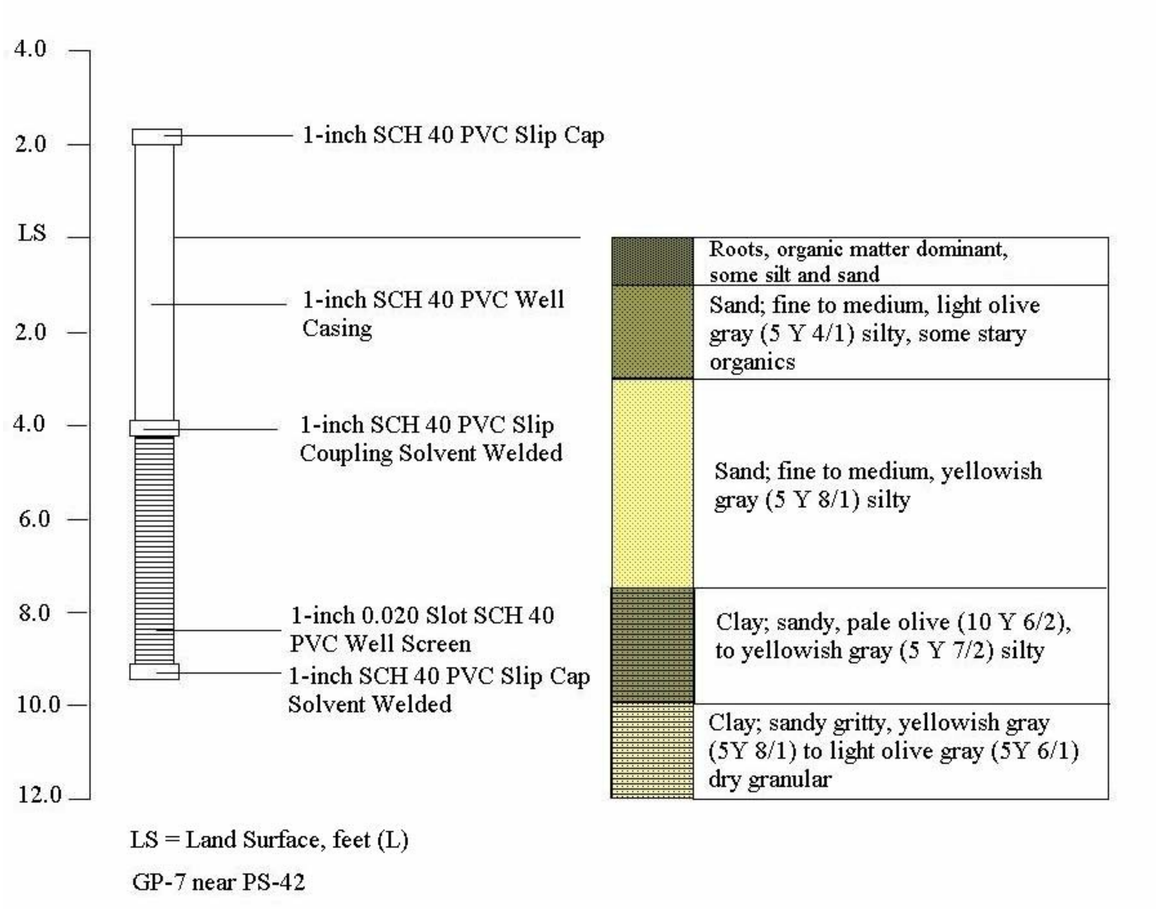

Figure 5. Direct push drilling results near PS42.

Figure 6 depicts the Enviro-Smart® soil moisture equipment used for the study site. Sensor depth(s) were at -3.93, -7.87, -11.81, -15.74, -19.68, -27.55, -39.37 and -59 in. (-10, -20, -30, -40, -50, -70, -100 and -150 cm) below land surface at each station. The termination depth at all wells was seen to be below the deepest water table elevation during the study. Each sensor was calibrated using factory calibration curves using the index for air and water and the results were within ± 1%.

SM data were collected at 5-minute intervals and averaged over 20-minute or one hour intervals. Two samples of temporal variations in SM averaging are shown in Figures

34 and 35 in Appendix B. In the absence of SM data, due to equipment malfunction, a variable specific yield (Sy) model is substituted.

Transect wells data collection began in October 2001. Fluctuations in water table were continuously measured at 5-minute intervals and queried at 20-minutes resolution and averaged over a 6.5 hour period for smoothing. The averaging approach was implemented to account for removal of noise effect. For missing water table elevations, due to equipment malfunction, measured data for the adjacent wells were used to generate a regression equation.

Stream gages were installed near upstream, mid-stream and downstream of the Long Flat Creek. In the event of missing data, constant water surface elevations were used. For precipitation measurements, two automatic tipping bucket rain gauges were installed to measure rainfall volume as well as temporal intensities. Two manual rainfall stations were also installed to verify the accuracy of continuous rain gauges and to prevent loss of data in the event of equipment failure.

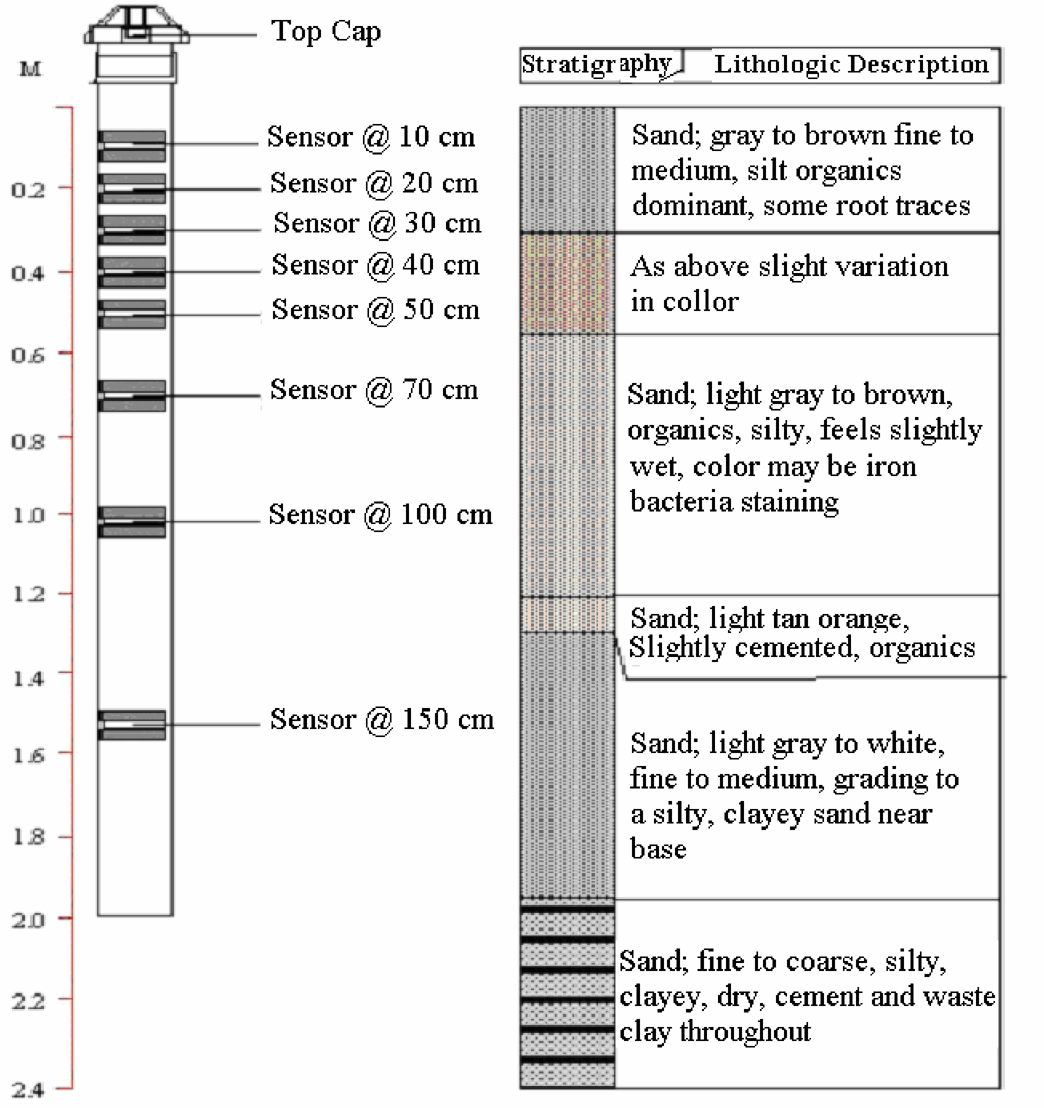

Figure 6. Enviro-smart® Soil Moisture probe.

CHAPTER FOUR RESULTS

Observed changes in soil moisture are shown with observed hydrological and meteorological data for selected presentation periods. Graphs depict the near instantaneous response of measured changes in soil moisture with meteorological stress, under both dry and wet conditions.

Figure 7 shows observed cumulative fluctuations in Total SM (the station is PS41 located near the stream) in response to periodic rainfall episodes in spring of 2002. The measurement approach is responsive enough to show TSM changes in direct response to precipitations events observed. At shorter time scales observed decline in TSM is observed during the diurnal ET process. A typical daily pattern of fluctuations in TSM, during periods of no rainfall are shown in Figure 8. Increases in TSM in response to an isolated rainfall episode on 4/14//02 in the upland region are shown in Figure 9. The rise in TSM is in immediate response to infiltration. Infiltration ceases as precipitation stops. For the next 24 hours succeeding this rainfall event, despite available solar radiation, ET effects are masked (or are negligible) as redistribution dominates the process due to downward propagation of the wetting front immediately following the event.

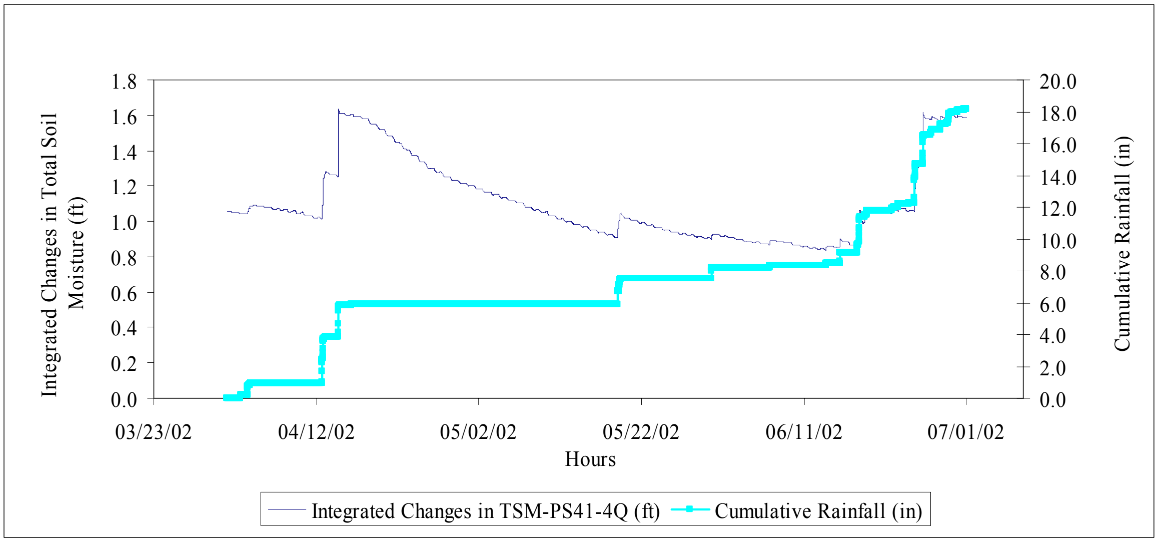

Figure 7. Observed changes in total soil moisture corresponding to several precipitation events during spring of 2002 near station PS41.

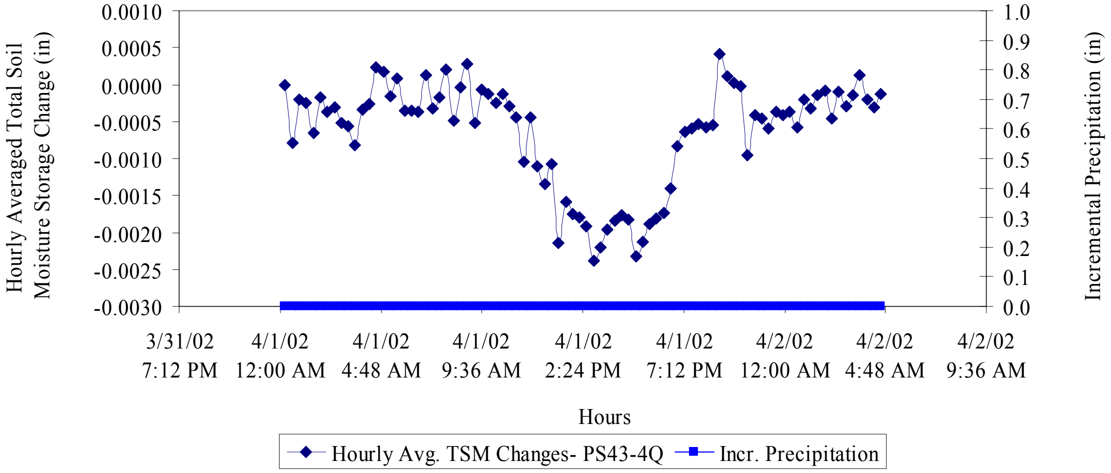

Figure 8. Observed 20-minute changes in total soil moisture during a high ET period for grassland cover (PS43).

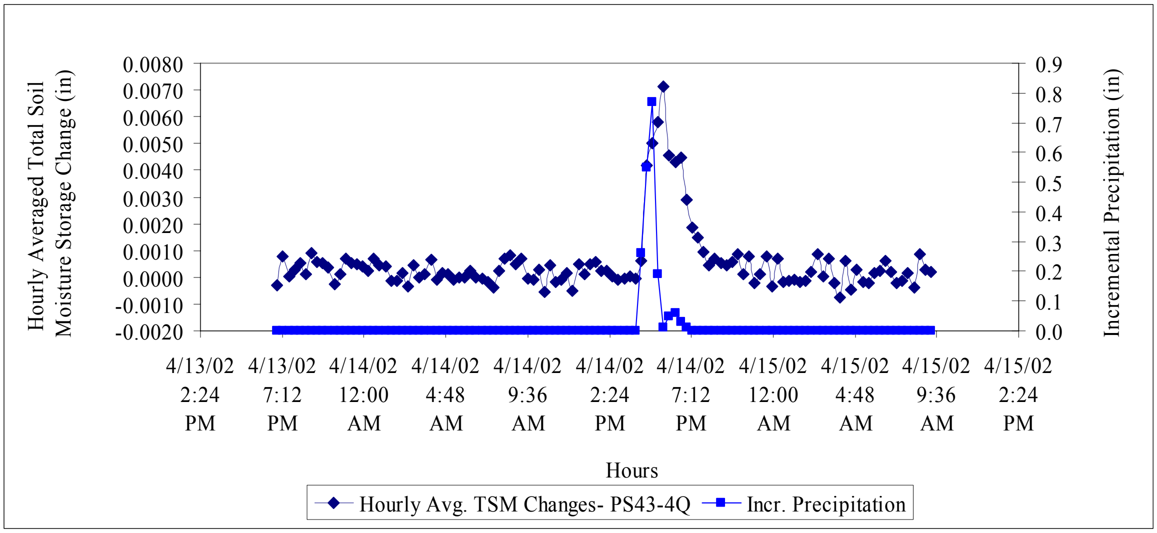

Figure 9. Change in total soil moisture (PS43) in response to a precipitation event.

Daily changes in TSM and water table fluctuation for upland grassland (PS43) is shown in Figure 10. The principal decline in water table coinciding with losses in TSM is in direct response to daily ET demands. Slight rises in water table, during very late evening or early morning hours, are from up-slope re-supply associated with the lateral flows. Figure 11 depicts daily losses in TSM and water table for forest cover (PS40) near the stream region for the same period of record. Steeper declines in water table and higher losses in TSM, for the same period of record, are in direct response to higher ET demands of that landuse. Rise in water table near station PS40 in very late evening and early morning hours are attributed to lateral flows. Losses in SM for the grassland and forested wetland regions continue well after solar radiations are diminished. Stomates shut down in the absence of solar radiations but in the presence of leaf water deficit the resultant suction/tension induces root water uptake, depletion of soil moisture, and storage of water in the conveyance mechanisms such as roots, trunk, shoots and leaves. Changes in SM after 7 p.m. are four times greater at forest compared to grass. This is attributed to higher root water uptake potential in direct response to landuse change. Figure 12 depicts simultaneous increases in TSM and rise in water table in direct response to a precipitation event on 4/14/02 for the upland grass region (PS43) as infiltration dominates the flow. For this event the water table rises steadily (recharge) in response to observed precipitation. After precipitation ceases, water table elevation does not fluctuate rapidly for several hours. Decline in water table is somewhat delayed due to redistribution effects and continued downward migration of infiltrated volumes. Slight and gradual decline in water table is observed sometime after the rainfall event ceases.

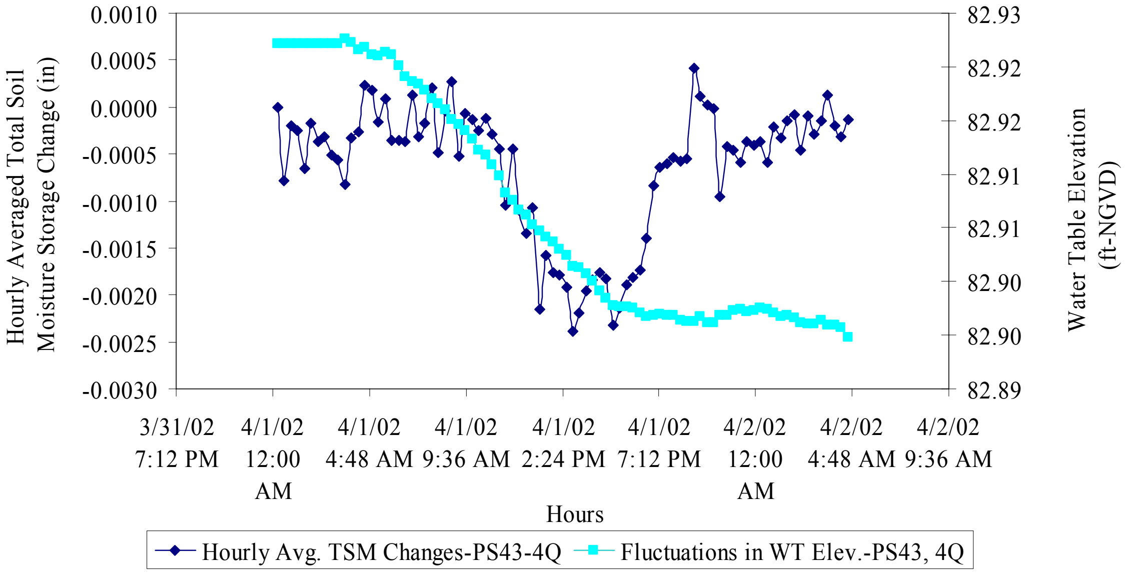

Figure 10. Decline in total soil moisture and water table supporting ET demand for grassland (PS43).

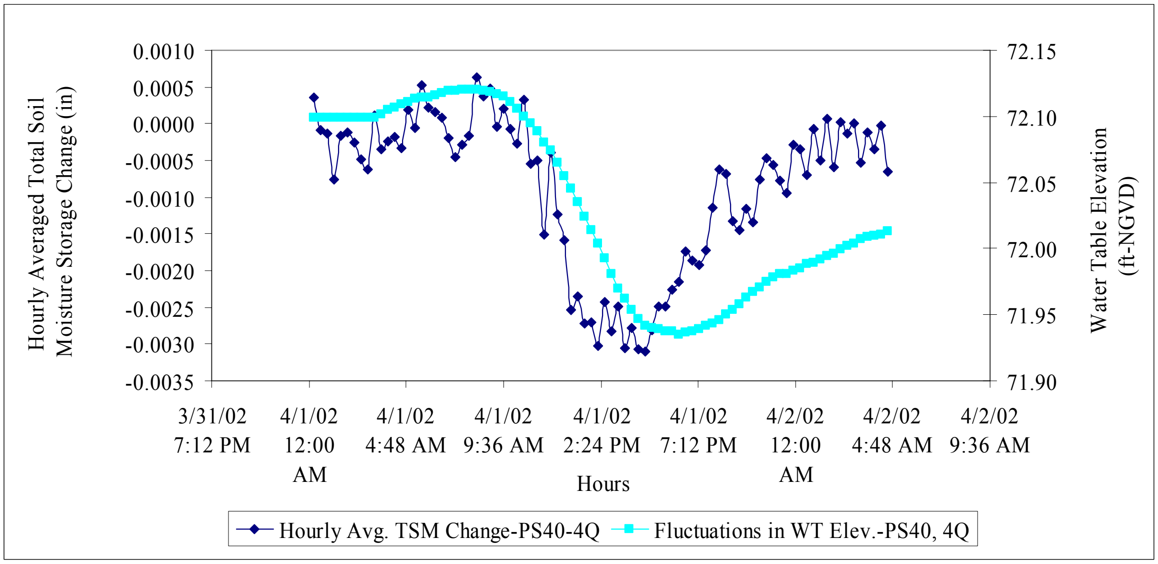

Figure 11. Steeper decline in water table and higher losses in total soil moisture for forested wetland nearest the stream (PS-40).

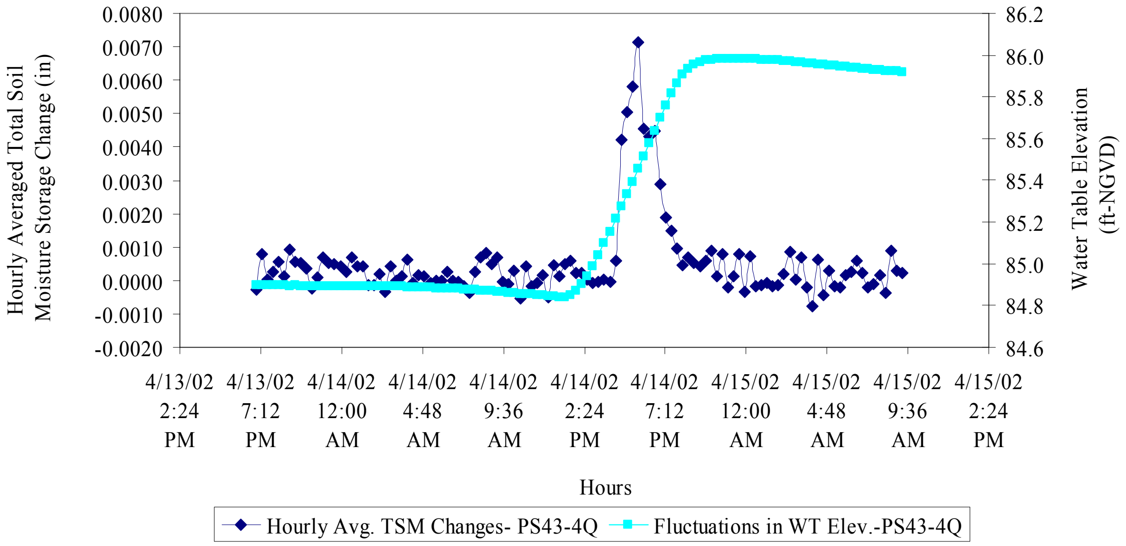

Figure 12. Increase in total soil moisture and rise in water table during a 1.93 inches rainfall event for grassland (PS43).

Instantaneous daily decline in TSM in response to solar radiation for grassland cover (PS-43) in upland region is depicted in Figure 13. Higher ET coincides with observed higher values of solar radiation. ET drops in direct response to observed lower solar radiation magnitudes. Figure 14 depicts changes in TSM corresponding to observed fluctuations in solar radiation during a precipitation event for grassland (PS43). Often solar radiation does not diminish completely during precipitation events. Observed positive changes in TSM prior to the rainfall event are in response to a separate precipitation event that was observed on April 12, 2002 from late in the afternoon to early morning on April 13, 2002. The total magnitude of this almost continuous event was 2.95 inches (75 mm).

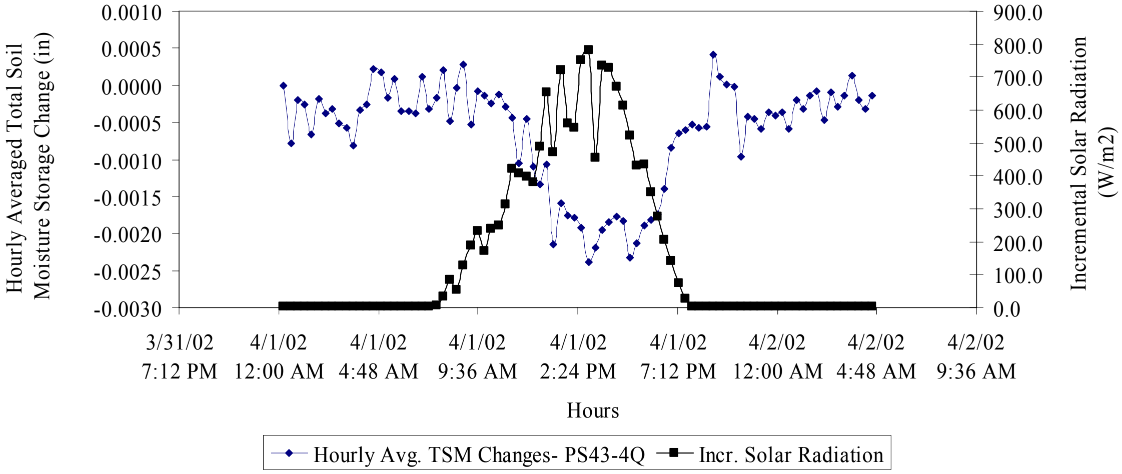

Figure 13. Observed losses in total soil moisture corresponding to fluctuations in solar radiation for grassland (PS43).

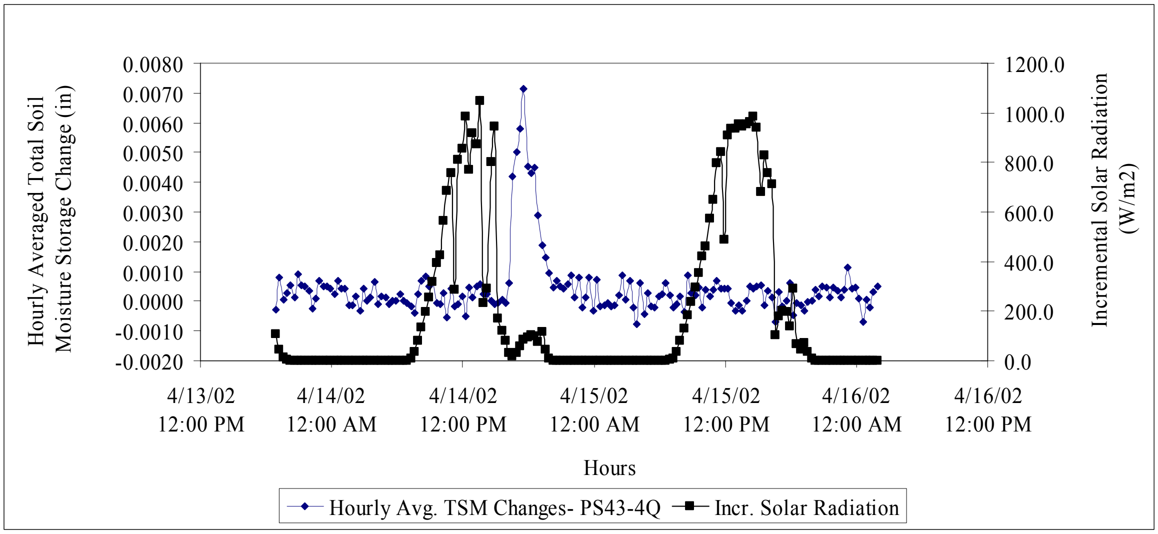

Figure 14. Change in total soil moisture and solar radiation during and after a rainfall event for grassland (PS43).

Monthly precipitation records for the 3 years for this research site are plotted against monthly averaged precipitation reported from NOAA (http://www.noaa.gov) for the region in Figure 15. Relatively rainfall magnitudes are comparable to average values observed except June, July and December in 2002 which were wetter than average and July of 2003 (dryer).

Quarterly magnitudes for computed PET from the J&H model, site PET and GPET are shown in Figure 36 in Appendix-C. The quarterly and annual results are also presented in Tables 4 and 5 respectively in Appendix C.

Samples of daily TSM and depression ET variability for grassland (PS43) and forested wetland (PS40) in 2003 are shown in Figures 37 and 38, respectively in Appendix D.

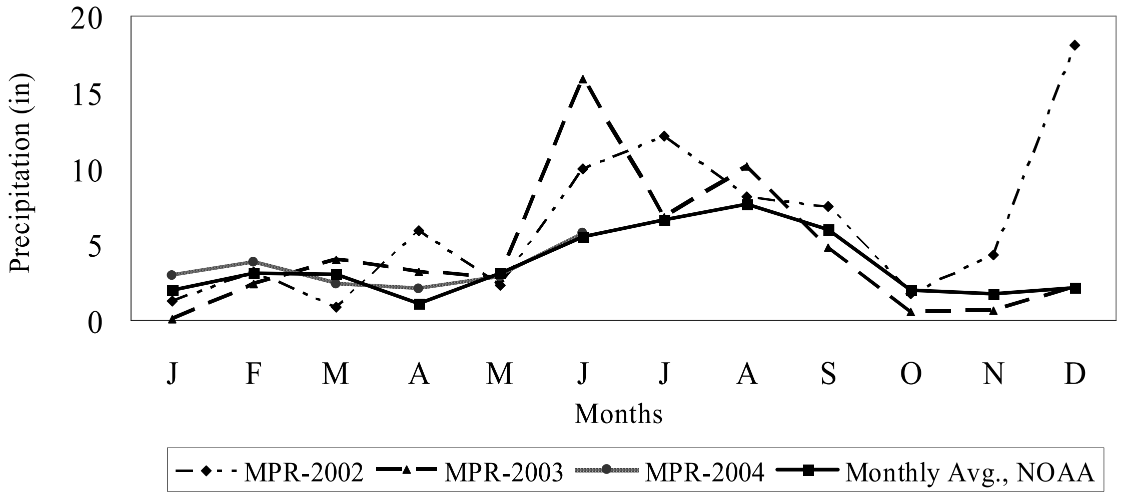

Figure 15. Monthly precipitation record from research site vs. monthly avg. from NOAA.

Monthly TSM, DS and Ic ET contributions were averaged for grassland covers (PS43, USF3 and USF1) and for Forested wetland (PS42, SP41 and PS40) in 2002, 2003 and 2004. Computed Site PET for each corresponding month is included in the graphs. Figure 16, 17 and 18 depicts ET contributions averaged for grassland covers and Figure 19, 20 and 21 depicts the ET contribution averaged for forested wetland.

For grassland cover, the highest TSM ET was observed in May 2002 contrasting with the highest total ET observed in July during 2002. Depression storage ET (DS ET) contributions were consistently higher during the wet periods. In 2003 and 2004 the highest TSM and total ET were observed in May. DS ET was observed more frequently in 2003 and 2004, in parts due to shallower DTWT for USF3 and USF1.

For the forested wetland, the highest TSM ET was observed in May 2002 contrasting with the highest total ET observed in April 2002. In 2003 and 2004 the highest TSM and total ET were observed in May. DS ET contributions were less frequent and considerably lower in magnitude as ADTWT was rarely sustained near land surface for an extended period of time.

Monthly total ET for each station, in 2002 and 2003, are shown in Figures 40 through 42 in Appendix E. The quarterly ADTWT for each station for the duration of the research are shown in Figures 43 through 44 also in Appendix E.

Monthly averaged plant (crop) coefficients ratio (Kc) (defined by equation 4 in earlier section) for TSM+DS ET to GPET were computed and averaged for grassland covers (PS43, USF3 and USF1) and for Forested wetland (PS42, SP41 and PS40) in 2002, 2003 and 2004. Computed monthly plant coefficients for the two distinct landuse covers are presented in Figure 22. Excluding the winter of 2002, Kc is consistently higher for forested wetland than grassland cover. This observed behavior was intuitively anticipated.

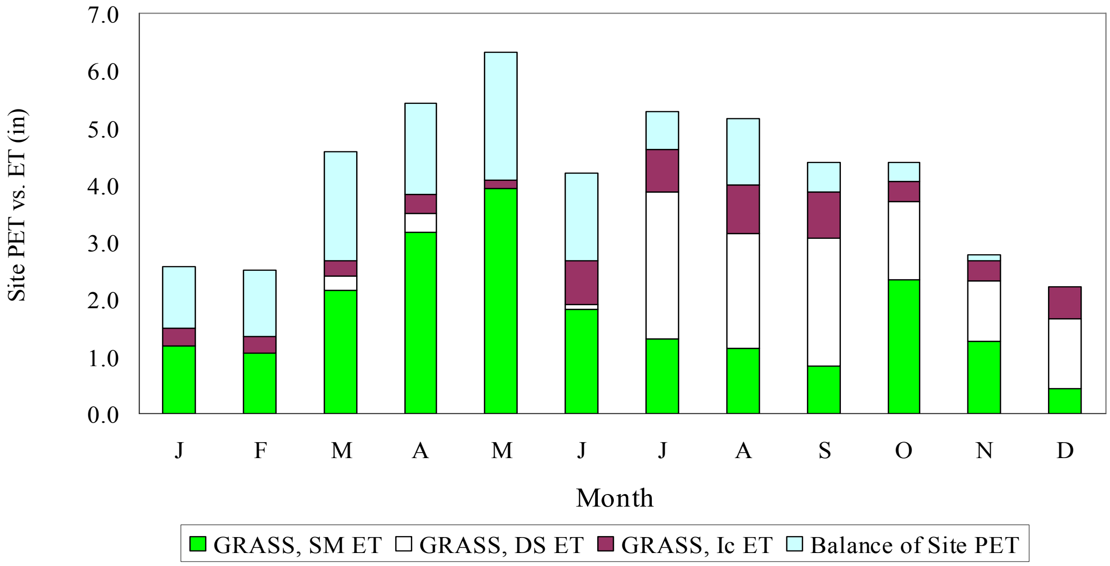

Figure 16. Monthly averaged ET contributions for grassland in 2002.

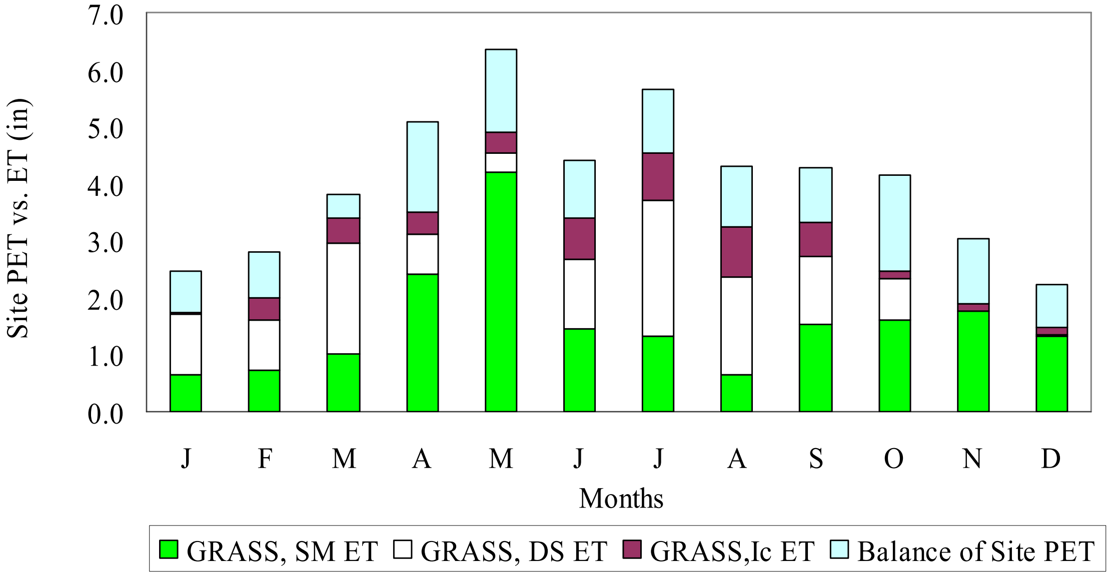

Figure 17. Monthly averaged ET contributions for grassland in 2003.

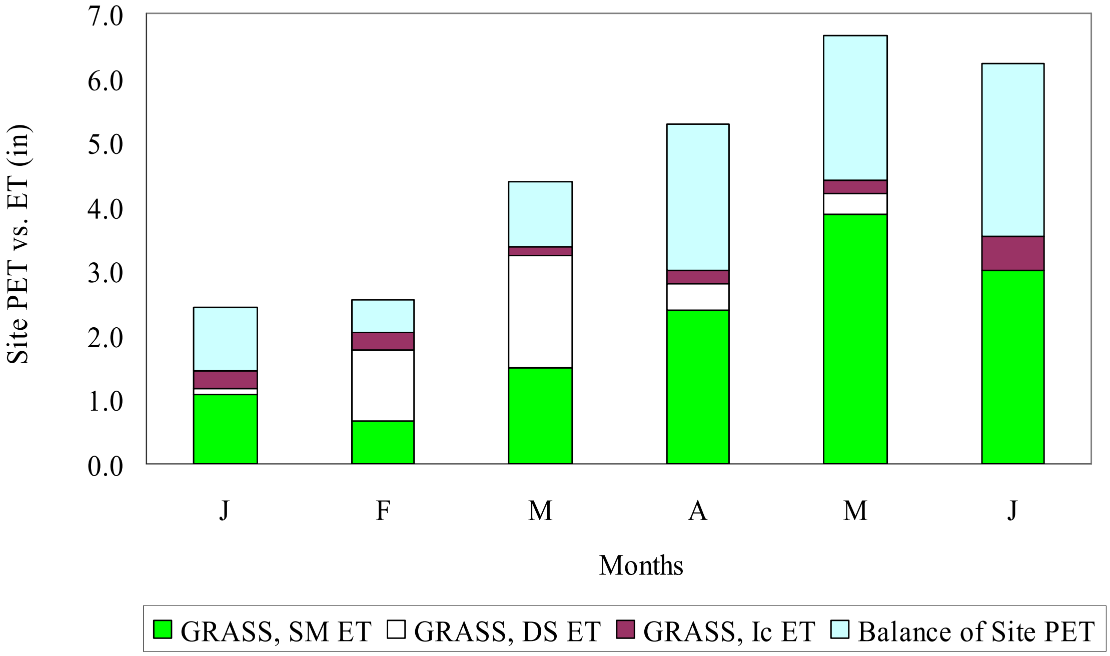

Figure 18. Monthly averaged ET contributions for grassland in 2004.

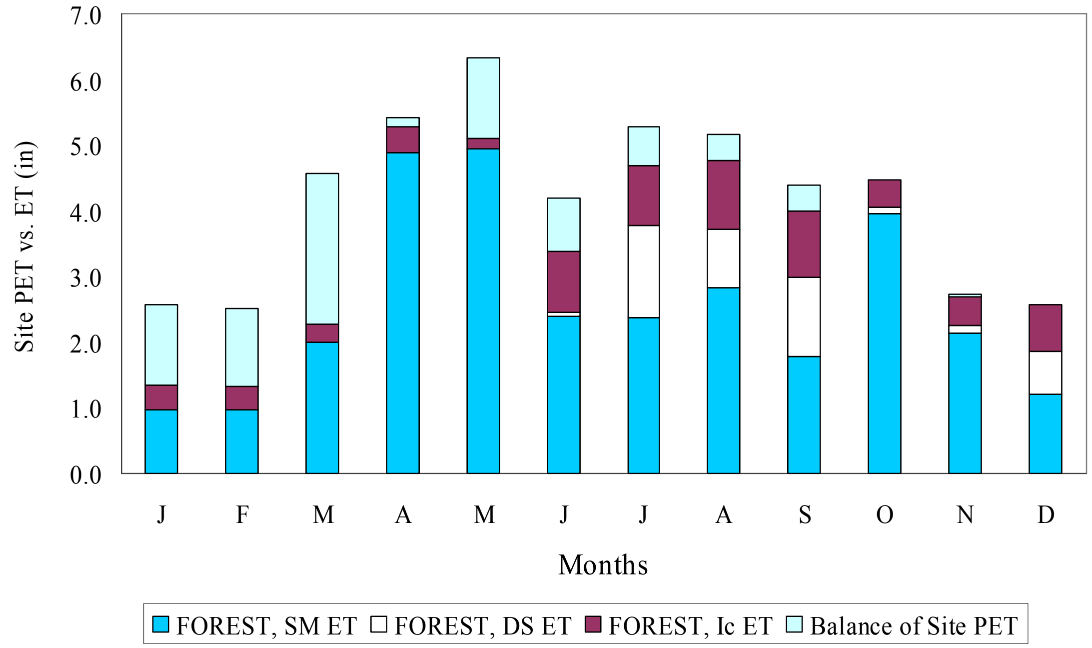

Figure 19. Monthly averaged ET contributions for forested wetland in 2002.

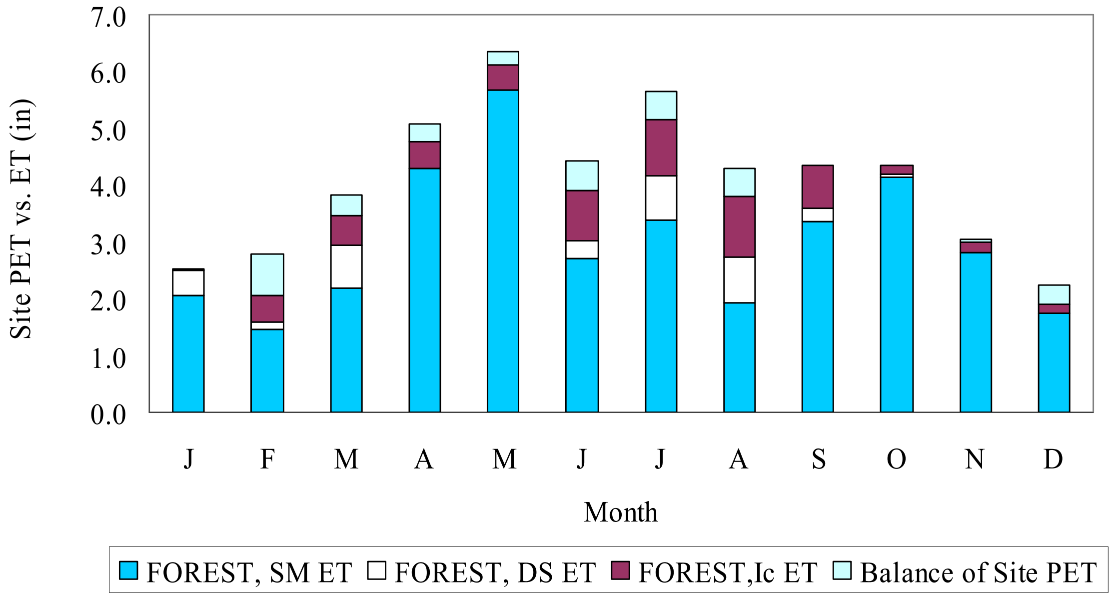

Figure 20. Monthly averaged ET contributions for forested wetland in 2003.

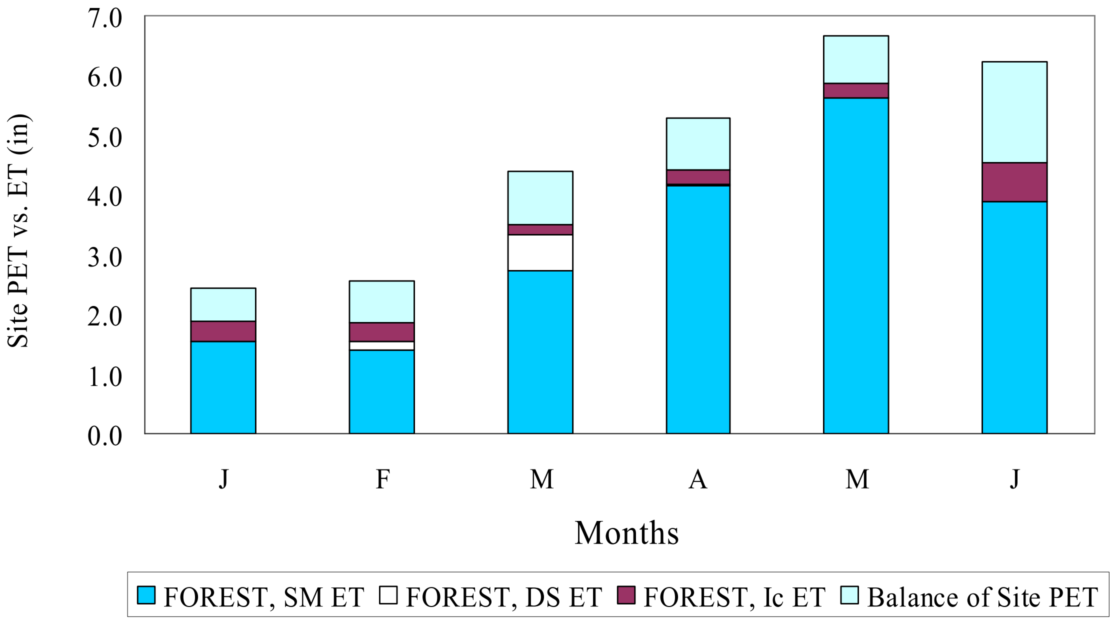

Figure 21. Monthly averaged ET contributions for forested wetland in 2004.

Monthly Kc ranged from 0.11 to 0.65 for grassland cover and 0.34 to 0.94 for forested wetland respectively. Lowest Kc ratio for grassland covers were observed during the wet periods and highest values were observed in the spring and in the fall of 2003. For forested wetland the lowest Kc ratio were observed in winter 2002, September 2002 and July 2003 while highest values were mostly observed in the spring and fall periods. The maximum values of Kc, slightly in excess of 1.4 and 1.2, were observed in August followed by September of 2003 for the forested wetland. Kc value close to unity was also observed for the forested wetland in August 2002. Higher Kc values are generally observed in the wet period and lower Kc values are observed in the dry period and Kc can vary considerably depending on the plant species. It is not uncommon for a close growing crop to ET in excess of PET.

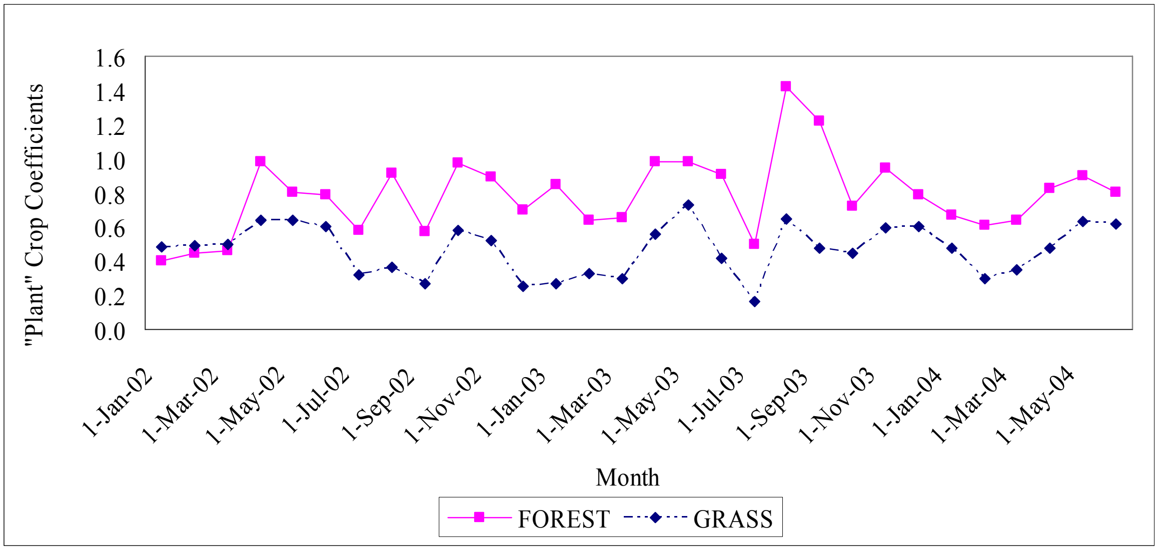

Figure 22. Monthly averaged plant coefficient for grass and forested wetland.

Quarterly observed water budget components for Ic ET, TSM ET, total ET, including TSM ET plus DS ET and Ic ET, infiltration, TRE, SRE, NR and ADTWT was averaged for grassland cover, stations PS43, USF-3 and USF1. Same components were also averaged for forested wetland covers, stations PS42, PS41 and PS40, for the two and half consecutive years. Results are presented in Figures 23 through 30. Quarterly values for water budget components for each station are presented in Tables 6 through 25 in Appendix-F.

Quarterly results for Ic ET, SM ET, total ET which includes TSM ET, plus DS ET and Ic ET, and infiltration are averaged for grassland cover (PS43, USF3 and USF1) and for forested wetland covers (PS42, PS41 and PS40) for the two and half consecutive years of research period and are shown in Figures 23 through 26 respectively. Quarterly observed TRE, SRE, NR and ADTWT averaged for grassland and forested wetland covers and are shown in Figures 27 through 30.

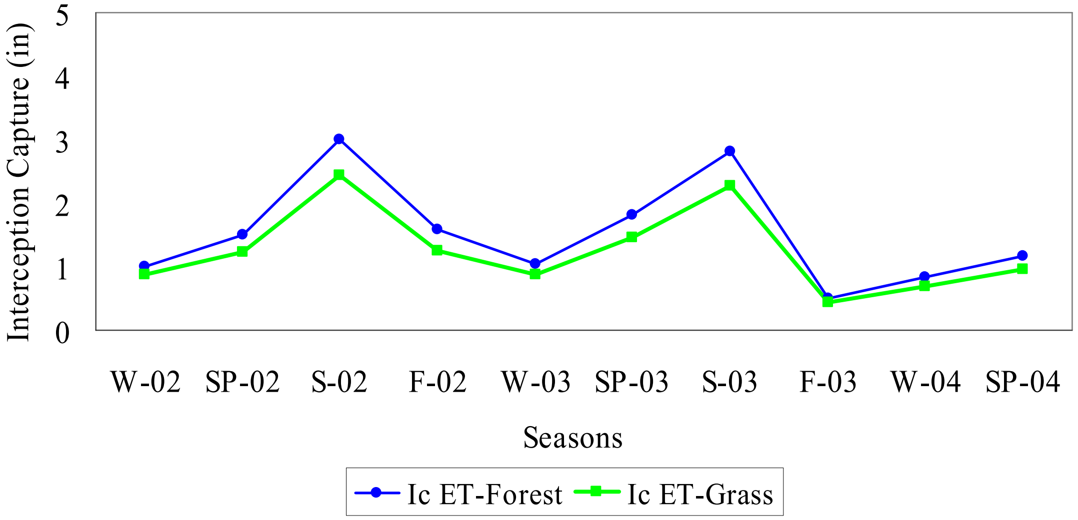

Figure 23. Quarterly total interceptions capture (Ic) ET for forest and grass from January 2002 through June 2004.

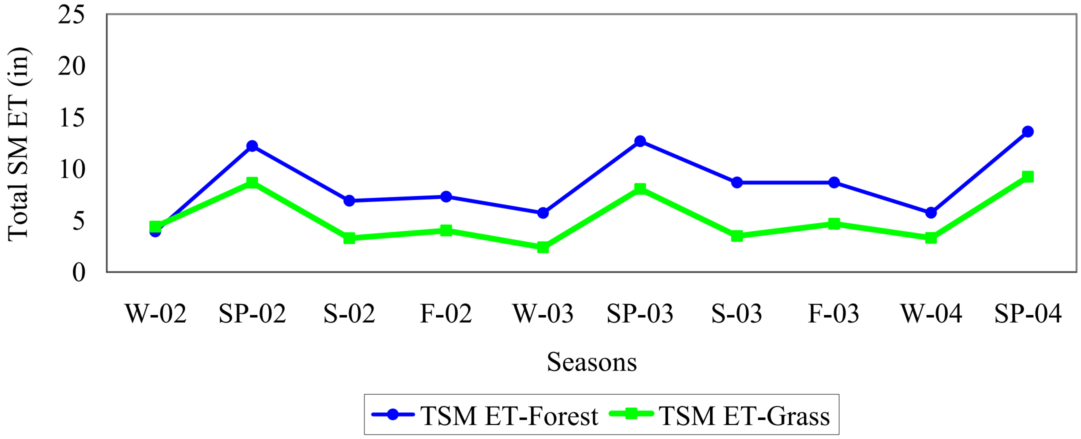

Figure 24. Quarterly total soil moisture ET for forest and grass from January 2002 through June 2004.

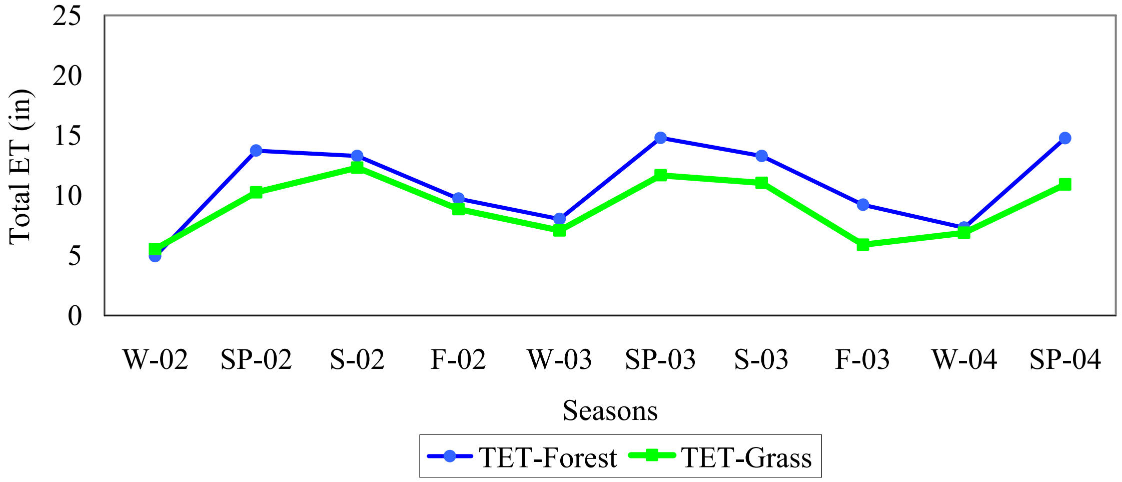

Figure 25. Quarterly total ET for forest and grass from January 2002 through June 2004.

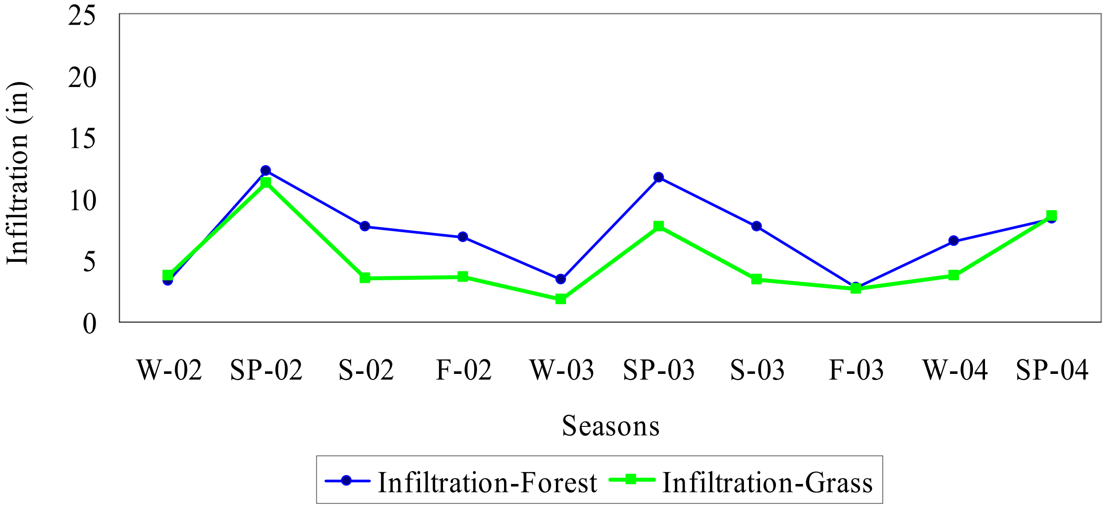

Figure 26. Quarterly infiltration for forest and grass from January 2002 through June 2004.

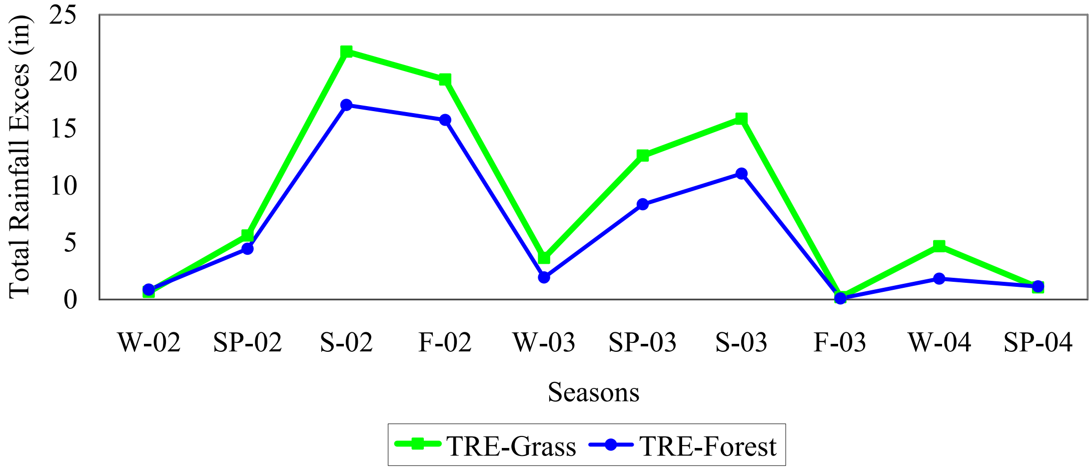

Figure 27. Quarterly total rainfall excess runoff for grass and forest from January 2002 through June 2004.

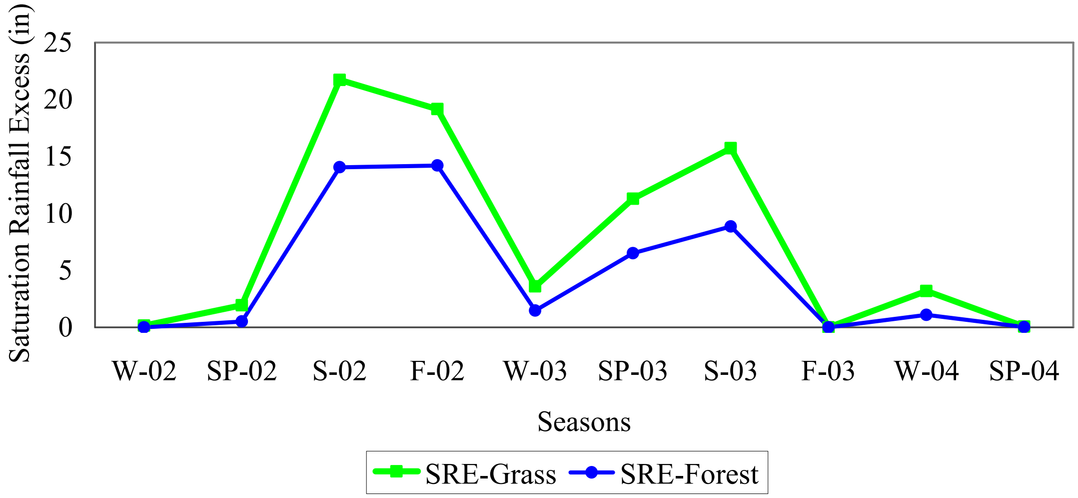

Figure 28. Quarterly saturation excess runoff for grass and forest from January 2002 through June 2004.

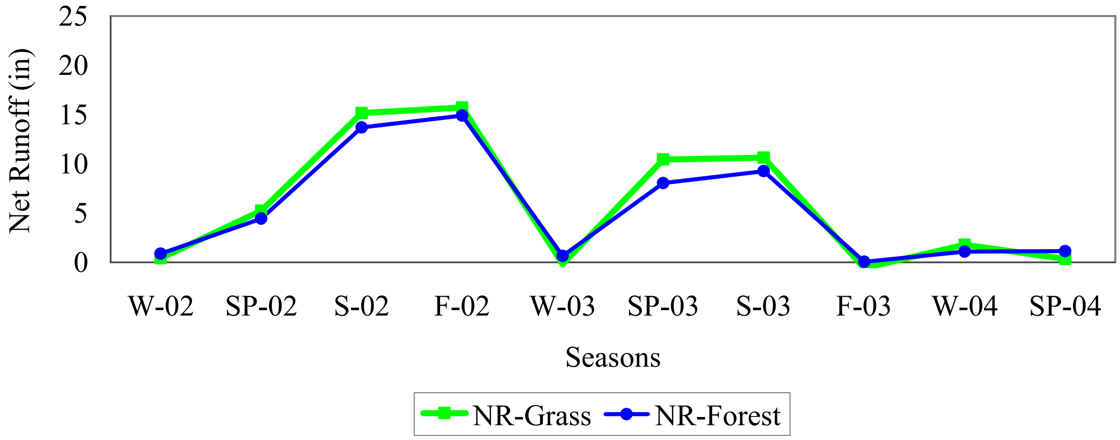

Figure 29. Quarterly net runoff for grass and forest from January 2002 through June 2004.

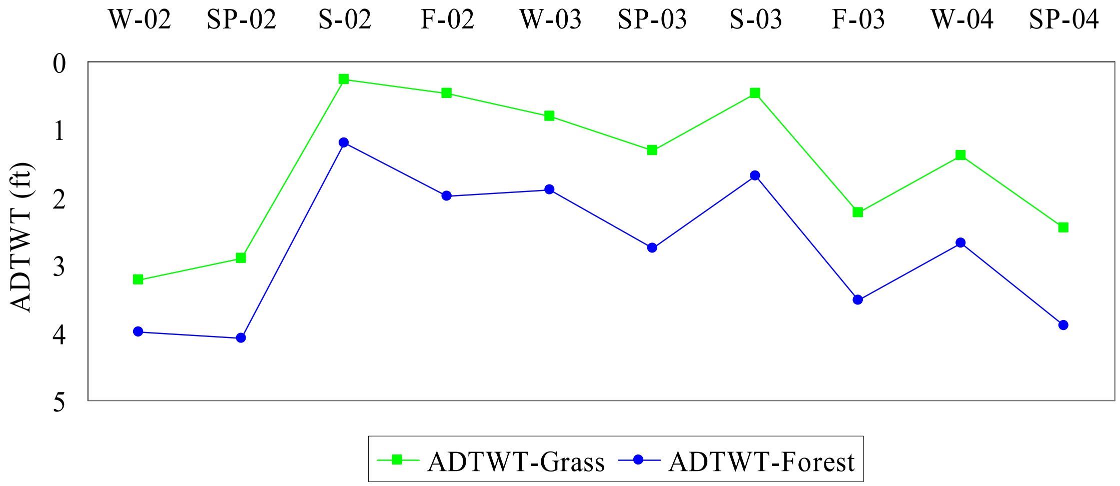

Figure 30. Quarterly averaged depth to water table for grass and forest from January 2002 through June 2004.

Comparison of observed hourly, monthly and quarterly TSM ET+DS ET with simulated site PET in 2002 and 2003 for grassland station PS43 and forested wetland station PS40 are graphically presented in Figures 45 through 50 and Figures 51 through 56 respectively in Appendix G. A sample of quarterly results for GPET, observed TSM ET and adjusted TSM ET for grassland and forest in 2003 are shown in Figures 57 and 58 in Appendix H.

CHAPTER FIVE DISCUSSIONS OF RESULTS, SUMMARY AND CONCLUSIONS

Results

Annual observed water budget components were averaged for grassland cover, (PS43, USF3 and USF1) and forested wetland covers (PS42, PS41 and PS40) in 2002, 2003 and January through end of June 2004. Results are presented in Tables 1, 2 and 3 respectively**.** Explanations for all the fields used in the tables are defined in chapter 2 under "definition" heading.

Not surprisingly, lower ET magnitudes were consistently observed for the grassland than the forested wetland. Lowest total ET values were observed in the dry periods for the two landuse covers. Highest total ET values were observed in the spring or summer time for forested wetland region. The highest ET demands, coinciding with a high plant growth cycle, were typically observed in the spring and in particular in the month of May. In some cases this trend was also observed in summer season particularly near the stream region.

The annual magnitude of interception capture, Ic, (interception ET) in 2002 made up about 8% of the water budget for grassland and 11% for forest land cover. In 2003 the magnitude was observed near 9% and 13% corresponding to the same landuse categories. For winter and spring in 2004 Ic ET was near 8% and 12% for the respective landuse regime.

Table 1. Annual water budget results for 2002.

Total Annual Results-2002																	
Period of Record	Landuse Category	Wells Location	Rainfall (in)	ET (in)				Runoff (in)				Lateral Flows (in)	Infiltration (in)	ADTWT (ft)	Δ in Storage (in)	Vertical Flows (in)	Dep. Storage Infiltration /ET (in)
		ID	P	Ic	Net ET from SM	DS ET	Total ET	TRE	SRE	URI	NR	Q	I	ADTWT	ΔS	VF	DSI
Annual 2002 Total for PS43-PS39 & USF3-USF1	Grass	USF-3	75.34	5.77	20.25	13.54	39.56	48.48	43.81	11.11	34.94	N/I	21.09	1.46	8.35	0.00	-1.05
	Grass	USF-1	75.34	5.77	20.30	11.28	37.36	44.99	43.73	9.25	33.71	N/I	24.58	1.36	8.78	0.00	0.51
	Grass	PS-43	75.34	5.77	20.51	7.68	33.96	48.61	41.33	8.67	40.93	0.89	20.96	2.32	9.71	1.79	2.16
	Mixed Zone	PS-42	75.34	4.75	29.47	5.71	39.94	40.71	35.73	11.93	34.99	0.50	29.88	2.54	12.10	-0.79	0.02
	Wetland	PS-41	75.34	8.69	28.41	6.73	43.83	41.53	35.59	11.82	34.81	0.53	25.12	2.31	9.31	0.06	1.15
	Forest	PS-40	75.34	7.75	34.97	0.31	43.04	32.14	15.07	15.58	31.83	0.35	35.45	3.58	14.74	-0.36	1.59
		PS-39	75.34	7.75	35.18	0.65	43.58	32.24	15.92	15.70	31.59	-0.06	35.35	3.04	14.74	-0.72	1.59

Table 2. Annual water budget results for 2003.

Total Annual Results-2003																	
Period of Record	Landuse Category	Wells Location	Rainfall (in)	ET (in)				Runoff (in)				Lateral Flows (in)	Infiltration (in)	ADTWT (ft)	Δ in Storage (in)	Vertical Flows (in)	Dep. Storage Infiltration /ET (in)
		ID	P	Ic	Net ET from SM	DS ET	Total ET	TRE	SRE	URI	NR	Q	I	ADTWT	ΔS	VF	DSI
Annual 2003 Total for PS43-PS39 & USF3-USF1	Grass	USF-3	53.13	5.04	16.19	12.36	33.60	33.92	31.09	2.50	21.55	N/I	14.21	1.16	-0.22	0.02	-0.91
	Grass	USF-1	53.13	5.04	18.03	14.71	37.78	31.47	30.80	6.58	16.76	N/I	16.66	0.87	2.54	0.01	0.11
	Grass	PS-43	53.13	5.04	21.64	9.68	36.36	31.52	29.89	2.72	21.84	1.03	16.57	1.58	-2.97	2.17	-0.22
	Mixed Zone	PS-42	53.13	4.17	35.29	3.44	42.90	23.77	20.98	7.50	20.33	0.55	25.19	2.02	-4.16	-0.63	1.07
	Wetland	PS-41	53.13	7.57	30.88	6.30	44.74	23.31	20.92	4.09	17.02	0.74	22.25	1.85	-5.56	0.55	-2.04
	Forest	PS-40	53.13	6.74	41.03	0.26	48.03	17.21	8.63	6.03	16.95	-0.43	29.18	3.51	-6.87	-2.32	2.06
		PS-39	53.13	6.74	39.99	0.40	47.13	17.17	9.83	6.27	16.78	-0.18	29.22	2.79	-6.88	0.52	2.04

Table 3. Semi-Annual water budget results for 2004.

Total Semi-Annual Results-2004																	
Period of Record	Landuse	Wells	Rainfall	ET (in)				Runoff (in)				Lateral Flows	Infiltration	ADTWT	Δ in Storage	Vertical Flows	Dep. Storage Infiltration /ET
	Category	Location	(in)									(in)	(in)	(ft)	(in)	(in)	(in)
		ID	P	Ic	Net ET from SM	DS ET	Total ET	TRE	SRE	URI	NR	Q	I	ADTWT	ΔS	VF	DSI
Annual 2004 Total for PS43-PS39 & USF3-USF1	Grass	USF-3	19.77	1.64	7.16	5.01	13.81	7.18	5.08	3.39	2.16	N/I	10.95	1.52	7.67	0.00	-0.25
	Grass	USF-1	19.77	1.64	15.27	4.88	21.79	5.59	1.91	4.96	0.71	N/I	12.54	1.48	2.27	0.00	-0.04
	Grass	PS-43	19.77	1.64	15.13	0.99	17.76	4.41	2.81	5.27	3.43	0.40	13.72	2.75	5.33	0.80	-0.29
	Mixed Zone	PS-42	19.77	1.34	19.63	1.07	22.03	3.86	2.00	6.38	2.79	0.26	14.57	2.68	0.80	-0.27	-0.73
	Wetland	PS-41	19.77	2.45	17.22	1.11	20.78	3.64	1.35	5.22	2.53	0.26	13.68	2.86	1.67	-0.01	-1.08
	Forest	PS-40	19.77	2.20	21.20	0.00	23.40	1.36	0.00	6.92	1.36	-0.16	16.21	4.33	0.21	-0.84	-4.68
		PS-39	19.77	2.20	20.68	0.01	22.89	1.37	0.02	6.96	1.36	-0.10	16.20	3.65	0.24	0.12	-4.68

The averaged value for observed SM ET for the grassland and forested wetland in 2002 was 20.35 inches (517 mm) to 30.95 inches (786 mm), respectively. This comprised approximately 27% and 41%, respectively of the observed annual precipitation of 75.3 inches (1,914 mm), a wetter than average period. In 2003, the average observed SM ET for the grassland and forest wetland was 18.62 in. (473 mm) and 35.7 in. (908 mm), respectively, corresponding to 35% and 67% of observed annual precipitation of 53.1 in. (1,350 mm) for a normal rainfall year.

For the winter and spring of 2004, SM ET ranged from 12.52 in. (318 mm) and 19.35 in. (491 mm) for the corresponding landuse covers respectively. This made up approximately 63% and 98% of the observed precipitation of 19.77 in. (502 mm) for the first six months in 2004.

Depression storage ET was assumed to be equal to the difference between GPET and SM ET when the water table was near or at land surface. Highest DS ET volumes were observed in the upland area, where the depth to water table (DTWT) was consistently shallower, declining across the transect wells to a minimum value near the stream region. This corresponded directly to increasing DTWT progressing towards the stream.

Daily and annual ET for the duration of the research were very similar to previous research findings for similar landuse covers in west-central Florida by Sumner (1996) with estimated daily ET rates ranging from 0.008 in./day (0.2 mm/day) in late December 1993 to 0.2 in./day (5 mm/day) in mid-July 1994 and Bidlake et al., (1996), (Bidlake et al., 1993) with annual ET estimates ranging from 38.18 in./yr (970 mm/yr) for a cypress swamp type to 39.76 in./yr (1,010 mm/yr) for the dry prairie type, 38.97 in./yr (990 mm/yr) for the marsh vegetation type and 41.73 in./yr (1,060 mm/yr) for the pine flatwood type (Bidlake et al., 1993).

Annual averaged DS ET fluctuated in the range of 10.83 in. (275 mm) to 4.25 in. (108 mm) making up 14% to 6% of the annual water budget for the grassland and forested wetland covers respectively in 2002, while 12.25 in. (311 mm) and 3.33 in. (85 mm) with a range of 23% to 6% range for the same landuse covers were observed in 2003. For the first six months in 2004 the magnitude of DS ET was 3.63 in. (92 mm) and 0.73 in. (18 mm), approximately 18% and 4%, corresponding to deeper ADTWT for this dryer period. The highest magnitude of DS ET was observed in the summer months when the water table was at or near land surface with high PET stress. In summer months DS ET became the single largest ET component for the upland region.

Total ET, sum of Ic, SM ET and DS ET, revealed somewhat expected variability across the transect. Higher total ET was observed near the stream and lower values in the upland area. In 2002, a wet year with 75.34 in. (1914 mm) of rainfall, total ET made up 49% to 56% of precipitation corresponding to grassland and forested wetland respectively. In 2003, a dryer year with 53.13 in. (1350 mm) of rainfall observed, values ranged from 68% to 85%, for the same respective landuse. In the first half of 2004, total ET made up in excess of 90% of the precipitation volume for the grassland. For forested wetland total ET was higher than precipitation by approximately 112%.

Systematically higher TRE and SRE and net runoff volumes were observed in the upland region and diminished toward the stream. Highest values were observed in summer seasons while lowest values were observed in winter, spring and fall seasons. SRE runoff was not observed in every season particularly near the stream region.

The highest TRE and SRE volumes were observed in the upland area. This is contrary to popular hill slope runoff models that suggest runoff is greater near the stream. SRE is defined as the observed rainfall excess when DTWT is shallow enough that the capillary fringe is at or near land surface thereby making the soil effectively fully saturated. For the Myakka soils at the study site, this corresponded to approximately 1 ft (0.3 m) from land surface. Consistent with the DTWT transition, lower TRE and SRE runoff volumes were observed near the stream region.

The TRE values in 2002 made up 63% and 51% of the rainfall volume for grassland and forested landuse respectively. In 2003, the observed magnitudes made up 61% to 40% respective to the same landuse regime. For 2004, the observed made up 29% to 15% of the observed rainfall volume. SRE runoff trailed behind TRE making up 57% and 38% of the precipitation for grassland and forested landuse respectively in 2002 while lower values in the range of 58% to 32% were observed in 2003. In the 1st half of 2004, the SRE made up 17% and 6% of the total observed rainfall for the upland and forest land, respectively. The results for 2004 only represent the winter and spring periods which are characteristically low runoff periods.

Net runoff (NR) values were consistently highest during the summer months, in 2002 and 2003. However, relatively high NR rates were observed in the fall of 2002, directly associated with higher than average precipitation volume for that season. Similar observations of high NR conditions prevailed in the un-characteristically wet spring of 2003. Overall higher NR volumes were observed in the upland areas rather than the near-stream areas. In 2002, the NR made up approximately 49% and 45% of the water budget across the transect wells for grassland and forest wetland respectively. In 2003, NR was

38% and 34% respectively. The NR declined significantly in the first six months of 2004 to approximately 11% for both landuse covers. This was consistent with lower rainfall and associated water table decline.

Systematically higher Hortonian runoff was observed near the stream while minimal to none was observed in the upland region. Hortonian runoff behavior revealed that this particular flow mechanism occurs only during intense storm periods.

Observed variability in monthly averaged crop coefficients deviate from simple sinusoidal pattern of monthly averaged PET. Higher values of Kc are observed in the peak growth period, spring time, and again in the fall period. This double peak behavior warrants more investigation but is probably attributed to SM availability, solar radiation reduction in the cloudy summer or decline in PET. Other meteorological elements, relative humidity and wind, may also be influencing this behavior.

The average depth to water table, ADTWT, was consistently shallower in the upland grassy region for most of the study period and was sustained near land surface during the wet periods for an extended period of time. This behavior was not consistent for forested wetland covers where consistently deeper fluctuations in ADTWT were observed including the wet period. For near the stream region ADTWT was rarely sustained near land surface, even during the wet periods, and consistently deepest depth was observed than any other stations.

Data filtering was required with the FDR technique for removing the effect of equipment noise. Multiple moving averaging techniques, 1, 4, 12 and 24 hr central moving averaging technique was performed to all integrated changes in SM record. The hourly averaged SM values did not effectively account for removal of the equipment noise effect. The 24 hr averaging period were simply too long and would have interfered with capturing the hourly variability of solar radiation on SM. The differences between 4 hr and 12 hr SM moving averaging results were not significant and this observation produced a comfort level to consider a conservative and reasonable approach and use the 12 hr SM averaging results. Data filtering were also necessary for water table fluctuations. Similar reasoning were employed to account for equipment noise effect and air entrapment influence on water table fluctuations and use of approximately 6.5 hr central moving averaging produced acceptable smoothing effect.

The methodology and the model demonstrated daily and seasonal variability in the TSM ET for various vegetative land covers for this shallow water table environment. A substitute technique was required to compensate for the FDR's inability to accurately estimate TSM changes during wet periods and in the event of the equipment malfunction or erroneous data. Obviously, the most useful data and our first preference would have been to use site specific pan data however, to achieve the resolution sought and on a continuous basis proved to be highly challenging. Therefore, J&H empirical model was used for PET data. The model uses the most influential parameters of solar radiation and temperature. The data were obtained from FAWN for ONA station. This station was selected due to closest proximity to the research site. The resultant PET data were further enhanced to adjust for temporal and special rainfall variability for the research site and account for the interception caption. This substitution produced acceptable result.

SM measurements are performed at point scale and then applied to the entire flow segment. This requires the assumption of homogenous soil conditions across each model section.

In almost every quarter, occurrences of higher infiltration than precipitation were observed. This observed behavior had a tendency to be more pronounced with higher rainfall intensities. Model calibration will be helpful. Rise in SM are also observed at night time and in the absence of rainfall. These SM increases are typically observed in the second and the third sensors for the upland but for near the stream region they are observed in multiple layers and in the deeper region.

Summary

One of the indications of how well ET estimation methods perform in Florida is whether or not the annual estimate falls within the expected limits. Temporal variability in annual PET in many parts of Florida is slight. A comparison of annual ET rates for grass land cover and forested wetland region were made against annual ET results generated by different techniques and models that were previously employed. The comparisons of the results are presented in Table 4 and graphically shown in Figure 31. Reviewing the data reveals the relative similarity of estimated ET for the grassland and forested wetland using the TSM model approach vs. previous methods. Excluding isolated variation, the annual TSM ET results fall well within the expected range for the duration of the research.

A comparison of annual Site PET rates for the research site was made against annual PET results generated by different models for open water. The Highest PET values were observed by J&H model while very similar values were observed for the site PET vs. other models for previous researches. Comparisons of the results are shown in Figure 32.

The TSM model allows for small or large scale (daily, weekly, monthly, quarterly and annual) ET estimation for multiple landuse regimes. A substitute technique/model is required for wet periods, when DTWT is near landsurface. Inclusion of estimated DS ET, based on site PET data utilizing J&H model, produced acceptable results for this research.

Table 4. ET results for grass and forest using various ET models.

ET Model	Technique	Period of Research	Region	Reference	Precipitation	Total ET	
						Grass	Forest/Wetland
Lysimeter	SM Measurements	2 Annual (1993-1996)	South- Florida	Abtew (1996)	-	-	52.4
EBBR & ECM	Meteorological Measurements	16 Months	West-Central Florida	Bidlake (1996)	-	38.2	41.7
EBBR & EBWSP	Meteorological Measurements	16 Months	West-Central Florida	Bidlake & Boetcher (1996)	88.38	-	55.9
EBBR	Meteorological Measurements	2 Annual	South- Florida	German (2000)	-	42.4	48.1
Lysimeter	SM Measurements	3 Annual	South- Florida	Mao (2002)	-		46.7
Lysimeter	SM Measurements	3 Annual	South- Florida	Mao (2002)	-		50.7
Soil Moisture Measurements	FDR	Annual (2002)	West-Central Florida	Ross/Rahgozar (2006)	75.34	36.95	41.67
Soil Moisture Measurements	FDR	Annual (2003)	West-Central Florida	Ross/Rahgozar (2006)	53.17	35.67	45.32
Soil Moisture Measurements	FDR	Semi-Annual(1/04-6/04)	West-Central Florida	Ross/Rahgozar (2006)	19.77	17.8	22.00
Penman & Modified Priestley - Taylor	Meteorological Measurements	2 Annual	West-Central Florida	Sumner (1996)	51.8	26.7	-
ECM & Priestley -Taylor Approach	Meteorological Measurements	2 Annual	North-Florida	Sumner (2001)	51.8	39	-
Water Budget Balance	Water Budget Balance	Long Term	16 Countries Across the Globe	Zhang (2001)	52	27.2	38.2

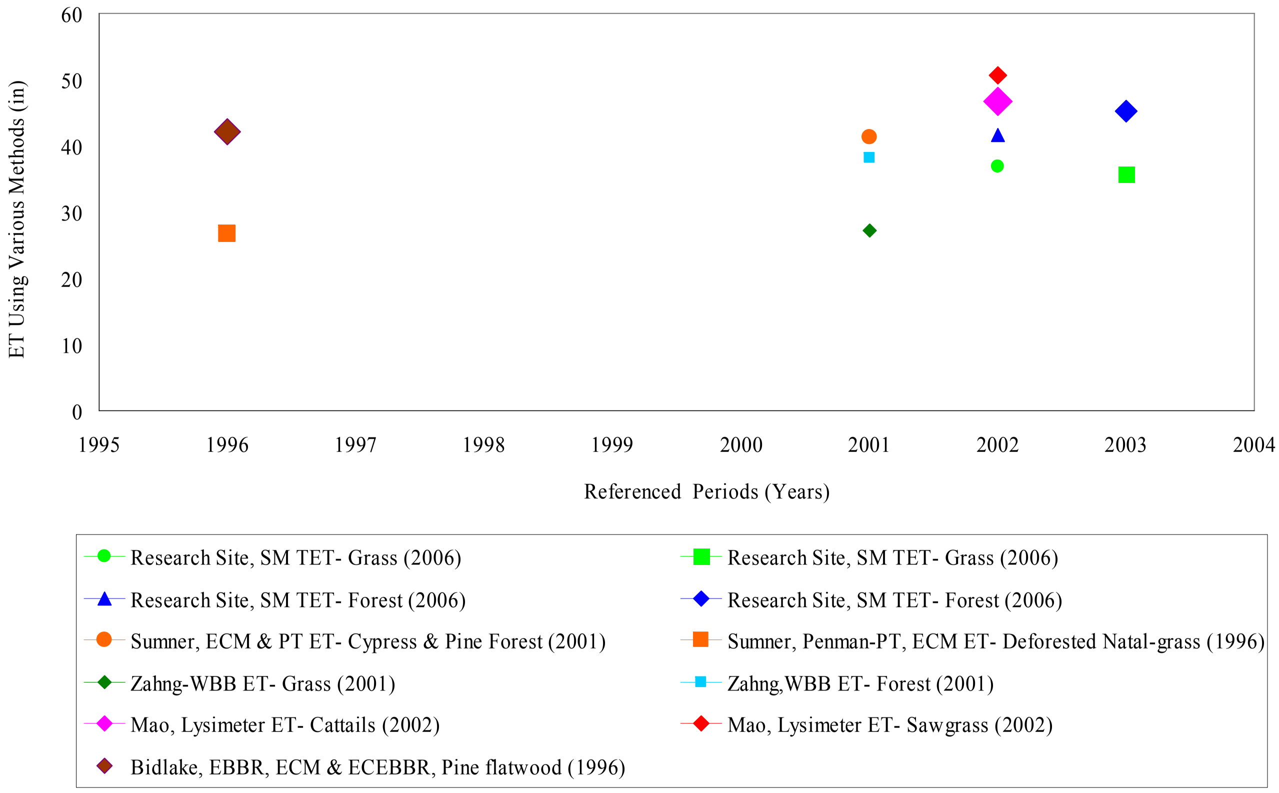

Figure 31. Estimated ET using various methods for grassland and forested wetland.

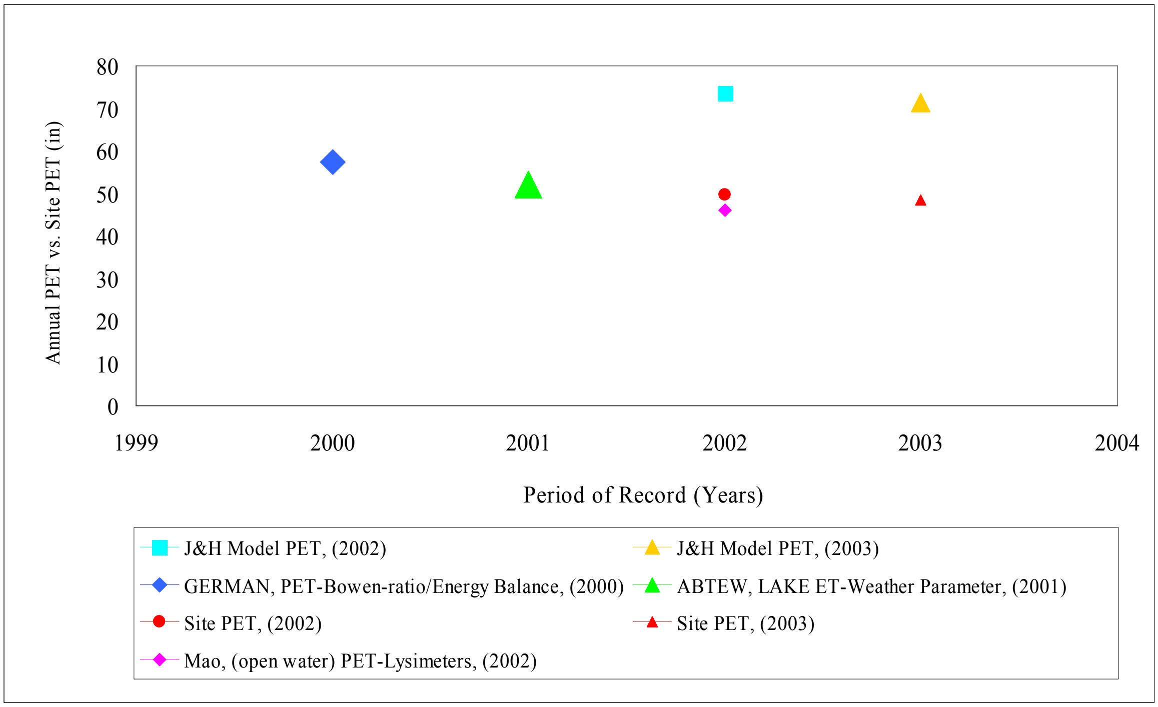

Figure 32. Estimated potential ET using various methods for open water vs. site PET.

Conclusions

FDR soil moisture sensors can be utilized to gain accurate soil water measurements at multiple depth intervals with negligible disturbances after initial installation. Employing FDR along flow transects can yield water budget fluxes including ET for small time scale resolution. Data filtering is required with the FDR sensors deployed. The method can then be used to investigate seasonal variability in the TSM ET for various vegetative land covers at least in shallow water table settings. More investigation is required to see if the technique works for deeper DTWT. Simultaneous test of this method with other well known methods will prove useful.

FDR technique is not reliable in measuring TSM fluxes during periods when depth to water table is near land surface. A substitute technique is required during these periods such as assuming the actual ET rate may proceed at PET. With this assumption, a potential ET model is required such as a pan or Penman measurement approach. Use of PET, particularly during wet periods, is considered an acceptable estimation of ET demand (Hillel and Guron, 1973; Hillel, 1997). Accurate estimates of local PET will enhance the predictive capabilities of the model. Therefore, the TSM approach must be considered a viable method only after acknowledging this additional data need and assumption.

A potential weakness of this technique is that the measurements are performed at point scale and then applied to the entire flow segment. It is clear that variability in vegetable cover and soil conditions exist across each model section. FDR soil moisture measurements of total profile water storage were generally good, with some minor exceptions. In almost every quarter, occurrences of higher infiltration than precipitation were observed for some events. This phenomenon, also observed in previous research Walker et al., (2004) is more pronounced with higher rainfall intensities. While the integration approach may be a contributing factor in this observed behavior, soil's structural and textural characteristics in various layers may play a role. Installation of sensors in each horizon will help in understanding if the observed behavior is surface or profiled controlled. Calibration for soils containing high clay and organic matter may also prove helpful.

The observed daily, monthly, and annual ET results were consistent with previous research findings for west-central Florida employing different techniques and approaches for the grassland and forested wetland landuse. This provides further evidence that, despite observed weaknesses, this approach can serve as an alternative methodology to measure ET in field settings with added benefits of resolving ET components and other water budget fluxes.

REFERENCES

Allen, R. G., L. S. Pereira, D. Raes, and M. Smith. (1999). Crop evaporation: Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56, FAO. Rome.

Abtew, W. and J. Okeysekera, (1995b). Estimation of Energy Requirements of Morning Dew Evaporation from Leaf Surfaces. Water Resources Bulletin 31(2):217-225.

Abtew, W., J. (1996a). " Evapotranspiration measurements and modeling for three wetland systems." " J. Am. Water Resour. Assoc., 32(3), 465-473.

Abtew, W., J. (2001). "Evaporation Estimates for Lake Okeechobee in South Florida". Journal of Irrigation Drainage Engineering, 127(3), 140:147.

Abtew, W., J. Okeysekera, M. Irizarry-Oritz, D. Lyons and A. Reardon. (2003). Evapotranspiraton Estimation for South Florida. Proceedings of World Water and Environmental Resources Congress 2003 and Related Symposia, P. Bizier and P.A. DeBarry, eds. ASCE.

Alsanabani, M.M. (1991). Soil water determination by time domain reflectometry: sampling domain and geometry. Ph.D. thesis. Department of Soil and Water Sciences, Univ. of Arizona, Tuscan, AZ 85721.

Baker, J. M., and R. J. Lascano. (1989). The spatial sensitivity of time-domain refectometry. Soil Sci. 147:378-384.

Bidlake W. R., Woodham, W.M. and Lopez, M.A.(1996). Evapotranspiration from Areas of Native Vegetation in West-Central Florida. U.S. Geological Survey Water –Survey Paper 2430.

Bidlake W. R., Boetcher, P. F.(1996). Near –Surface Water balance of an undeveloped upland site in West-Central Florida. U.S. Geological Survey Water –Supply Paper 2452.

Bidlake, W. R., Woodham, W.M., and Lopez, M.A., (1993), Evapotranspiration from areas of native vegetation in Wets- Central Florida: U.S. Geological Survey Open File Report 93-415, 35p.

Bouten, W., Heimovaara, T. J., A., (1992). Spatial patterns of throughfall and soil water dynamics in a Douglas fir stand. Water Resources Research 28 (12), 3227-3233.

Bridge, B. J., Y. Sabburg, K.D. Habash, Y.A. Ball, and N.H. Hancock, 1996. The dielectric behavior of clay soils and its application to time domain reflectometry. Aust. J. Soil. Res. 34:825-835.

Brooks, H. K., (1981). Guide to the physiographic divisions of Florida: Gainsville, Florida Cooperative Extension Service, Institute of Food and Agricultural Services.

Buss, P. 1993. The use of capacitance based measurements of real time soil water profile dynamics for irrigation scheduling. In Under pressure. Irrig. 93. Proc. Natl. Conf. Irrig. Assoc. Australia and the Natl. Committee on Irrig. And Drainage, Launceston, Tasmania. 17-19 May 1993. Irrig. Assoc. of Australia. Homebush, NSW.

Crave, A., Gascuel-Odoux, C., (1977). The influence of topography on time and space distribution of soil surface water content. Hydrological Processes 11, 203-210.

Dawson, T. E., (1995). Determining water use by trees and forests from isotopic, energy balance and transpiration analysis: the roles of tree size and hydraulic lift. Section of Ecology and Systematics, Carson Hall, Cornell University, Ithaca, NY 14853, USA. Tree Physiology 16, 263-272.

Dalton, F. N., Herkelrath, W. N., Rawlins, D. S. and Rhoades, J. D., (1984). Time domain reflectometry: Simultaneous measurement of soil water content and electrical conductivity with a single probe, Science 224, 989-990.

Dean, T. J., J. P. Bell, and A.J.B. Baty, (1987). Soil moisture measurement by an improved capacitance technique, Part I. Sensor design and performance. J. Hydrol. (Amsterdam) 93:67-78.

Dolan, T. J., A. J. Hermann, S.E. Bayley, and J. Zoltek, Jr., (1984). Evapotranspiration of a Florida, U.S.A., Freshwater Wetland. J. of Hydrology 74:355-371.

Doorenbos, J. and Pruitt, W. O., (1977). Guidelines for Predicting Crop Water Requirements. FAO Irrigation and Drainage Paper 24, Food and Agriculture Organization of the United Nations, Rome.

Engman, E. T., (1991). Applications of microwave remote sensing of soil moisture for water resources and agriculture. Remote Sens. Environ. 35, 213-226.

Engman, E. T., and Chauhan, B, (1995). Status of microwave soil moisture measurements with remote sensing. Remote Sens. Eviron. 51, 189-198.

Evett R. Steven, Howell A. Terry, Steiner L. Jean, and Cresap, L. James, (1993). Evapotranspiration by Soil Water Balance Using TDR and Neutron Scattering.

Evett, R.S. and J. L. Steiner, (1995). Precision of neutron scattering and capacitance type soil water content gauges from field calibration. Soil Sci. Soc. Am. J. 59:961-968.

Famiglietti, J. S., Devereaux, J. A., Laymon, C., Tsegaye, T., Houser, P.R., Jackson, T.J., Graham, S.T., Rodell, M., Van Oevelen, P.J., (1990). Ground-based investigation of spatial-temporal soil moisture variability within remote sensing footprints during Southern Great Plains 1997 hydrology experiment. Water Resour. Res. 35, 1839-1851.

Gardner, C. M., F.T. Ulaby, M. T. Hallikaninen, and M. A. El-Rayes, 1985. Microwave dielectric behavior of wet soil –part II: Dielectric mixing models. IEEE Trans. Geosci. Remote Sens. 23:35-46.

German, E. R. (2000). Regional Evaluation of Evapotranspiration in the Everglades. USGS. Water-Resources Investigations Report 00-4217, Tallahassee, FL.

Grayson, R.B., Western, A.W., (1998). Towards areal estimation of soil water content from point measurements: time and space stability of mean response. J. Hydrol. 207, 68-82.

Herkelrath, W. N., S.P. Hamburg, and F. Murphy. (1991). Automatic, real-time monitoring of soil moisture in a remote field area with time-domain reflectometry. Water Resour. Res. 27:857-864.

Hanks, R. J., and Shawcroft, R. W. (1965). An economical lysimeter for evapotranspiration studies. Agron. J. 57, 634-636.

Hanson, R. L. (1991). “ Evapotranspiration and Drought.” In; National Water Summary 1988-89—Hydrologic Events Floods and Droughts. R.W. Paulson, E.B. Chase, R.S. Roberts and D.W. Moody (eds.). USGS, Water-Supply paper 2375, 99-104.

Hargreaves, G. H. and Samani, Z. A. (1985). Reference crop evapotranspiration from temperature. Applied Engineering in Agriculture, 1(2):96-99.

Harrold, L. L. (1966).Measuring evapotranspiration by lysimetry.In: “ Evapotranspiration and Its Role in Water Resources Management.” Am. Soc. Agr. Eng., St. Joseph, MI.

Hawley, M. E. Jackson, T.J. McCuen R. H. (1983). Sorface soil moisture variation on small agricultural watersheds. J. Hydrol 62: 170-200.

Henninger, D.L., Peterson, G.W., Engman, E.T., (1976). Surface soil moisture within a Watershed- variations, factores influencing, and relationship to surface runoff. Soil Science Society of America Journal 40, 773-776.

Hillel, D. (1997). Small-Scale Irrigation for Arid Zones: Principles and Options, Development Monograph No.2. United Nations Food and Agriculture Organization, Rome.

Hillel, D. (1982). Negev: Land, Water and life in a Desert Environment. Praeger, New York.

Hillel, and Guron, Y. (1973). Relation between Evapotranspiration rate and maize yield. Water Resour. Res. 9, 743-748.

Hills, R. C., Reynolds, S. C., (1969). Illustrations of soil moisture variability in selected areas and plots of different sizes. Journal of Hydrology 8, 27-47.

Jackson, I. J., (1975). Relationships between rainfall parameters and interception by tropical forest. Journal of Hydrology 24, 215-238.

Jackson, T. J. and Schmugge, T. J. (1989). Passive microwave remote sensing system for soil moisture: Some supporting research. IEEE Trans. Geosci. Remote Sens. GE-27, 225-235.

Jensen, M. E. and Haise, H. R., (1963). Estimating evapotranspiration from solar radiation .J. Irrig. Drainage Div. ASDE, 89: 15-41.

Jones, J. W., Allen, L. H., Jr. Shih, S.F., Rogers, J.S., Hammond, L.C., Smajstrla, A.G., and Martsolf, J.D., (1984). Estimated and measured evapotranspiration for Florida climate, crops, and soils, Gainesville, Florida Agricultural Experiment Stations, Institute of Food and Agricultural Sciences, Technical Bulletin 840, 65 p.

Itenfisu, D., R. L. Elliot, R.G. Allen and I.A. Walter. (2000). Comparison of Reference Evapotranspiration Calculation across a Range of Climates. Proc. Of the National Irrigation Symposium, November 2000, Phoenix, AZ, American Society of Civil Engineers, Environmental and Water Resources Institute, New York, NY.

Ladekarl, U. K., (1997). Estimation of the components of soil water balance in a Danish oak stand from measurements of soil moisture using TDR. Journal of Forest Ecology and Management, Vol. 104. May 1998. pp 227-238.

Lin, D. S., Mancini, M., Troch, P., Wood, E. F., and Jackson, T. J. (1994). Comparisons of remotely sensed and model simulated soil moisture over a heterogeneous watershed. Remote Sensing of Environment 48, 159-171.

Mao, L. M., Bergman, M. J. and Tai, C. (2002). Evapotranspiration Measurement and Estimation of Three Wetland Environments in the Upper St. Johns River Basin, Florida". Journal of the American Water Resources Association, 5(38), 1271-1285.

Mitsch, W. J. and J. G. Gosselink., (1993). Wetlands, Second Edition, Van Nostrand Reinhold, New York, NY.

Mohanty, B. P., Famiglietti, J. S., Skaggs, T. H., (2000a). Evolution of soil moisture spatial structure in a mixed vegetation pixel during the Southern Great Plains 1997 (SGP97) Hydrology Experiment. Water Resources Research 36 (12), 3675-3687.

Monteith, J. L., (1965). Evaporation and environment, in: The state and movement of water in living organisms, Symposium of the Society of Experimental Biology: San Diego, California (G.E. Fogg, ed.), Academic Press, New York, p.205-234.

Moore, I. D., Burch, G. I., (1988). Topographic effects on the distribution of surface soil water and the location of ephemeral moisture gullies. Transactions of the ASAE 31 (4), 1098-1107.

Nachabe, M., Shah, N., Ross, M., Vomacka, J., (2005). Evapotranspiration of Two Vegetative Covers in a Shallow Water Table Environment. Soil Sciences Society of America Journal 69, 492-499.

Nyberg, L., (1996). Spatial variability of soil water content in the covered catchment at Gardsjon, Sweden. Soil Sciences Society of America Journal 56, 1267-1271.

Paltineanu I. C. and Starr, J. L., (1997). Real-time Soil Water Dynamics Using Multisensor Capacitance Probes: Laboratory Calibration. Soil Sci. Soc. Am. J. 61: 1576-1585 (1997).

Penman, H. L., (1948). Natural evaporation from open water, bare soil, and grass: Proceedings of Loyal Society of London, Series A, v. 193, p. 120-146.

Phene, C. J., McCormic, R. L., Davis, K. R., and Oierro, J., (1989). A lysimeter system for precise evapotranspiration measurements and irrigation control. Trans. Am. Soc. Agric. Eng. 32, 477-484.

Priestley, C. H. B., and Taylor, R. J., (1972). On the assessment of surface heat flux and evaporation using large-scale parameters: Monthly Weather Review, v. 100, no. 2, p. 81-92.

Reid, I., (1973). The influence of slope orientation upon the soil moisture regime, and its hydrogeomorphological significance. Journal of Hydrology 19, 309-321.

Ross, M. A., Trout, K. E., Swarna, P., Said, A, Rahgozar, M. S. (2005). Micro-scale high-resolution measurement of surface and groundwater interaction in a coastal plain, shallow water table. University of South Florida, Tampa, FL, Final Report.

Said, A., Nachabe, M., Ross, M. A., Vomacka, J., (2004). Methodology for Estimating Specific Yield in Shallow Water Environment Using Continuous Soil Moisture Data. Journal of Irrigation and Drainage Engineering, Vol. 131, No. 6, November/December 2005, pp.533-538.

Schellekens, J., Bruijnzeel, L. A., Scatena, F. N., Bink, N. J., Holwerda, F., (2000). Evaporation from a tropical rain forest., Luquillo Experimental Forest. Eastern Puerto Rico. Water Resources Research 36, 2183-2196.

Shuttleworth, W. J., Calder, I. R., (1979). Has the Priestley Taylor equation any relevance to forest evaporation?. Journal of Applied Meteorology 18, 639-646.

Smajstrla, A. G., (1990). Agricultural Field Scale Irrigation Requirements Simulation (AFSIRS) Model. Agricultural Engineering Department, University of Florida. 252 pp.

Stephen, J. C. (1959). Evapotranspiration studies pertaining to the agricultural watersheds in Florida. USDA. ARS. Soil and Water Conservation Research Division. Fort Lauderdale, FL, 39.1-39.31.

Schmugger, T. (1990). Measurements of surface soil moisture and temperature. In: Hobbs, R. J., and Mooney, H. A., eds., “Remote sensing of Biosphere Functioning.” Springer-Verlag, New York.

Sumner D. M. (1996) Evapotranspiration from successional vegetation in a deforested area of the Lake Wales Ridge, Florida. U.S. Geological Survey; Water-Resource Investigation Report 96-4244.

Sumner D. M. (2001) Evapotranspiration from a Cypress and Pine Forest Subjected to Natural Fires, Volusia County, Florida, 1998-1999. U.S. Geological Survey; Water-Resource Investigation Report 01-4245.

Topp, G. C., Davis, J. J., Annan, A. P., (1980). Electromagnetic determination of soil water content: measurements in coaxial transmission lines. Water Resour. Res. 16, 574-582.

Topp, G. C., and Davis, J. L. (1985). Time-Domain reflectomerty (TDR) and its application to irrigation scheduling. In: Hillel, D., ed., “Advances in irrigation,” Vol. 3. Academic Press, San Diego.

Topp, G. C., (1993). Soil water content. p. 541-557. In M.R. Carter (ed.) Soil sampling and methods of analysis. Lewis Publ., Boca Raton, FL.

van Bavel, C. H. M., and Myers, L. E. (1962). An automatic weighing lysimeter. Agr. Eng. 43, 580-583.

van Bavel, C. H. M., and Hillel, D. (1975). A simulation study of soil heat and moisture dynamics as affected by a dry mulch. In: “Proc. Summer Comput. Simulate. Conf.,” San Francisco, C.A. Simulation Councils, LaJolla, C.A.

van Bavel, C. H. M., and Hillel, D. (1976). Calculating potential and actual evaporation from a bare soil surface by simulation of concurrent flow of water and heat. Agr. Meteorol. 17, 453-476.

van Bavel, C. H. M., Lascano, R.J., and Baker, J. M. (1985). Calibrating two-probe, gamma-gauge densitometers, Soil Sci. 140, 393-395.

Viessman, W., Klapp, J. W., Lewis, G. L. and Harbaugh, T. E. (1977). Introduction to Hydrology, Harper & Row, New York.

Visher, F. N. and Hughes, G. H. (1969). The difference between rainfall and potential evaporation in Florida, 2nd Ed. Florida Bureau of Geology Map Series 32, Tallahassee, Fl.

Walker, J. P., Willgoose, G. R., and Kalma, J. D. (2004). In situ measurement of soil moisture: a comparison of techniques. Journal of Hydrology 293, 85-99.

Walter, I. A., R. G. Allen, R. Elliot, M. E. Jensen, D. Itenfisu, B. Mecham, T.A. Howell, R. Snyder, P. Brown, S. Echings, T. Spofford, M. Hattendorf, R.H. Cuenca, J.L. Wright, D. Martin. (2000). ASCE’s Standardized Reference Evapotranspiration Equation. Proc. Of the Watershed Management 2000 Conference, June 2000, Ft. Collins, CO, American Society of Civil Engineers, St. Joseph, MI.

Watson, K., R. Gatto, P. Weir, and P. Buss, (1995). Moisture and salinity sensor and method of use. U.S. Patent 5 418 466. Date issued: 23 May. **year**

Waylen, P. R. and Zorn, R. (1998). “Prediction of mean annual flows in North and Central Florida.” Journal of American Water Resources Association. 34(1), 149-157.

Western, A. W., Grayson, R. B., Bl’oschl, G., Willgoose, G. R., McMahoon, T. A., (1999a). Observed spatial organization of soil moisture and its relation to terrain indices. Water Resources Research 35 (3), 797-810.

Whalley, W. R., T.Y. Dean, and P. Izzard, (1992). Evaluation of the capacitance technique as a method for dynamically measuring soil water content. J. Agric. Eng. Res. 52:147-155.

White**,** I., and Perroux, K. M. (1987). Use of sorptivity to determine field soil hydraulic properties. Soil Sci, Soc, Am, J. 51, 1093-1101.

Wilson, D. J., Westren, A. W., Grayson, R. B., Berg, A. A., Lear, M. S., Rodell, M., Famiglietti, J. S., Woods, R. A., and McMahon, T. A. (2003). Spatial distribution of soil moisture over 6 and 30 cm depth, Mahurangi river catchment, New Zealand. Journal of Hydrology, Vol. 276, May 2003. pp. 254-274.

Zegelin S. J., I. White, and G.F. Russell. (1992). A critique of the time domain reflectometry technique for determining field soil water content. p, 187-208. In G.C. Topp et al. (ed.) Advantages in measurement of soil physical properties; Bringing theory into practice. SSSA Spec. Publ. 30. SSSA, Madison, WI.

Zinke, P. J., (1967). Forest interception studies in the United States. In: Sopper, W. E., Lull, H. W. (Eds.). International Symposium on Forest Hydrology. Pergamon Press, New York, pp. 137-160.

APPENDICES

Appendix A: Soil Description at the Field Study Site

An intensive filed study was conducted at field-scale to measure hydrologic response of a small (185 acres) basin tributary to a first-order perennial stream in west-central Florida (Ross et al. 2004). Data summarized here are discussed in more detail in Ross et al. (2004).

Direct push drilling sample results, were performed along most transect wells. Samples were used for evaluation of textural classification of the soil, saturated hydraulic conductivity and porosity. A sample of the result for USF3 is shown in Figure 33. Higher clay concentrations at shallow depths were observed near USF3 and USF1. The depth to confining clay layer for USF3 and USF1 are near 5.4 ft (1.65 m) and 4.375 ft (1.33 m) respectively. High concentrations of organic matter in the upper region were observed near some stations overlaying typical sandy/silty soil in lower horizons. Soil characteristics of PS42 and PS41 did not reveal high organic content in the upper region, although similar characteristics in the remaining horizons were prevalent. Review of particle size analysis performed on collected samples show a relative decrease in particle diameter with depth. Consistent with grain size distribution vertical hydraulic conductivity also decreased with depth and this trend was noted in all soil stations.

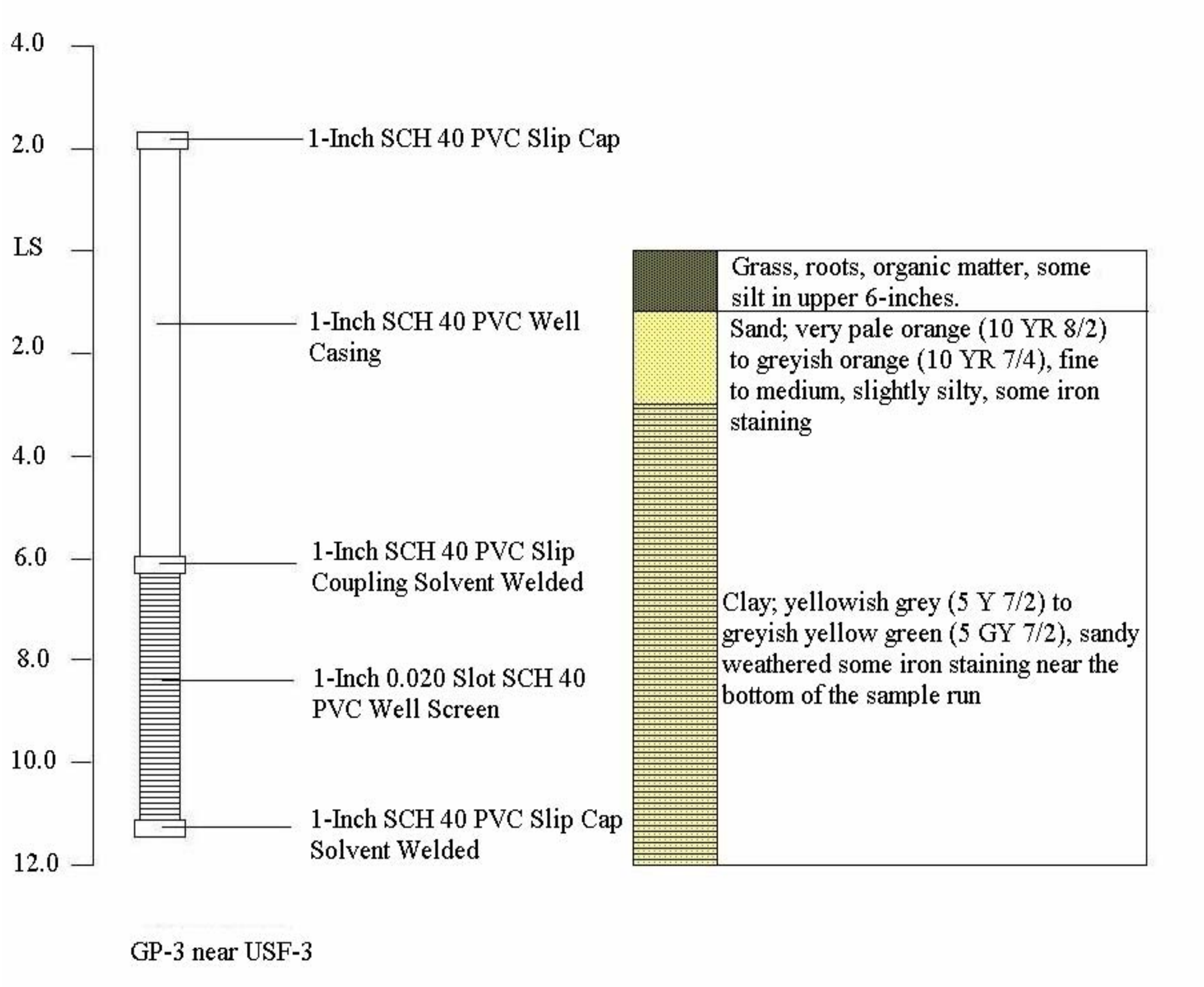

Figure 33. Direct push drilling results near USF3.

Appendix B: Influence of Temporal Variability in Soil Moisture Averaging on ET Results

For ET estimation all negative *(I-ET-L)* cell values in the numerical model were separated from the positive cell values by a simple algorithm in the model. Vertical soil moisture observations with capacitance shift devices in sandy soils are very precise and relatively stable. However, integration over depth to get small fluctuations pushes the limit and the signal can be noisy. Five minute values averaged hourly were ultimately averaged over a 12 hour period using a central moving averaging technique. This technique was also used with water table elevations when soil moisture data was absent and the *Sy* model was used.

The influence of SM averaging was used on ET results and is shown in Figures 34 and 35 for station PS43 and PS40 respectively. From the graphs it is observed that variable SM averaging has a greater influence on some stations (e.g.; PS43) than others (PS40). For the grassland land cover, 24 hour SM averaging for the most part resulted in lowest SM ET while the hourly averaging resulted in the highest SM ET. This was also consistent for forested land covers. The difference between hourly vs. 12 and 24 hrs SM averaging is considerably higher in winter of 2004 than any other period. This behavior was not observed for the forested wetland.

Given that the ET cycle is primarily radiation driven, the 12 hour averaging was considered more appropriate than longer or shorter periods considered. For this research 12 hour moving averages were used as a middle approach toward achieving results for SM ET. The magnitudes of other components of the water budget such as infiltration and TRE are also influenced by the averaging period selected.

Appendix B: (Continued)

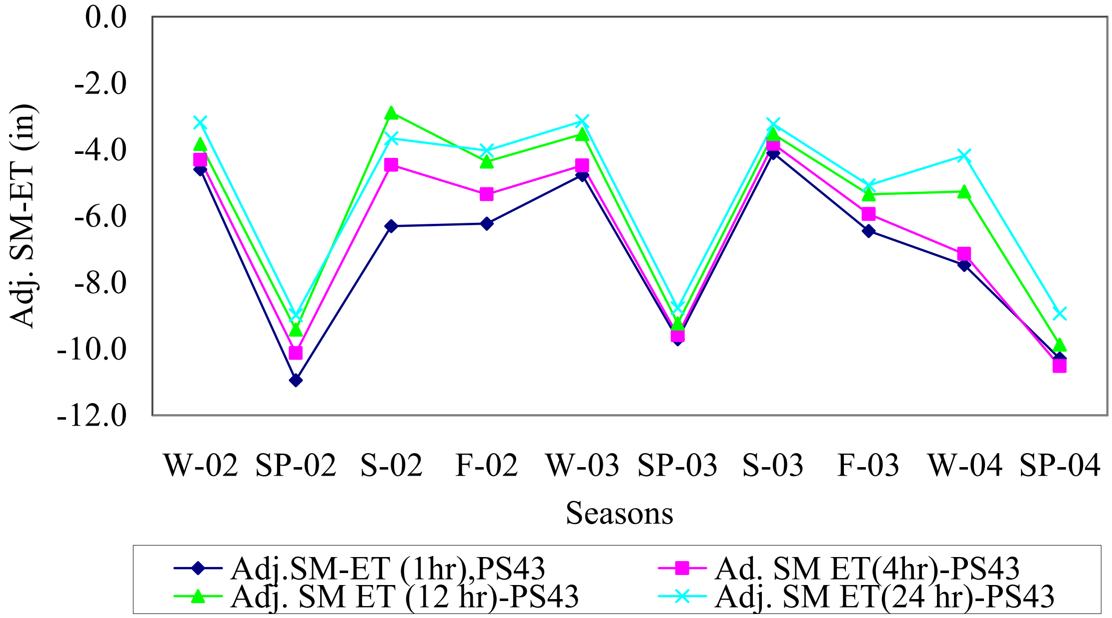

Figure 34. Temporal variability in soil moisture for grassland cover (Station PS43).

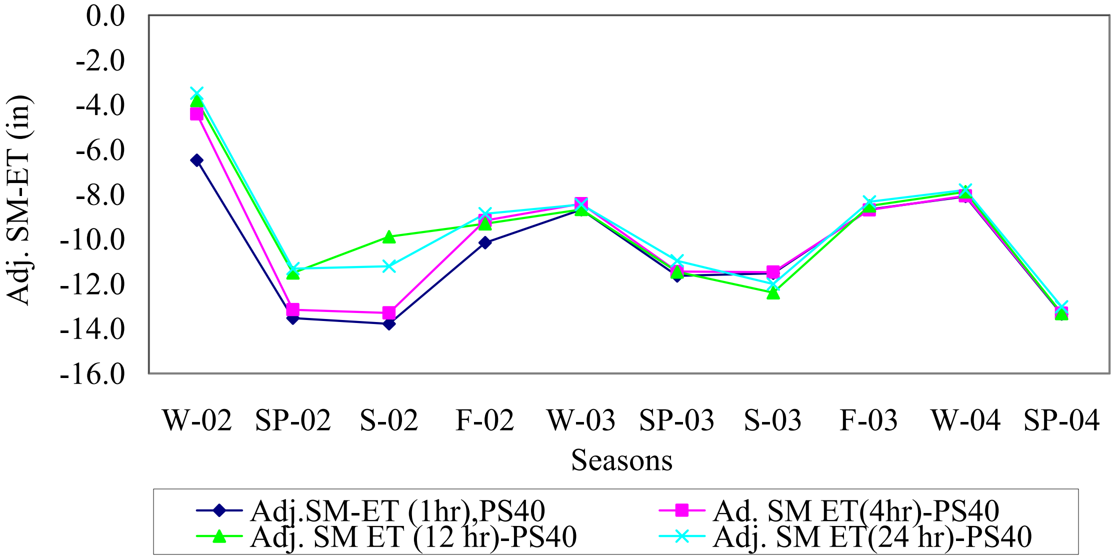

Figure 35. Temporal variability in soil moisture for forest cover (Station PS40).

Appendix C: Techniques for Estimation of Potential ET, Site Potential ET, Ground Potential ET and Adjusted SM

The PET values were estimated using the empirical equation of Jensen and Haise (1963).

$$ETP_{J\&H} = \left[\frac{R_S}{2450} * ((0.025 * T_{ave}) + 0.08) \right]$$

where $ETP_{\mathrm{J\&H}}$ = monthly mean of daily potential evapotranspiration (mm/day); Rs = monthly mean of daily (total) solar radiation (Kj/m^2 /day); Ta = monthly mean of daily air temperature ($^{\mathrm{o}}$ C).

The input parameters for the equation were instantaneous hourly resolution for solar radiation and temperature. The solar radiation and temperature data were obtained from Florida Automated Weather Network (FAWN) (http://fawn.ifas.ufl.edu/), stored in Mine data from the FAWN archived weather data. The data collected from the ONA site were utilized due to close proximity of this site to the research site. A pan factor of 0.7 was employed uniformly to J&H model PET records and results were further adjusted to account for temporal and spatial variability for the research site as site PET. The site PET records were further refined to account for interception capture (Ic). The new set are termed ground potential ET (GPET).

The quarterly magnitudes of estimated PET, site PET and GPET for full calendar year in 2002, 2003 and for the first six months in 2004 are presented graphically in Figure 36 and in Tables 5 and 6 respectively.

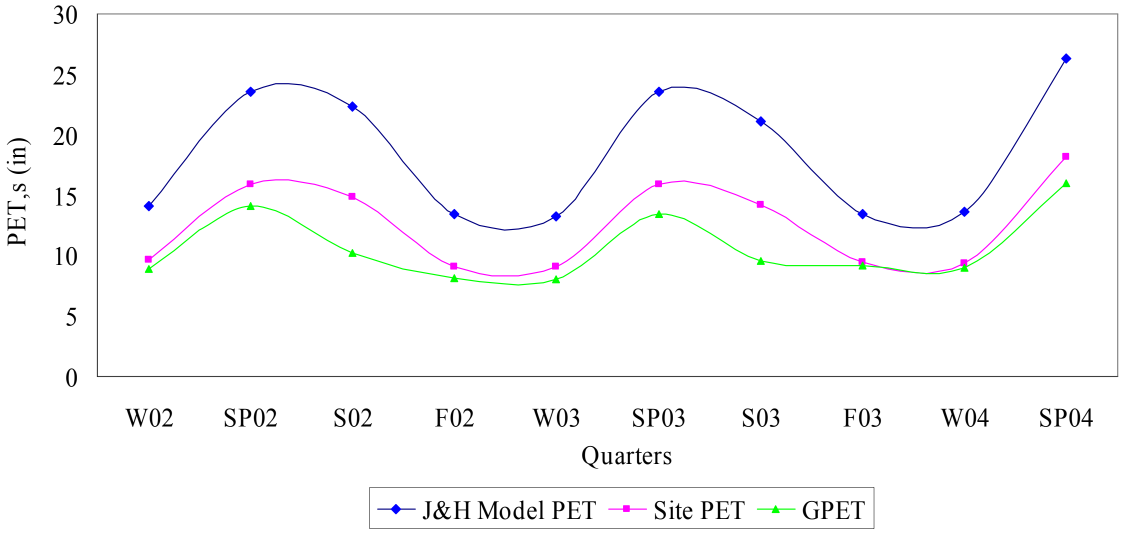

Figure 36. Quarterly values of potential ET, site potential ET and ground potential ET (GPET).

Appendix C: (Continued)

Table 5. Quarterly values computed for PET, site PET and GPET.

Period Of Record	Annual	Quarters	Quarterly J&H Model PET Using FAWN-ONA Site's Solar Radiation & Temperature Data (in)	Quarterly Site PET with Uniform Pan Factor of 0.7 Adjusted with Rainfall Records (in)	Quarterly GPET (in)
Period Of Record	2002	3rd (1/1/02-3/31/02)	14.1	9.7	8.9
		4th (4/1/02-6/30/02)	23.6	15.9	14.1
		5th (7/1/02-9/30/02)	22.3	14.8	10.3
		6th (10/1/02-12/31/02)	13.4	9.1	8.2
	2003	7th (1/1/03-3/31/03)	13.2	9.1	8.0
		8th (4/1/03-6/30/03)	23.5	15.9	13.4
		9th (7/1/03-9/30/03)	21.1	14.2	9.6
		10th (10/1/03-12/31/03)	13.5	9.4	9.1
	2004	11th (1/1/04-3/31/04)	13.6	9.4	9.0
		12th (4/1/04-6/30/04)	26.3	18.2	16.0

Table 6. Annual values computed for PET, site PET and GPET.

Period Of Record	J&H Model PET Using FAWN-ONA Site's Solar Radiation & Temperature Data (in)	Site PET with Uniform Pan Factor of 0.7 Adjusted with Rainfall Records (in)	GPET (in)
Annual 2002 1/1/02-12/31/02	73.4	49.5	41.5
Annual 2003 1/1/03-12/31/03	71.3	48.5	40.2
Semi-Annual 2004 1/1/04-06/30/04	39.9	27.5	25.0

Appendix D: Daily Variability in SM and DS ET with Landuse

Sample of observed daily ET and DS ET for the annual year in 2003 are shown in Figures 37 and 38 for the grassland cover (PS43) and forested wetland (PS40) respectively. For grassland covers highest magnitudes of ET are observed in spring period while some fluctuations in ET magnitudes were observed near station USF3. This pattern of behavior was also observed in 2002 & 2004. For forested wetland highest ET demand are observed in the summer period. This trend in behavior was also observed in 2002.

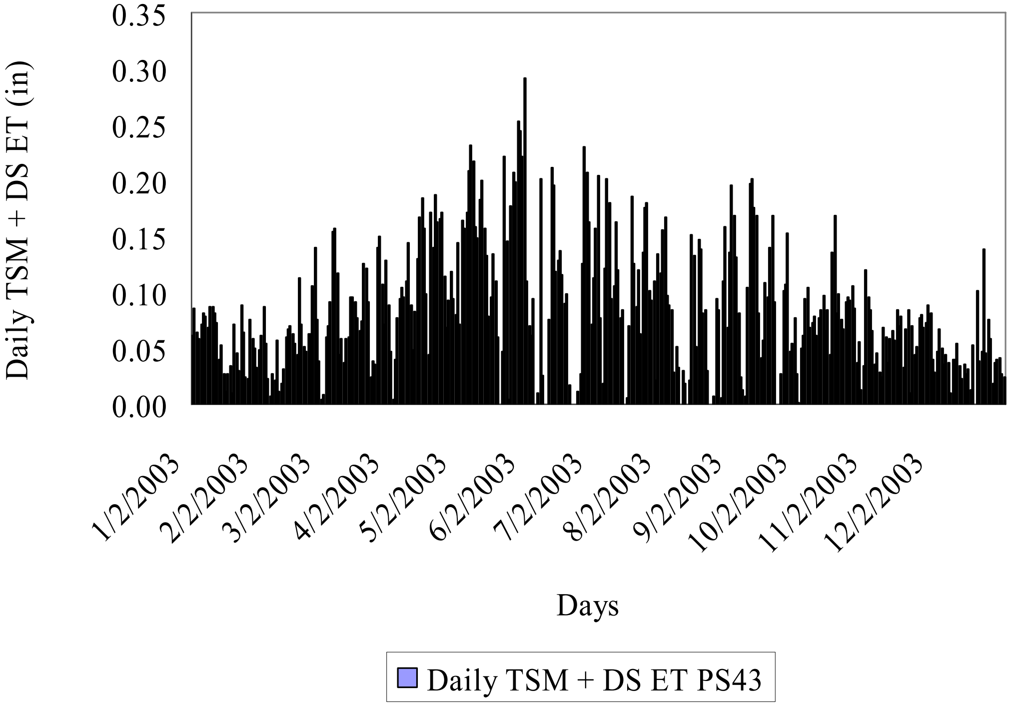

Figure 37. Daily fluctuations in soil moisture and depression storage ET for grassland (PS-43) in 2003.

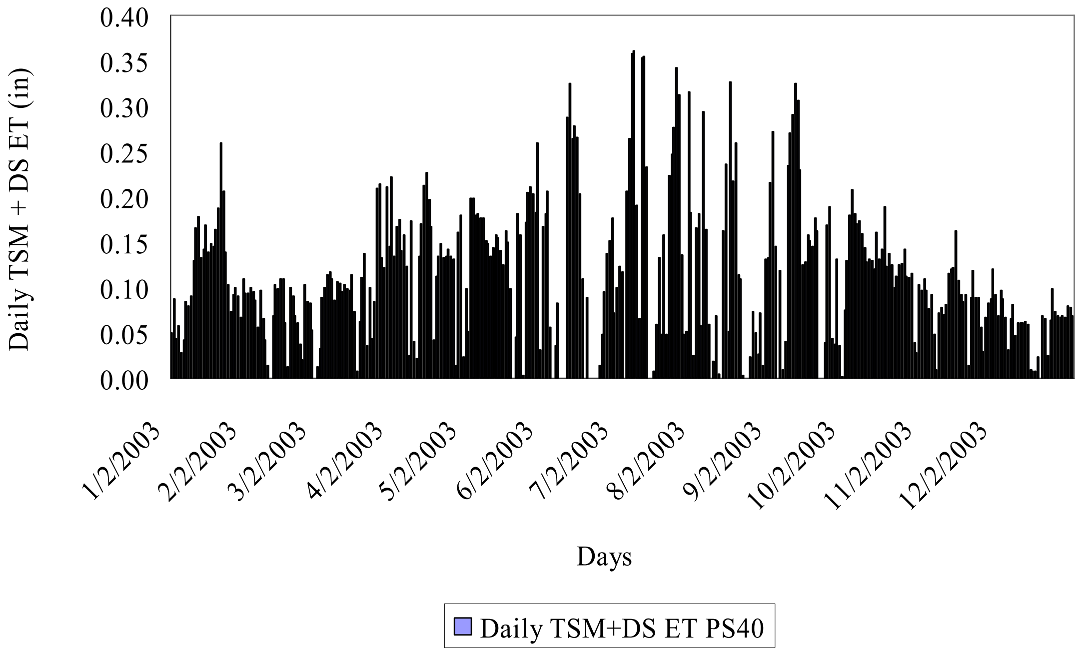

Figure 38. Daily soil moisture and depression storage ET for forested wetland (PS-40) in 2003.

Appendix E: Monthly Distribution of SM, DS and Ic ET and Quarterly Averaged DTWT

Monthly TSM, DS and Ic ET, total ET (TET), magnitudes for grassland covers (PS43, USF3 and USF1) in 2002, 2003 (wet and dry year respectively) are shown in Figures 39 and 40 respectively. For the grass land cover highest TET magnitudes are typically observed in the springs and summers extending into the fall seasons. Lowest TET magnitudes are typically observed in the winter periods. Results are consistent with various models previously used for ET estimation.

Monthly TET magnitudes for forested wetland covers (PS42, PS41 and PS40) in 2002, 2003 (wet and dry year respectively) are shown in Figures 41 and 42. For forested wetland cover highest TET magnitudes are typically observed in the springs, in particular the month of May, and summer extending to fall season. The lowest magnitudes are typically observed in the winter periods. Results are consistent with various models previously used for ET estimation.

Quarterly averaged DTWT for grassland stations (PS43, USF3 and USF1) and for forested wetland stations (PS42, PS41 and PS40) for the duration of the research are shown in Figures 43 and 44. Shallowest averaged DTWT are observed in the wet periods for the two landuse covers. Consistently deepest average DTWT are observed in forested wetland region in support of higher ET demands. Despite reasonably significant rainfall volume in the spring periods, ADTWT is the deepest across the transect wells in the same period supporting high ET demands coinciding with the most active growing period.

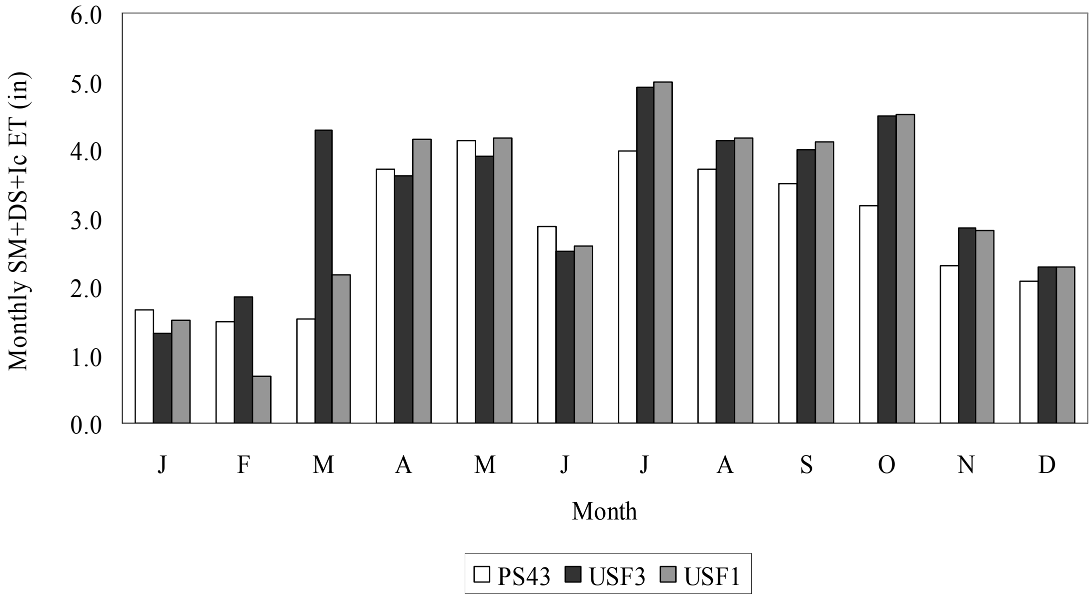

Figure 39. Monthly total soil moisture, depression storage and interception capture ET distribution for grassland cover (PS43, USF3 and USF1) in 2002.

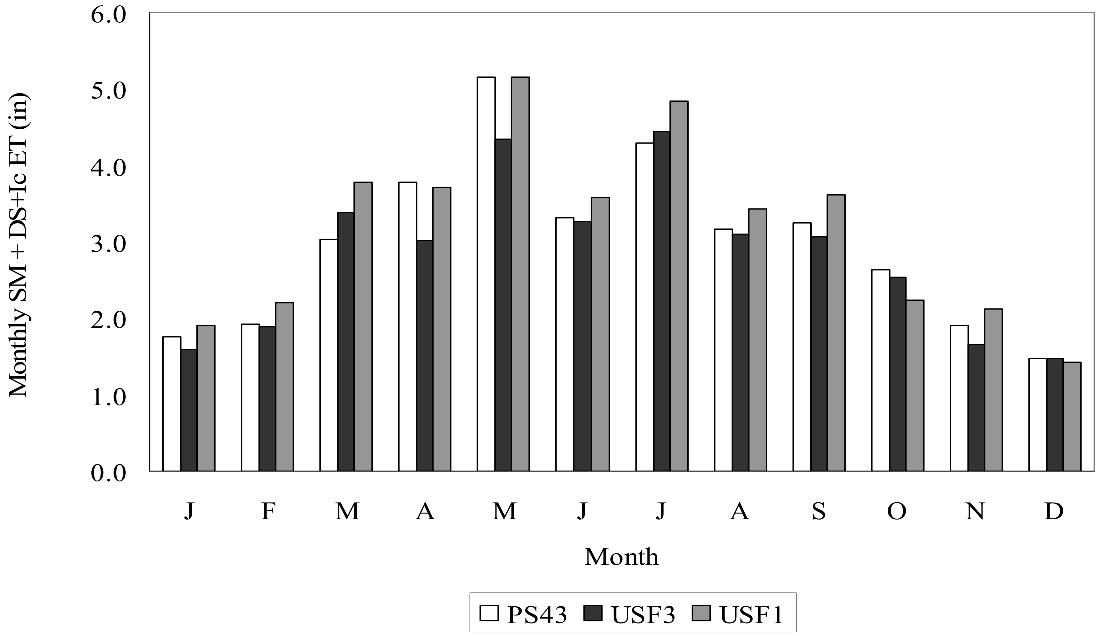

Figure 40. Monthly total soil moisture, depression storage and interception capture ET distribution for grassland cover (PS43, USF3 and USF1) in 2003.

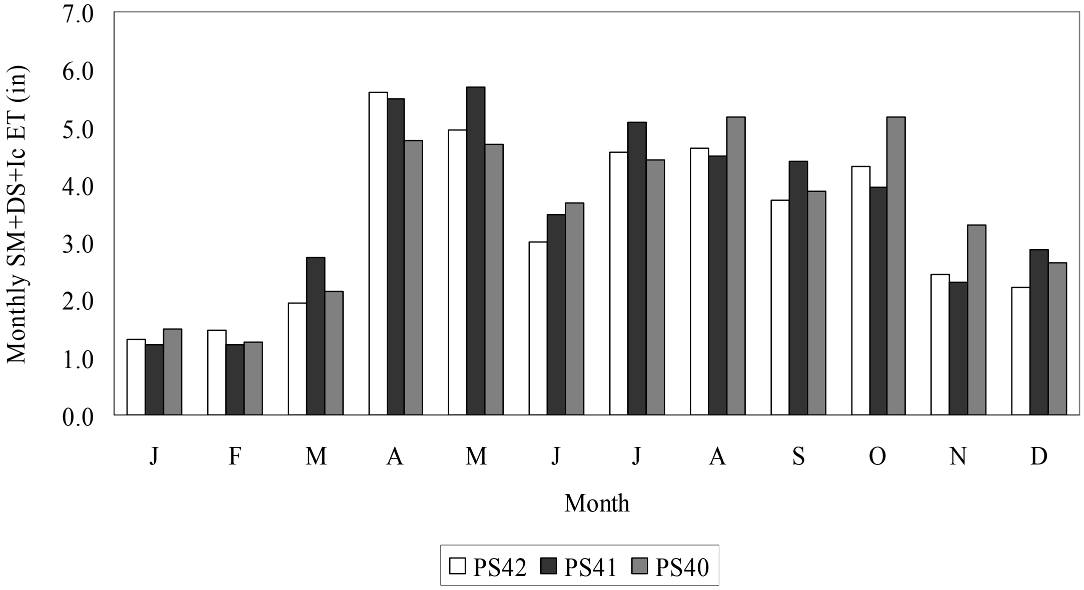

Figure 41. Monthly total soil moisture, depression storage and interception capture ET distribution for forest covers (PS42, PS41 and PS40) in 2002.

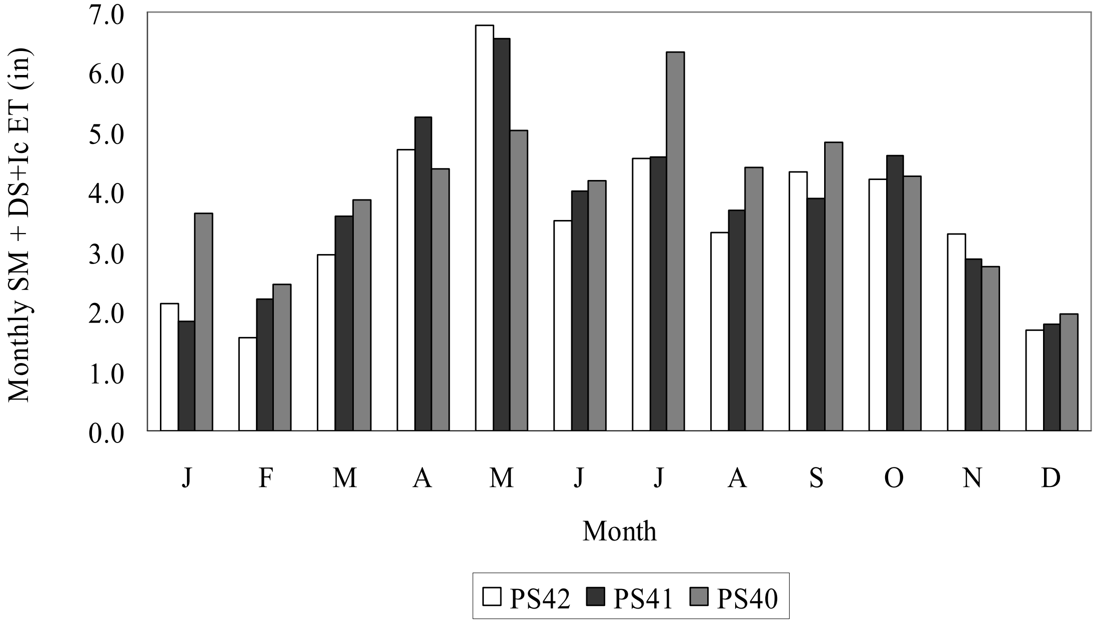

Figure 42. Monthly total soil moisture, depression storage and interception capture ET distribution for forest covers (PS42, PS41 and PS40) in 2003.

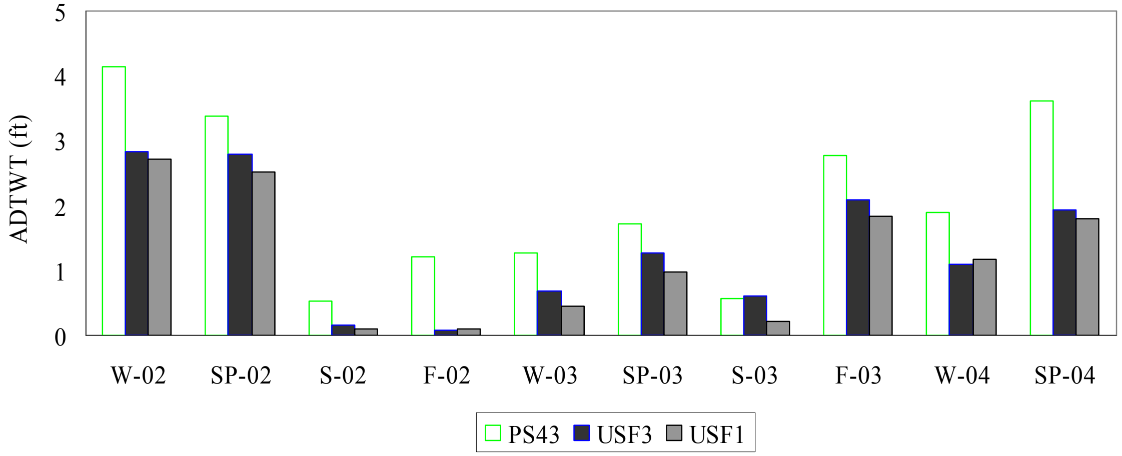

Figure 43. Quarterly averaged depth to water table for grassland stations (PS43, USF3 and USF1).

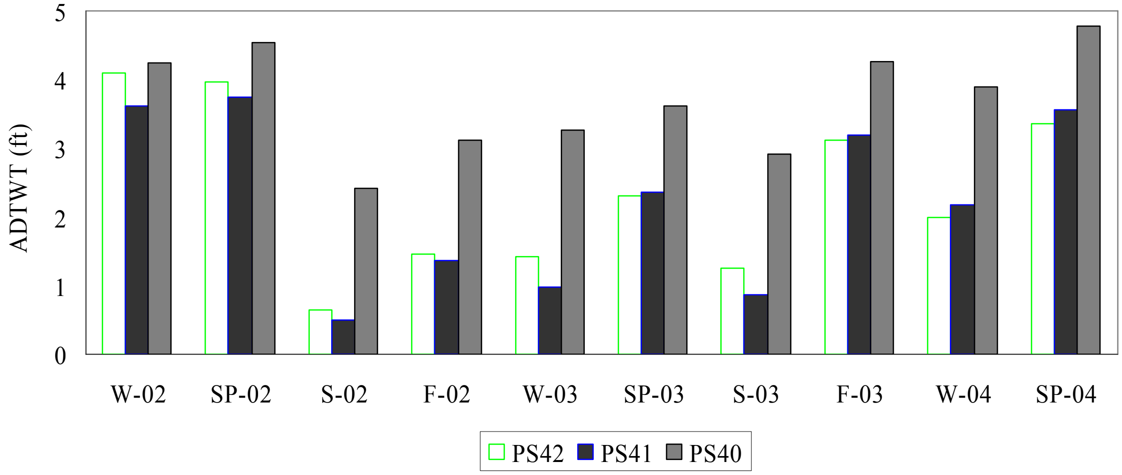

Figure 44. Quarterly averaged depth to water table for forested wetland stations (PS42, PS41 and PS40).

Appendix F: Quarterly Water Budget Components

3rd Quarter Water Budget Components

Total precipitation was near 5.24 inches. Observed total ET ranged from 4.68 inches in the upland grassy region (PS43) to 5.19 in. (132 mm) in the forested wetland region near the stream (PS40). Lowest ET values were observed in this winter. Total SM and Ic ET were second to rainfall. Relatively uniform total ET was observed across the transect wells.

Highest total ET was observed near station UFS3 with a value of 7.5 in. (191 mm). Observed infiltration along the transect wells behaved in a uniform manner fluctuating just above or below 3 to slightly over 4 in. (76 to 102 mm). Minimal TRE was observed along the transect wells. This is the only quarter where slightly higher runoff was observed near the stream vs. the upland. Zero to negligible SRE runoff was observed for this quarter.

ADTWT remained just below 4 ft (1.22 m) near all wells with the exception of PS41 where ADTWT was observed near 3.62 ft (1.1 m). Shallower ADTWT was observed near stations USF3 and USF1. Total Lateral flows were observed to diminish progressively from 0.15 in. (3.8 mm) in the upland area to about -0.19 in. (-4.8 mm) near the stream. For the month of January SM data were missing for station PS43 and USF1 while relatively minimal gaps were periodically observed for the remaining stations. Observed quarterly results for all water budget components for PS43 through PS40 and USF3 and USF1 in this quarter are presented in Tables 7 and 8 respectively.

Appendix F: (Continued)

Table 7. Quarterly water budget results for winter 2002 for PS43-PS39.

Hydrologic Observations for Winter 2002					
Table (7)	3 Qtr- Derived Hydrologic Fluxes & Storages				
WINTER, 2002 (3 Qtr) (in/qtr)	PS43	PS42	PS41	PS40	PS39
(1) Interception Storage, SIc (in)/Event	0.05	0.04	0.08	0.07	0.07
(2) Total interception capture, EIc	0.85	0.72	1.19	1.09	1.09
(3) Saturation Rainfall Excess, SRE	0.00	0.00	0.00	0.00	0.00
(4) Total Rainfall Excess, TRE	1.03	0.55	0.86	1.19	1.18
(5) Net Runoff	1.03	0.55	0.86	1.19	1.18
(6) Infiltration, I	3.36	3.97	3.19	2.96	2.97
(7) Total Precipitation, P	5.24	5.24	5.24	5.24	5.24
(8) Total Lateral Flow, Q_{GW}	0.15	0.08	0.03	-0.19	0.01
(9) Total Change in Lateral Flow, ΔQ_{GW}	0.15	-0.07	-0.05	-0.23	0.21
(10) Total Observed Total Soil Moisture ET	-3.83	-4.00	-4.00	-3.81	-3.55
(11) Adjusted TSM ET (with GPET)	-3.83	-4.00	-4.00	-3.81	-3.55
(12) Difference Between Obs. & Adjusted TSM ET	0.00	0.00	0.00	0.00	0.00
(13) Deep Water TSM ET(DTWT > 1 FT BLS)	-3.83	-4.00	-4.00	-3.81	-3.55
(14) Shallow Water TSM ET+ ET from DS (DTWT $\leq$ 1 FT BLS)	0.00	0.00	0.00	0.00	0.00
(15) Depression Storage ET (DS ET)	0.00	0.00	0.00	0.00	0.00
(16) Shallow Water TSM ET- ET from DS (DTWT $\leq$ 1 FT BLS)	0.00	0.00	0.00	0.00	0.00
(17)Total ET (Adj. TSM ET, DS ET& Ic)	-4.68	-4.72	-5.19	-4.90	-4.64
(18) Total Change in Storage, ΔS	3.11	1.00	1.52	1.36	1.36
(19) Upstream Runoff Infiltration (Observed Infiltration Several Hours After a Rainfall Event)	2.45	1.19	1.50	1.60	1.68
(20) Depression Storage Infiltration/ET: Increase/Decrease Observed from Two Hours after a Rainfall Event up to 24 hrs or the Next Event, Whichever Shorter (Using Hourly TSM Integration)	2.16	0.02	1.15	1.59	1.59
(21) Soil Moisture Increase in the Absence of Rainfall Event	1.55	0.21	0.93	0.65	0.73
(22) Soil Moisture Increase When Rainfall Event Not Recorded	0.00	0.00	0.00	0.00	0.00
(23) Balance (B) (I+ΔQ+ET(SM & Sy)-ΔS+19+21+22)	0.31	-0.15	-0.09	-0.45	0.42
(24) Avg. Depth to Water Table (ADTWT)(ft)	4.14	4.09	3.62	4.25	3.44

Appendix F: (Continued)

Table 8. Quarterly water budget results for winter 2002 for USF3 and USF1.

Hydrologic Observations for Winter 2002		
Table (8)	3 Qtr- Derived Hydrologic Fluxes & Storages	
WINTER, 2002 (3 Qtr) (in/qtr)	USF3	USF1
(1) Interception Storage, SIc (in)/Event	0.05	0.05
(2) Total interception capture, EIc	0.87	0.87
(3) Saturation Rainfall Excess, SRE	0.40	0.04
(4) Total Rainfall Excess, TRE	0.80	0.16
(5) Net Runoff	0.05	0.16
(6) Infiltration, I	3.57	4.21
(7) Total Precipitation, P	5.24	5.24
(8) Total Lateral Flow, Q_{GW}	0.00	0.00
(9) Total Change in Lateral Flow, ΔQ_{GW}	0.00	0.00
(10) Total Observed Total Soil Moisture ET	-5.88	-3.51
(11) Adjusted TSM ET (with GPET)	-5.88	-3.51
(12) Difference Between Obs. & Adjusted TSM ET	0.00	0.00
(13) Deep Water TSM ET(DTWT > 1 FT BLS)	-4.91	-3.51
(14) Shallow Water TSM ET+ ET from DS (DTWT $\leq$ 1 FT BLS)	-1.72	0.00
(15) Depression Storage ET (DS ET)	-0.75	0.00
(16) Shallow Water TSM ET- ET from DS (DTWT $\leq$ 1 FT BLS)	-0.97	0.00
(17)Total ET (Adj. TSM ET, DS ET& Ic)	-7.50	-4.38
(18) Total Change in Storage, ΔS	1.35	2.94
(19) Upstream Runoff Infiltration (Observed Infiltration Several Hours After a Rainfall Event)	4.26	1.75
(20) Depression Storage Infiltration/ET: Increase/Decrease Observed from Two Hours after a Rainfall Event up to 24 hrs or the Next Event, Whichever Shorter (Using Hourly TSM Integration)	1.08	0.51
(21) Soil Moisture Increase in the Absence of Rainfall Event	0.73	1.07
(22) Soil Moisture Increase When Rainfall Event Not Recorded	0.00	0.00
(23) Balance (B) ($I+\Delta Q+ET(SM \& Sy)-\Delta S+19+21+22$)	0.00	0.00
(24) Avg. Depth to Water Table (ADTWT)(ft)	2.84	2.71

4th Quarter Water Budget Components

Total precipitation measured to 18.14 in. (461 mm). The highest total ET values was observed almost along the entire transect wells, PS43-PS40, regardless of the landuse regime. Total ET was second to precipitation along the transect wells. PS-41 in the forested wetland region was the station with highest observed ET volume. For PS43 to PS40, infiltration was third to precipitation, slightly lower than total ET, regardless of the landuse. Higher TRE runoff was observed in the upland region than near the stream. Observed SRE runoff was minimal in the upland region and gradually diminished toward the stream to zero. Higher SRE were observed near stations USF3 and USF1.

Deeper ADTWT fluctuations were observed in this quarter along the transect wells ranging from 3 ft (0.91 m) near PS43 to 4.53 ft (1.38 m) near the stream. ADTWT for USF3 and USF1 were shallower. None to negligible DS ET was observed across the transect wells PS43-PS40 but the magnitude was considerable near stations USF-3 and USF-1. Total Lateral flows were observed to diminish progressively from the upland to near the stream. Minimal SM data were missing for all stations except PS41 were no missing data was observed. Observed quarterly results for all water budget components for PS43 through PS40 and USF3 and USF1 in this quarter are presented in Tables 9 and 10 respectively.

Appendix F: (Continued)

Table 9. Quarterly water budget results for spring of 2002 for PS43-PS39.

Hydrologic Observations for Spring 2002					
Table (9)	4 Qtr- Derived Hydrologic Fluxes & Storages				
SPRING, 2002 (4Qtr) (in/qtr)	PS43	PS42	PS41	PS40	PS39
(1) Interception Storage, SIc (in)/Event	0.05	0.04	0.08	0.07	0.07
(2) Total interception capture, EIc	1.22	1.01	1.83	1.63	1.63
(3) Saturation Rainfall Excess, SRE	1.26	1.18	0.38	0.00	0.00
(4) Total Rainfall Excess, TRE	6.94	4.71	4.53	4.11	4.13
(5) Net Runoff	6.87	4.66	4.51	4.11	4.13
(6) Infiltration, I	9.98	12.42	11.78	12.40	12.38
(7) Total Precipitation, P	18.14	18.14	18.14	18.14	18.14
(8) Total Lateral Flow, Q_{GW}	0.20	0.09	0.05	0.01	-0.06
(9) Total Change in Lateral Flow, ΔQ_{GW}	0.20	-0.11	-0.04	-0.04	-0.07
(10) Total Observed Total Soil Moisture ET	-9.44	-12.53	-13.95	-11.97	-11.96
(11) Adjusted TSM ET (with GPET)	-9.44	-12.53	-13.95	-11.97	-11.96
(12) Difference Between Obs. & Adjusted TSM ET	0.00	0.00	0.00	0.00	0.00
(13) Deep Water TSM ET(DTWT > 1 FT BLS)	-9.41	-12.43	-13.79	-11.97	-11.96
(14) Shallow Water TSM ET+ ET from DS (DTWT $\leq$ 1 FT BLS)	-0.10	-0.15	-0.18	0.00	0.00
(15) Depression Storage ET (DS ET)	-0.07	-0.05	-0.01	0.00	0.00
(16) Shallow Water TSM ET- ET from DS (DTWT $\leq$ 1 FT BLS)	-0.03	-0.10	-0.16	0.00	0.00
(17)Total ET (Adj. TSM ET, DS ET& Ic)	-10.73	-13.59	-15.79	-13.60	-13.59
(18) Total Change in Storage, ΔS	5.31	7.94	6.42	6.39	6.39
(19) Upstream Runoff Infiltration (Observed Infiltration Several Hours After a Rainfall Event)	4.86	8.33	8.69	6.63	6.62
(20) Depression Storage Infiltration/ET: Increase/Decrease Observed from Two Hours after a Rainfall Event up to 24 hrs or the Next Event, Whichever Shorter (Using Hourly TSM Integration)	-0.95	-0.72	-1.21	-1.80	-1.80
(21) Soil Moisture Increase in the Absence of Rainfall Event	0.24	0.00	0.91	0.28	0.28
(22) Soil Moisture Increase When Rainfall Event Not Recorded	0.00	0.00	0.00	0.00	0.00
(23) Balance (B) ($I+\Delta Q+ET(SM \& Sy)-\Delta S+19+21+22$)	0.39	-0.21	-0.08	-0.08	-0.14
(24) Avg. Depth to Water Table (ADTWT)(ft)	3.38	3.97	3.74	4.53	3.92

Table 10. Quarterly water budget results for spring 2002 for USF3 and USF1.

Hydrologic Observations for Spring 2002		
Table (10)	4 Qtr- Derived Hydrologic Fluxes & Storages	
SPRING, 2002 (4 Qtr) (in/qtr)	USF3	USF1
(1) Interception Storage, SIc (in)/Event	0.05	0.05
(2) Total interception capture, EIc	1.22	1.22
(3) Saturation Rainfall Excess, SRE	1.29	3.24
(4) Total Rainfall Excess, TRE	5.55	4.37
(5) Net Runoff	5.04	3.76
(6) Infiltration, I	11.37	12.55
(7) Total Precipitation, P	18.14	18.14
(8) Total Lateral Flow, Q_{GW}	0.00	0.00
(9) Total Change in Lateral Flow, ΔQ_{GW}	0.00	0.00
(10) Total Observed Total Soil Moisture ET	-8.23	-9.03
(11) Adjusted TSM ET (with GPET)	-7.95	-8.55
(12) Difference Between Obs. & Adjusted TSM ET	-0.28	-0.48
(13) Deep Water TSM ET(DTWT > 1 FT BLS)	-7.95	-8.55
(14) Shallow Water TSM ET+ ET from DS (DTWT ≤ 1 FT BLS)	-0.78	-1.09
(15) Depression Storage ET (DS ET)	-0.50	-0.61
(16) Shallow Water TSM ET- ET from DS (DTWT ≤ 1 FT BLS)	-0.28	-0.48
(17)Total ET (Adj. TSM ET, DS ET& Ic)	-9.68	-10.38
(18) Total Change in Storage, ΔS	5.10	5.81
(19) Upstream Runoff Infiltration (Observed Infiltration Several Hours After a Rainfall Event)	3.51	5.70
(20) Depression Storage Infiltration/ET: Increase/Decrease Observed from Two Hours after a Rainfall Event up to 24 hrs or the Next Event, Whichever Shorter (Using Hourly TSM Integration)	-1.11	0.92
(21) Soil Moisture Increase in the Absence of Rainfall Event	0.36	0.64
(22) Soil Moisture Increase When Rainfall Event Not Recorded	0.00	0.00
(23) Balance (B) (I+ΔQ+ET(SM & Sy)-ΔS+19+21+22)	0.00	0.00
(24) Avg. Depth to Water Table (ADTWT)(ft)	2.79	2.52

5th Quarter Water Budget Components

The highest quarterly precipitation volume, totaling 27.78 in. (706 mm), was observed in this quarter. Total ET fluctuation was observed from approximately 11 in. (279 mm) near PS43 to 13.43 in. (341 mm) near PS40. For USF3 and USF1 observed total ET fluctuated approximately within that range. Highest infiltration was observed near the stream, PS40, of about 12.68 in. (322 mm). For USF3 and USF1 the observed infiltration range was approximately 3 to 4.77 in. (76 to 121 mm). TRE runoff was second to precipitation for the upland grassy region ranging from 22.25 to about 19.62 in. (565 to 498 mm) near station PS41. For near the stream total ET was second to precipitation. This behavior was not observed near station USF1. Quite on the contrary TRE near this station behaved similar to that of the upland grassy region with TRE prevailing as the second dominant component in the water budget. SRE magnitude was almost identical to TRE except for station PS40 where lower value was observed. Considerably lower SRE runoff was observed near the stream region.

ADTWT fluctuations were observed to range from just above 0.1 ft (3 cm) in the grassland region and dropping to 2.42 ft (0.74 m) near the stream. Deeper ADTWT was observed during this period near the stream region. This observation is supported by higher total ET demand, infiltration and considerably lower SRE runoff near the stream region.

DS ET was approximately 5.69 to 5.68 in. (145 mm) to fluctuating across the transect wells but for near the stream station PS40 negligible value was observed. For stations USF3 to USF1 DS ET fluctuations were observed in the range of approximately 7.44 to 6.69 in. (189 to 170 mm).

Total Lateral flows were observed to fluctuate in the range of 0.28 in. (7.1 mm) in the upland area to about 0.38 in. (10 mm) near the stream. No missing SM data were observed for PS43 and minimal to negligible missing data were observed on isolated basis for the remaining stations. Observed quarterly results for all water budget components for PS43 through PS40 and USF3 and USF1 in this quarter are presented in Tables 11 and 12 respectively.

Appendix F: (Continued)

Table 11. Quarterly water budget results for summer 2002 for PS43-PS39.

Hydrologic Observations For Summer 2002					
Table (11)	5 Qtr- Derived Hydrologic Fluxes & Storages				
SUMMER, 2002 (5 Qtr) (in/qtr)	PS43	PS42	PS41	PS40	PS39
(1) Interception Storage, SIc (in)/Event	0.05	0.04	0.08	0.07	0.07
(2) Total interception capture, EIc	2.42	1.98	3.71	3.29	3.29
(3) Saturation Rainfall Excess, SRE	22.25	19.55	19.62	3.01	3.47
(4) Total Rainfall Excess, TRE	22.34	19.73	19.67	11.81	11.86
(5) Net Runoff	16.64	15.53	13.99	11.56	11.38
(6) Infiltration, I	3.02	6.07	4.40	12.68	12.63
(7) Total Precipitation, P	27.78	27.78	27.78	27.78	27.78
(8) Total Lateral Flow, Q_{GW}	0.28	0.18	0.25	0.38	-0.03
(9) Total Change in Lateral Flow, ΔQ_{GW}	0.28	-0.11	0.07	0.13	-0.41
(10) Total Observed Total Soil Moisture ET	-2.89	-6.51	-4.34	-9.89	-10.28
(11) Adjusted TSM ET (with GPET)	-2.89	-6.51	-4.34	-9.89	-10.28
(12) Difference Between Obs. & Adjusted TSM ET	0.00	0.00	0.00	0.00	0.00
(13) Deep Water TSM ET(DTWT > 1 FT BLS)	-1.56	-4.10	-1.35	-9.83	-10.20
(14) Shallow Water TSM ET+ ET from DS (DTWT $\leq$ 1 FT BLS)	-7.02	-6.60	-8.67	-0.31	-0.56
(15) Depression Storage ET (DS ET)	-5.69	-4.20	-5.68	-0.25	-0.48
(16) Shallow Water TSM ET- ET from DS (DTWT $\leq$ 1 FT BLS)	-1.33	-2.40	-3.00	-0.06	-0.08
(17)Total ET (Adj. TSM ET, DS ET& Ic)	-11.00	-12.68	-13.73	-13.43	-14.05
(18) Total Change in Storage, ΔS	0.12	0.48	0.07	5.70	5.70
(19) Upstream Runoff Infiltration (Observed Infiltration Several Hours After a Rainfall Event)	0.22	0.86	0.12	4.21	4.30
(20) Depression Storage Infiltration/ET: Increase/Decrease Observed from Two Hours after a Rainfall Event up to 24 hrs or the Next Event, Whichever Shorter (Using Hourly TSM Integration)	-0.71	-2.01	-2.74	-4.21	-4.21
(21) Soil Moisture Increase in the Absence of Rainfall Event	0.13	0.42	0.69	0.18	0.17
(22) Soil Moisture Increase When Rainfall Event Not Recorded	0.00	0.00	0.00	0.00	0.00
(23) Balance (B) ($I+\Delta Q+ET(SM \& Sy)-\Delta S+19+21+22$)	0.56	-0.21	0.15	0.26	-0.70
(24) Avg. Depth to Water Table (ADTWT)(ft)	0.54	0.65	0.50	2.42	2.11

Appendix F: (Continued)

Table 12. Quarterly water budget results for summer 2002 for USF3 and USF1.

Hydrologic Observations for Summer 2002		
Table (12)	5 Qtr- Derived Hydrologic Fluxes & Storages	
SUMMER, 2002 (5 Qtr) (in/qtr)	USF3	USF1
(1) Interception Storage, SIc (in)/Event	0.05	0.05
(2) Total interception capture, EIc	2.43	2.43
(3) Saturation Rainfall Excess, SRE	22.38	20.57
(4) Total Rainfall Excess, TRE	22.39	20.58
(5) Net Runoff	14.95	13.89
(6) Infiltration, I	2.96	4.77
(7) Total Precipitation, P	27.78	27.78
(8) Total Lateral Flow, Q_{GW}	0.00	0.00
(9) Total Change in Lateral Flow, ΔQ_{GW}	0.00	0.00
(10) Total Observed Total Soil Moisture ET	-2.98	-3.96
(11) Adjusted TSM ET (with GPET)	-2.98	-3.96
(12) Difference Between Obs. & Adjusted TSM ET	0.00	0.00
(13) Deep Water TSM ET(DTWT > 1 FT BLS)	-0.17	-0.06
(14) Shallow Water TSM ET+ ET from DS (DTWT ≤ 1 FT BLS)	-10.25	-10.58
(15) Depression Storage ET (DS ET)	-7.44	-6.69
(16) Shallow Water TSM ET- ET from DS (DTWT ≤ 1 FT BLS)	-2.81	-3.90
(17)Total ET (Adj. TSM ET, DS ET& Ic)	-12.85	-13.07
(18) Total Change in Storage, ΔS	0.07	0.87
(19) Upstream Runoff Infiltration (Observed Infiltration Several Hours After a Rainfall Event)	0.14	0.32
(20) Depression Storage Infiltration/ET: Increase/Decrease Observed from Two Hours after a Rainfall Event up to 24 hrs or the Next Event, Whichever Shorter (Using Hourly TSM Integration)	-1.25	-1.06
(21) Soil Moisture Increase in the Absence of Rainfall Event	0.15	0.24
(22) Soil Moisture Increase When Rainfall Event Not Recorded	0.00	0.00
(23) Balance (B) (I+ΔQ+ET(SM & Sy)-ΔS+19+21+22)	0.00	0.00
(24) Avg. Depth to Water Table (ADTWT)(ft)	0.15	0.10

6th Quarter Water Budget Components

Total precipitation for this frontal storm period was 24.18 in. (614 mm). Seasonally uncharacteristic precipitation volume of 24.18 in. (614 mm) was the contributing factor for TRE runoff to be second to precipitation along the transect wells regardless of the landuse regime. Total ET ranged from 7.55 in. (192 mm) near PS43 and gradually increased to 11.11 in. (282 mm) near PS40. Higher total ET was observed near stations USF3 and USF1 than grassland station PS43. Total ET was relatively high across the transect wells for the fall period. This is attributed to SM availability. Observed infiltration ranged from approximately 4.61 in. (117 mm) in the upland and fluctuated to about 7.41 in. (188 mm) near the stream. Relatively shallow ADTWT was observed in the upland but deeper fluctuation was observed near the stream region. For USF-3 and USF-1 the ADTWT was just near land surface. For near the stream region ADTWT was observed in excess of three feet below land surface. Higher DS ET volume was observed in the upland grassy region, PS43, while negligible volume was observed near the stream. DS ET contributions for USF3 and USF1 was considerably higher than for PS43 making up almost half the total ET for this region. The total Lateral flows were observed to diminish almost progressively from the upland area to near the stream. Periodic missing SM data were observed for stations PS43, USF and USF1 and relatively minimal gaps were periodically observed for the remaining stations except station PS40 were negligible SM data were missing. Observed quarterly results for all water budget components for PS43 through PS40 and USF3 and USF1 in this quarter are presented in Tables 13 and 14 respectively.

Appendix F: (Continued)

Table 13. Quarterly water budget results for fall 2002 for PS43-PS39.

Hydrologic Observations for Fall 2002					
Table (13)	6 Qtr- Derived Hydrologic Fluxes & Storages				
FALL, 2002 (6 Qtr) (in)/qtr	PS43	PS42	PS41	PS40	PS39
(1) Interception Storage, SIc (in)/Event	0.05	0.04	0.08	0.07	0.07
(2) Total interception capture, EIc	1.28	1.04	1.96	1.74	1.74
(3) Saturation Rainfall Excess, SRE	17.82	15.00	15.59	12.06	12.45
(4) Total Rainfall Excess, TRE	18.29	15.72	16.48	15.03	15.07
(5) Net Runoff	16.38	14.25	15.45	14.97	14.90
(6) Infiltration, I	4.61	7.42	5.74	7.41	7.37
(7) Total Precipitation, P	24.18	24.18	24.18	24.18	24.18
(8) Total Lateral Flow, Q_{GW}	0.26	0.16	0.20	0.16	0.01
(9) Total Change in Lateral Flow, ΔQ_{GW}	0.26	-0.11	0.04	-0.04	-0.15
(10) Total Observed Total Soil Moisture ET	-4.36	-6.44	-6.12	-9.31	-9.39
(11) Adjusted TSM ET (with GPET)	-4.36	-6.44	-6.12	-9.31	-9.40
(12) Difference Between Obs. & Adjusted TSM ET	0.00	0.00	0.00	0.00	0.00
(13) Deep Water TSM ET(DTWT > 1 FT BLS)	-3.90	-5.70	-5.48	-9.30	-9.38
(14) Shallow Water TSM ET+ ET from DS (DTWT ≤ 1 FT BLS)	-2.37	-2.21	-1.68	-0.07	-0.19
(15) Depression Storage ET (DS ET)	-1.91	-1.47	-1.04	-0.06	-0.17
(16) Shallow Water TSM ET- ET from DS (DTWT ≤ 1 FT BLS)	-0.46	-0.74	-0.65	0.00	-0.02
(17)Total ET (Adj. TSM ET, DS ET& Ic)	-7.55	-8.95	-9.12	-11.11	-11.30
(18) Total Change in Storage, ΔS	1.17	2.68	1.29	1.29	1.29
(19) Upstream Runoff Infiltration (Observed Infiltration Several Hours After a Rainfall Event)	1.14	1.55	1.52	3.14	3.10
(20) Depression Storage Infiltration/ET: Increase/Decrease Observed from Two Hours after a Rainfall Event up to 24 hrs or the Next Event, Whichever Shorter (Using Hourly TSM Integration)	-0.51	-0.23	0.02	0.48	0.48
(21) Soil Moisture Increase in the Absence of Rainfall Event	0.12	0.22	0.33	0.29	0.34
(22) Soil Moisture Increase When Rainfall Event Not Recorded	0.00	0.00	0.00	0.00	0.00
(23) Balance (B) (I+ΔQ+ET(SM & Sy)-ΔS+19+21+22)	0.53	-0.22	0.09	-0.09	-0.30
(24) Avg. Depth to Water Table (ADTWT)(ft)	1.21	1.45	1.36	3.12	2.68

Appendix F: (Continued)

Table 14. Quarterly water budget results for fall 2002 for USF3-USF1.

Hydrologic Observations for Fall 2002		
Table (14)	6 Qtr- Derived Hydrologic Fluxes & Storages	
FALL, 2002 (6Qtr) (in/qtr)	USF3	USF1
(1) Interception Storage, SIc (in)/Event	0.05	0.05
(2) Total interception capture, EIc	1.25	1.25
(3) Saturation Rainfall Excess, SRE	19.75	19.88
(4) Total Rainfall Excess, TRE	19.75	19.88
(5) Net Runoff	14.90	15.89
(6) Infiltration, I	3.18	3.05
(7) Total Precipitation, P	24.18	24.18
(8) Total Lateral Flow, Q_{GW}	0.00	0.00
(9) Total Change in Lateral Flow, ΔQ_{GW}	0.00	0.00
(10) Total Observed Total Soil Moisture ET	-3.43	-4.29
(11) Adjusted TSM ET (with GPET)	-3.43	-4.29
(12) Difference Between Obs. & Adjusted TSM ET	0.00	0.00
(13) Deep Water TSM ET(DTWT > 1 FT BLS)	0.00	0.00
(14) Shallow Water TSM ET+ ET from DS (DTWT ≤ 1 FT BLS)	-8.28	-8.28
(15) Depression Storage ET (DS ET)	-4.85	-3.99
(16) Shallow Water TSM ET- ET from DS (DTWT ≤ 1 FT BLS)	-3.43	-4.29
(17)Total ET (Adj. TSM ET, DS ET& Ic)	-9.53	-9.53
(18) Total Change in Storage, ΔS	1.84	-0.83
(19) Upstream Runoff Infiltration (Observed Infiltration Several Hours After a Rainfall Event)	3.21	1.48
(20) Depression Storage Infiltration/ET: Increase/Decrease Observed from Two Hours after a Rainfall Event up to 24 hrs or the Next Event, Whichever Shorter (Using Hourly TSM Integration)	0.22	0.11
(21) Soil Moisture Increase in the Absence of Rainfall Event	0.96	1.38
(22) Soil Moisture Increase When Rainfall Event Not Recorded	0.00	0.00
(23) Balance (B) (I+ΔQ+ET(SM & Sy)-ΔS+19+21+22)	0.00	0.00
(24) Avg. Depth to Water Table (ADTWT)(ft)	0.08	0.11

7th Quarter Water Budget Components

In the winter of 2003, 7th quarter, total ET was higher than rainfall across the transect wells. Higher total ET values were observed than the previous year, in parts due to higher DS ET contributions. Appreciable variability in TSM ET was observed across the transect wells corresponding to variability in land use. ADTWT fluctuated considerably deeper near the stream region than the upland. In USF-3 and USF-1 the ADTWT was considerably closer to and almost near land surface.

Total observed precipitation was 6.38 in. (162 mm). In this season total ET is the dominant parameter in the hydrologic cycle. Higher TET was observed near the steam than the upland region. Minimal infiltration was observed in the upland but highest value was observed near the stream. Slightly higher TRE runoff was observed in the upland than near the stream. Observed TRE for all grassland regimes were similar in volume but slightly higher for USF3 and USF1. SRE trailed behind TRE in the upland but zero volume was observed near the stream. Minimal negative runoff values are indicative of no net runoffs. Considerably shallower ADTWT was observed near USF3 and USF1 in comparison with PS43 but deeper fluctuation was observed near the stream.

DS ET behavior was vary similar to previous season, in volume and fluctuations, across the transect wells. For USF3 and USF1 DS ET ranged between 3.99 to 5.22 in. (101 to 133 mm) contributing to more than half the volume of total ET. Total Lateral flows were observed to diminish progressively from the upland area to near the stream. Very minimal SM data were observed missing for PS41 and negligible data were missing for PS43.

No missing SM data were observed for PS42 and PS40. Moderate SM data were missing for USF3 and USF1. Observed quarterly results for all water budget components for PS43 through PS40 and USF3 and USF1 in this quarter are presented in Tables 15 and 16 respectively.

Appendix F: (Continued)

Table 15. Quarterly water budget results for winter 2003 for PS43-PS39.

Hydrologic Observations for Winter 2003					
Table (15)	7 Qtr- Derived Hydrologic Fluxes & Storages				
WINTER, 2003 (7 Qtr) (in/qtr)	PS43	PS42	PS41	PS40	PS39
(1) Interception Storage, SIc (in)/Event	0.05	0.04	0.08	0.07	0.07
(2) Total interception capture, EIc	0.87	0.74	1.26	1.13	1.13
(3) Saturation Rainfall Excess, SRE	3.23	2.71	1.73	0.00	0.00
(4) Total Rainfall Excess, TRE	3.24	2.82	1.94	1.05	1.04
(5) Net Runoff	1.00	1.26	-0.21	0.92	0.75
(6) Infiltration, I	2.27	2.82	3.18	4.20	4.21
(7) Total Precipitation, P	6.38	6.38	6.38	6.38	6.38
(8) Total Lateral Flow, Q_{GW}	0.26	0.14	0.29	-0.08	-0.04
(9) Total Change in Lateral Flow, ΔQ_{GW}	0.26	-0.12	0.15	-0.37	0.04
(10) Total Observed Total Soil Moisture ET	-3.53	-4.31	-4.17	-8.66	-8.37
(11) Adjusted TSM ET (with GPET)	-3.53	-4.31	-4.17	-8.66	-8.37
(12) Difference Between Obs. & Adjusted TSM ET	0.00	0.00	0.00	0.00	0.00
(13) Deep Water TSM ET(DTWT > 1 FT BLS)	-2.67	-3.86	-3.15	-8.56	-8.19
(14) Shallow Water TSM ET+ ET from DS (DTWT $\leq$ 1 FT BLS)	-3.11	-2.00	-3.17	-0.23	-0.48
(15) Depression Storage ET (DS ET)	-2.25	-1.56	-2.15	-0.13	-0.29
(16) Shallow Water TSM ET- ET from DS (DTWT $\leq$ 1 FT BLS)	-0.87	-0.44	-1.02	-0.10	-0.19
(17)Total ET (Adj. TSM ET, DS ET& Ic)	-6.65	-6.60	-7.58	-9.93	-9.79
(18) Total Change in Storage, ΔS	-0.43	-0.62	-0.18	-2.68	-2.68
(19) Upstream Runoff Infiltration (Observed Infiltration Several Hours After a Rainfall Event)	0.40	0.50	0.21	1.48	1.57
(20) Depression Storage Infiltration/ET: Increase/Decrease Observed from Two Hours after a Rainfall Event up to 24 hrs or the Next Event, Whichever Shorter (Using Hourly TSM Integration)	-0.18	-0.29	-0.31	-0.77	-0.77
(21) Soil Moisture Increase in the Absence of Rainfall Event	0.76	0.36	0.86	0.05	0.06
(22) Soil Moisture Increase When Rainfall Event Not Recorded	0.00	0.00	0.00	0.00	0.00
(23) Balance (B) $(I+\Delta Q+ET(SM \& Sy)-\Delta S+19+21+22)$	0.51	-0.24	0.31	-0.74	0.07
(24) Avg. Depth to Water Table (ADTWT)(ft)	1.27	1.42	0.98	3.27	2.62

Appendix F: (Continued)

Table 16. Quarterly water budget results for winter 2003 for USF3 and USF1.

Hydrologic Observations for Winter 2003		
Table (16)	7 Qtr- Derived Hydrologic Fluxes & Storages	
WINTER, 2003 (7 Qtr) (in/qtr)	USF3	USF1
(1) Interception Storage, SIc (in)/Event	0.05	0.05
(2) Total interception capture, EIc	0.87	0.87
(3) Saturation Rainfall Excess, SRE	3.85	3.71
(4) Total Rainfall Excess, TRE	3.95	3.71
(5) Net Runoff	-0.04	-1.50
(6) Infiltration, I	1.56	1.80
(7) Total Precipitation, P	6.38	6.38
(8) Total Lateral Flow, Q_{GW}	0.00	0.00
(9) Total Change in Lateral Flow, ΔQ_{GW}	0.00	0.00
(10) Total Observed Total Soil Moisture ET	-1.93	-1.73
(11) Adjusted TSM ET (with GPET)	-1.93	-1.73
(12) Difference Between Obs. & Adjusted TSM ET	0.00	0.00
(13) Deep Water TSM ET(DTWT > 1 FT BLS)	-0.63	-0.23
(14) Shallow Water TSM ET+ ET from DS (DTWT ≤ 1 FT BLS)	-5.29	-6.72
(15) Depression Storage ET (DS ET)	-3.99	-5.22
(16) Shallow Water TSM ET- ET from DS (DTWT ≤ 1 FT BLS)	-1.29	-1.50
(17)Total ET (Adj. TSM ET, DS ET& Ic)	-6.79	-7.82
(18) Total Change in Storage, ΔS	-0.09	0.51
(19) Upstream Runoff Infiltration (Observed Infiltration Several Hours After a Rainfall Event)	0.05	0.08
(20) Depression Storage Infiltration/ET: Increase/Decrease Observed from Two Hours after a Rainfall Event up to 24 hrs or the Next Event, Whichever Shorter (Using Hourly TSM Integration)	-0.04	0.10
(21) Soil Moisture Increase in the Absence of Rainfall Event	0.26	0.41
(22) Soil Moisture Increase When Rainfall Event Not Recorded	0.00	0.00
(23) Balance (B) (I+ΔQ+ET(SM & Sy)-ΔS+19+21+22)	0.00	0.01
(24) Avg. Depth to Water Table (ADTWT)(ft)	0.68	0.44

8th Quarter Water Budget Components

This season is a mixture of partially frontal and partially convective storm pattern. On the average, observed precipitation totaling 21.82 in. (554 mm) is rather typical for the region and the season. Total ET for this period of active plant growing season fluctuated in the range of 12.2 to 15.82 in. (310 to 402 mm) in the upland area to 13.58 in. (345 mm) near the stream at PS40. Highest total ET was observed near PS41. For US3 and USF1 the observed total ET was 10.52 to 12.31 in. (267 to 313 mm) respectively. The highest total ET magnitude was observed in the spring quarter regardless of the land use cover. For PS43 through PS40 transect wells, ET was unquestionably the second dominant component in the hydrologic cycle with distinct variability to land use across the transect wells.

Excluding grassland (PS43), observed infiltration ranked as the third component along the transect wells. High TRE runoff volume was observed in the grassland zones while considerably lesser fluctuations were observed in forested wetland regions. Observed SRE fluctuations were similar to TRE but lesser in volume particularly near the stream region. A gradual decline in ADTWT was observed from the grassland to near the stream region were deepest ADTWT was observed. Despite significant precipitation volume ADTWT was deeper in the upland than the winter quarter.

Typical DS ET behavior was observed across most transect wells, higher in upland grassy areas and diminishing towards the stream region, except USF-1 were highest volume was observed. Total Lateral flows were observed to diminish progressively from the upland area to near the stream region. Very minimal SM data were missing for PS43 and PS40. Some SM data were observed missing for USF3 and USF1.

Appendix F: (Continued)

Observed quarterly results for all water budget components for PS43 through PS40 and USF3 and USF1 in this quarter are presented in Tables 17 and 18 respectively.

Appendix F: (Continued)

Table 17. Quarterly water budget results for spring 2003 for PS43-PS39.

Hydrologic Observations for Spring 2003					
Table (17)	8 Qtr- Derived Hydrologic Fluxes & Storages				
SPRING, 2003 (8 Qtr) (in/qtr)	PS43	PS42	PS41	PS40	PS39
(1) Interception Storage, SIc (in)/Event	0.05	0.04	0.08	0.07	0.07
(2) Total interception capture, EIc	1.46	1.19	2.24	1.99	1.99
(3) Saturation Rainfall Excess, SRE	11.03	7.66	7.15	4.71	5.88
(4) Total Rainfall Excess, TRE	12.08	9.28	8.26	7.52	7.52
(5) Net Runoff	10.58	9.14	7.61	7.39	7.43
(6) Infiltration, I	8.28	11.35	11.32	12.31	12.31
(7) Total Precipitation, P	21.82	21.82	21.82	21.82	21.82
(8) Total Lateral Flow, Q_{GW}	0.26	0.14	0.12	-0.12	-0.04
(9) Total Change in Lateral Flow, ΔQ_{GW}	0.26	-0.12	-0.02	-0.23	0.08
(10) Total Observed Total Soil Moisture ET	-9.23	-13.64	-12.93	-11.46	-11.24
(11) Adjusted TSM ET (with GPET)	-9.23	-13.64	-12.93	-11.46	-11.24
(12) Difference Between Obs. & Adjusted TSM ET	0.00	0.00	0.00	0.00	0.00
(13) Deep Water TSM ET(DTWT > 1 FT BLS)	-8.82	-13.43	-12.55	-11.35	-11.14
(14) Shallow Water TSM ET+ ET from DS (DTWT ≤ 1 FT BLS)	-1.92	-0.35	-1.03	-0.24	-0.18
(15) Depression Storage ET (DS ET)	-1.51	-0.14	-0.65	-0.13	-0.09
(16) Shallow Water TSM ET- ET from DS (DTWT ≤ 1 FT BLS)	-0.41	-0.21	-0.38	-0.11	-0.10
(17)Total ET (Adj. TSM ET, DS ET& Ic)	-12.20	-14.98	-15.82	-13.58	-13.31
(18) Total Change in Storage, ΔS	0.00	0.51	0.03	2.71	2.71
(19) Upstream Runoff Infiltration (Observed Infiltration Several Hours After a Rainfall Event)	1.51	3.89	2.73	2.22	2.30
(20) Depression Storage Infiltration/ET: Increase/Decrease Observed from Two Hours after a Rainfall Event up to 24 hrs or the Next Event, Whichever Shorter (Using Hourly TSM Integration)	-0.71	-1.74	-2.66	-2.36	-2.36
(21) Soil Moisture Increase in the Absence of Rainfall Event	0.84	1.96	1.22	1.10	1.20
(22) Soil Moisture Increase When Rainfall Event Not Recorded	0.73	1.63	1.01	0.93	1.00
(23) Balance (B) (I+ΔQ+ET(SM & Sy)-ΔS+19+21+22)	0.51	-0.24	-0.04	-0.47	0.16
(24) Avg. Depth to Water Table (ADTWT)(ft)	1.72	2.30	2.36	3.62	2.83

Appendix F: (Continued)

Table 18. Quarterly water budget results for spring 2003 for USF3 and USF1.

Hydrologic Observations for Spring 2003		
Table (18)	8 Qtr- Derived Hydrologic Fluxes & Storages	
SPRING, 2003 (8 Qtr) (in/qtr)	USF-3	USF-1
(1) Interception Storage, SIc (in)/Event	0.05	0.05
(2) Total interception capture, EIc	1.46	1.46
(3) Saturation Rainfall Excess, SRE	11.08	11.71
(4) Total Rainfall Excess, TRE	13.44	12.31
(5) Net Runoff	11.31	9.44
(6) Infiltration, I	6.96	8.09
(7) Total Precipitation, P	21.86	21.86
(8) Total Lateral Flow, Q_{GW}	0.00	0.00
(9) Total Change in Lateral Flow, ΔQ_{GW}	0.00	0.00
(10) Total Observed Total Soil Moisture ET	-6.94	-7.98
(11) Adjusted TSM ET (with GPET)	-6.94	-7.98
(12) Difference Between Obs. & Adjusted TSM ET	0.00	0.00
(13) Deep Water TSM ET(DTWT > 1 FT BLS)	-5.84	-5.11
(14) Shallow Water TSM ET+ ET from DS (DTWT ≤ 1 FT BLS)	-3.23	-5.74
(15) Depression Storage ET (DS ET)	-2.12	-2.87
(16) Shallow Water TSM ET- ET from DS (DTWT ≤ 1 FT BLS)	-1.10	-2.87
(17)Total ET (Adj. TSM ET, DS ET& Ic)	-10.52	-12.31
(18) Total Change in Storage, ΔS	1.06	0.40
(19) Upstream Runoff Infiltration (Observed Infiltration Several Hours After a Rainfall Event)	1.63	3.43
(20) Depression Storage Infiltration/ET: Increase/Decrease Observed from Two Hours after a Rainfall Event up to 24 hrs or the Next Event, Whichever Shorter (Using Hourly TSM Integration)	-1.19	-1.10
(21) Soil Moisture Increase in the Absence of Rainfall Event	0.21	0.00
(22) Soil Moisture Increase When Rainfall Event Not Recorded	1.03	1.62
(23) Balance (B) (I+ΔQ+ET(SM & Sy)-ΔS+19+21+22)	0.00	0.00
(24) Avg. Depth to Water Table (ADTWT)(ft)	1.27	0.97

9th Quarter Water Budget Components

Precipitation amount for this convective period was 21.58 in. (548 mm). Total ET fluctuated in the range of 11.38 to 11.84 in. (289 to 301 mm) in the upland grassland areas while progressively increasing to about 15.47 in. (393 mm) near the stream region PS40. Observed infiltration was considerably higher near the stream than the upland grassy region. TRE runoff was the 2nd largest observed component in the upland grassy region. Close to and near the stream region lower TRE runoff was observed. Total ET was the 2nd largest observed component of the hydrologic cycle near the stream region. Observed infiltration behaved in a reverse pattern to TRE, in that, low infiltration values were observed in the upland grassland areas while for near the stream region higher infiltration were observed. SRE runoff trailed just behind TRE runoff along the transect wells except for nears the stream region were considerably lower volume were observed. ADTWT for the upland grassland region was consistently at or near land surface while deepest ADTWT is observed only near the stream. For forested regions fluctuations were deeper.

The highest DS ET is observed in this quarter particularly in the upland while diminishing toward the stream where negligible volume was observed. Total Lateral flows were observed to diminish progressively from the upland area to near the stream. Minimal SM data were missing for this quarter along all stations except USF1 were moderate SM data were observed missing. Observed quarterly results for all water budget components for PS43 through PS40 and USF3 and USF1 in this quarter are presented in Tables 19 and 20 respectively.

Appendix F: (Continued)

Table 19. Quarterly water budget results for summer 2003 for PS43-PS39.

Hydrologic Observations for Summer 2003					
Table (19)	9 Qtr- Derived Hydrologic Fluxes & Storages				
SUMMER, 2003 (9 Qtr) (in/qtr)	PS43	PS42	PS41	PS40	PS39
(1) Interception Storage, SIc (in)/Event	0.05	0.04	0.08	0.07	0.07
(2) Total interception capture, EIc	2.28	1.87	3.48	3.08	3.08
(3) Saturation Rainfall Excess, SRE	15.63	10.61	12.03	3.92	3.95
(4) Total Rainfall Excess, TRE	15.81	11.58	13.04	8.53	8.49
(5) Net Runoff	10.24	9.90	9.62	8.53	8.47
(6) Infiltration, I	3.49	8.13	5.06	9.97	10.01
(7) Total Precipitation, P	21.58	21.58	21.58	21.58	21.58
(8) Total Lateral Flow, Q_{GW}	0.31	0.15	0.25	0.00	-0.04
(9) Total Change in Lateral Flow, ΔQ_{GW}	0.31	-0.16	0.10	-0.25	-0.04
(10) Total Observed Total Soil Moisture ET	-3.53	-8.51	-5.13	-12.39	-12.31
(11) Adjusted TSM ET (with GPET)	-3.53	-8.51	-5.13	-12.39	-12.31
(12) Difference Between Obs. & Adjusted TSM ET	0.00	0.00	0.00	0.00	0.00
(13) Deep Water TSM ET(DTWT > 1 FT BLS)	-1.78	-7.71	-3.77	-12.39	-12.26
(14) Shallow Water TSM ET+ ET from DS (DTWT ≤ 1 FT BLS)	-7.32	-2.47	-4.78	0.00	-0.06
(15) Depression Storage ET (DS ET)	-5.57	-1.68	-3.42	0.00	-0.02
(16) Shallow Water TSM ET- ET from DS (DTWT ≤ 1 FT BLS)	-1.75	-0.80	-1.36	0.00	-0.04
(17)Total ET (Adj. TSM ET, DS ET& Ic)	-11.38	-12.06	-12.03	-15.47	-15.41
(18) Total Change in Storage, ΔS	0.11	0.70	0.06	-2.14	-2.15
(19) Upstream Runoff Infiltration (Observed Infiltration Several Hours After a Rainfall Event)	0.64	1.79	0.84	1.67	1.71
(20) Depression Storage Infiltration/ET: Increase/Decrease Observed from Two Hours after a Rainfall Event up to 24 hrs or the Next Event, Whichever Shorter (Using Hourly TSM Integration)	1.04	2.85	1.30	2.80	2.79
(21) Soil Moisture Increase in the Absence of Rainfall Event	0.22	0.78	0.64	0.25	0.25
(22) Soil Moisture Increase When Rainfall Event Not Recorded	0.18	0.26	0.13	0.18	0.18
(23) Balance (B) (I+ΔQ+ET(SM & Sy)-ΔS+19+21+22)	0.61	-0.31	0.20	-0.50	-0.08
(24) Avg. Depth to Water Table (ADTWT)(ft)	0.57	1.25	0.87	2.91	2.30

Appendix F: (Continued)

Table 20. Annual water budget results for summer 2003 for USF3 and USF1.

Hydrologic Observations for Summer 2003		
Table (20)	9 Qtr- Derived Hydrologic Fluxes & Storages	
SUMMER, 2003 (9 Qtr) (in/qtr)	USF3	USF1
(1) Interception Storage, SIc (in)/Event	0.05	0.05
(2) Total interception capture, EIc	2.28	2.28
(3) Saturation Rainfall Excess, SRE	16.16	15.38
(4) Total Rainfall Excess, TRE	16.39	15.39
(5) Net Runoff	10.98	9.89
(6) Infiltration, I	2.91	3.91
(7) Total Precipitation, P	21.58	21.58
(8) Total Lateral Flow, Q_{GW}	0.00	0.00
(9) Total Change in Lateral Flow, ΔQ_{GW}	0.00	0.00
(10) Total Observed Total Soil Moisture ET	-2.90	-4.07
(11) Adjusted TSM ET (with GPET)	-2.90	-4.07
(12) Difference Between Obs. & Adjusted TSM ET	0.00	0.00
(13) Deep Water TSM ET(DTWT > 1 FT BLS)	-1.17	-1.01
(14) Shallow Water TSM ET+ ET from DS (DTWT ≤ 1 FT BLS)	-7.13	-8.55
(15) Depression Storage ET (DS ET)	-5.40	-5.49
(16) Shallow Water TSM ET- ET from DS (DTWT ≤ 1 FT BLS)	-1.72	-3.06
(17)Total ET (Adj. TSM ET, DS ET& Ic)	-10.58	-11.84
(18) Total Change in Storage, ΔS	0.11	0.05
(19) Upstream Runoff Infiltration (Observed Infiltration Several Hours After a Rainfall Event)	0.14	0.59
(20) Depression Storage Infiltration/ET: Increase/Decrease Observed from Two Hours after a Rainfall Event up to 24 hrs or the Next Event, Whichever Shorter (Using Hourly TSM Integration)	0.80	1.27
(21) Soil Moisture Increase in the Absence of Rainfall Event	0.38	0.35
(22) Soil Moisture Increase When Rainfall Event Not Recorded	0.13	0.19
(23) Balance (B) (I+ΔQ+ET(SM & Sy)-ΔS+19+21+22)	0.02	0.00
(24) Avg. Depth to Water Table (ADTWT)(ft)	0.61	0.22

10th Quarter Water Budget Components

Precipitation for this frontal storm period was measured at 3.35 in. (85 mm). Total ET for this dry and presumably low active plant growing season fluctuated in the ranged of bout 6.1 in. (155 mm) in the upland area while a relatively uniform volume with slight fluctuations above 9 in. (229 mm) were observed for the remaining stations. Lesser total ET was observed near stations USF3 and USF1 to a maximum of 4.95 in. (126 mm). In this quarter total ET was the dominant component in the hydrologic cycle regardless of the landuse regime. Relatively uniform infiltration was observed across the transect wells. Observed infiltration was the third to precipitation. Minimal to negligible TRE runoff were observed across the transect wells. Zero SRE were observed regardless of the landuse type. Relatively deep ADTWT was observed in the upland grassland while gradually declining deeper toward the stream. In 2003, ADTWT was the deepest across the transect wells in this quarter. DS ET contributions were minimal to negligible across transects wells and none was observed near the stream region. Very similar behavioral characteristics of the upland region were observed near USF-3 and USF-1.

Lateral flows fluctuated from the upland while steadily declining to negative values near the stream region. Some SM data were periodically missing near for stations PS42 and USF3 but moderate data were missing for USF1. Negligible SM data were missing for station PS40 while no missing SM data were observed for stations PS43 and PS41. Observed quarterly results for all water budget components for PS43 through PS40 and USF3 and USF1 in this quarter are presented in Tables 21 and 22 respectively.

Appendix F: (Continued)

Table 21. Quarterly water budget results for fall 2003 for PS43-PS39.

Hydrologic Observations for Fall 2003					
Table (21)	10 Qtr- Derived Hydrologic Fluxes & Storages				
FALL, 2003 (10 Qtr) (in/qtr)	PS43	PS42	PS41	PS40	PS39
(1) Interception Storage, SIc (in)/Event	0.05	0.04	0.08	0.07	0.07
(2) Total interception capture, EIc	0.43	0.37	0.59	0.54	0.54
(3) Saturation Rainfall Excess, SRE	0.00	0.00	0.00	0.00	0.00
(4) Total Rainfall Excess, TRE	0.39	0.09	0.08	0.12	0.12
(5) Net Runoff	0.03	0.02	0.00	0.12	0.12
(6) Infiltration, I	2.53	2.89	2.68	2.69	2.69
(7) Total Precipitation, P	3.35	3.35	3.35	3.35	3.35
(8) Total Lateral Flow, Q_{GW}	0.22	0.12	0.08	-0.24	-0.06
(9) Total Change in Lateral Flow, ΔQ_{GW}	0.22	-0.10	-0.04	-0.32	0.17
(10) Total Observed Total Soil Moisture ET	-5.34	-8.83	-8.65	-8.51	-8.08
(11) Adjusted TSM ET (with GPET)	-5.34	-8.83	-8.65	-8.51	-8.08
(12) Difference Between Obs. & Adjusted TSM ET	0.00	0.00	0.00	0.00	0.00
(13) Deep Water TSM ET(DTWT > 1 FT BLS)	-5.24	-8.78	-8.56	-8.51	-8.08
(14) Shallow Water TSM ET+ ET from DS (DTWT $\leq$ 1 FT BLS)	-0.46	-0.11	-0.17	0.00	0.00
(15) Depression Storage ET (DS ET)	-0.36	-0.07	-0.08	0.00	0.00
(16) Shallow Water TSM ET- ET from DS (DTWT $\leq$ 1 FT BLS)	-0.11	-0.05	-0.09	0.00	0.00
(17)Total ET (Adj. TSM ET, DS ET& Ic)	-6.13	-9.27	-9.32	-9.05	-8.62
(18) Total Change in Storage, ΔS	-2.65	-4.75	-5.48	-4.75	-4.75
(19) Upstream Runoff Infiltration (Observed Infiltration Several Hours After a Rainfall Event)	0.16	1.32	0.31	0.66	0.69
(20) Depression Storage Infiltration/ET: Increase/Decrease Observed from Two Hours after a Rainfall Event up to 24 hrs or the Next Event, Whichever Shorter (Using Hourly TSM Integration)	-0.37	0.25	-0.37	2.39	2.39
(21) Soil Moisture Increase in the Absence of Rainfall Event	0.31	0.12	0.30	0.11	0.13
(22) Soil Moisture Increase When Rainfall Event Not Recorded	0.00	0.00	0.00	0.00	0.00
(23) Balance (B) ($I+\Delta Q+ET(SM \& Sy)-\Delta S+19+21+22$)	0.53	0.16	0.09	-0.61	0.37
(24) Avg. Depth to Water Table (ADTWT)(ft)	2.77	3.11	3.19	4.26	3.39

Appendix F: (Continued)

Table 22. Annual water budget results for fall 2003 for USF3 and USF1.

Hydrologic Observations for Fall 2003		
Table (22)	10 Qtr- Derived Hydrologic Fluxes & Storages	
FALL, 2003 (10 Qtr) (in/qtr)	USF3	USF1
(1) Interception Storage, SIc (in)/Event	0.05	0.05
(2) Total interception capture, EIc	0.43	0.43
(3) Saturation Rainfall Excess, SRE	0.00	0.00
(4) Total Rainfall Excess, TRE	0.14	0.06
(5) Net Runoff	-0.70	-1.07
(6) Infiltration, I	2.78	2.86
(7) Total Precipitation, P	3.35	3.35
(8) Total Lateral Flow, Q_{GW}	0.00	0.00
(9) Total Change in Lateral Flow, ΔQ_{GW}	0.00	0.00
(10) Total Observed Total Soil Moisture ET	-4.43	-4.25
(11) Adjusted TSM ET (with GPET)	-4.43	-4.25
(12) Difference Between Obs. & Adjusted TSM ET	0.00	0.00
(13) Deep Water TSM ET(DTWT > 1 FT BLS)	-4.05	-3.83
(14) Shallow Water TSM ET+ ET from DS (DTWT ≤ 1 FT BLS)	-1.22	-1.55
(15) Depression Storage ET (DS ET)	-0.84	-1.13
(16) Shallow Water TSM ET- ET from DS (DTWT ≤ 1 FT BLS)	-0.38	-0.42
(17)Total ET (Adj. TSM ET, DS ET& Ic)	-4.85	-4.95
(18) Total Change in Storage, ΔS	-1.29	1.58
(19) Upstream Runoff Infiltration (Observed Infiltration Several Hours After a Rainfall Event)	0.69	2.47
(20) Depression Storage Infiltration/ET: Increase/Decrease Observed from Two Hours after a Rainfall Event up to 24 hrs or the Next Event, Whichever Shorter (Using Hourly TSM Integration)	-0.48	-0.16
(21) Soil Moisture Increase in the Absence of Rainfall Event	0.63	1.75
(22) Soil Moisture Increase When Rainfall Event Not Recorded	0.00	0.00
(23) Balance (B) (I+ΔQ+ET(SM & Sy)-ΔS+19+21+22)	0.00	0.00
(24) Avg. Depth to Water Table (ADTWT)(ft)	2.08	1.84

11th Quarter Water Budget Components

In the winter of 2004, observed precipitation measured near 9.15 in. (232 mm). Total ET for this relatively dry and minimal plant growing season fluctuated in the ranged of about 7 in. (178 mm) in the upland grassland areas and fluctuating to about 8.8 in. (224 mm) near the stream region. Total ET was the second dominant component regardless of the landuse regime. Observed infiltration was lower in magnitude for the grassland than near the stream. TRE runoff were observed across the transect wells ranging higher in magnitudes in the upland while gradually decreasing to minimal values near the stream. Higher TRE was observed near USF3 and USF1. SRE runoff trailed behind TRE runoff across the transect wells. ADTWT was observed shallower in the upland with gradual decline toward the stream where the deepest ADTWT was observed. Observed DS ET was minimal across the transect wells except for near the steam where zero magnitude was observed. For USF-3 and USF-1 some of the highest DS ET was observed at both stations. This was believed consistent with the shallowest ADTWT observed at these stations.

Lateral flows fluctuated from the upland while steadily declining and fluctuating to negative values near the stream region. Some SM data were observed missing for stations PS42, PS41 and PS40 and USF1. No SM data were observed missing for stations PS43 or USF3. Observed quarterly results for all water budget components for PS43 through PS40 and USF3 and USF1 in this quarter are presented in Tables 23 and 24 respectively.

Appendix F: (Continued)

Table 23. Quarterly water budget results for winter 2004 for PS43-PS39.

Hydrologic Observations for Winter 2004					
Table (23)	11 Qtr- Derived Hydrologic Fluxes & Storages				
WINTER, 2004 (11 Qtr) (in/qtr)	PS43	PS42	PS41	PS40	PS39
(1) Interception Storage, SIc (in)/Event	0.05	0.04	0.08	0.07	0.07
(2) Total interception capture, EIc	0.69	0.57	1.01	0.91	0.91
(3) Saturation Rainfall Excess, SRE	2.79	1.96	1.35	0.00	0.02
(4) Total Rainfall Excess, TRE	3.54	2.56	2.12	0.78	0.76
(5) Net Runoff	2.55	1.49	1.01	0.78	0.75
(6) Infiltration, I	4.92	6.02	6.02	7.46	7.48
(7) Total Precipitation, P	9.15	9.15	9.15	9.15	9.15
(8) Total Lateral Flow, Q_{GW}	0.23	0.15	0.17	-0.16	-0.05
(9) Total Change in Lateral Flow, ΔQ_{GW}	0.23	-0.08	0.02	-0.33	0.11
(10) Total Observed Total Soil Moisture ET	-5.82	-5.31	-4.50	-8.79	-8.71
(11) Adjusted TSM ET (with GPET)	-5.26	-5.06	-4.32	-7.88	-7.45
(12) Difference Between Obs. & Adjusted TSM ET	-0.56	-0.25	-0.19	-0.91	-1.26
(13) Deep Water TSM ET(DTWT > 1 FT BLS)	-4.62	-4.86	-4.09	-7.88	-7.37
(14) Shallow Water TSM ET+ ET from DS (DTWT $\leq$ 1 FT BLS)	-1.63	-1.27	-1.34	0.00	-0.09
(15) Depression Storage ET (DS ET)	-0.99	-1.07	-1.11	0.00	-0.01
(16) Shallow Water TSM ET- ET from DS (DTWT $\leq$ 1 FT BLS)	-0.64	-0.20	-0.23	0.00	-0.08
(17)Total ET (Adj. TSM ET, DS ET& Ic)	-6.94	-6.70	-6.44	-8.79	-8.37
(18) Total Change in Storage, ΔS	2.41	4.59	4.80	2.85	2.88
(19) Upstream Runoff Infiltration (Observed Infiltration Several Hours After a Rainfall Event)	1.67	3.15	2.94	3.72	3.77
(20) Depression Storage Infiltration/ET: Increase/Decrease Observed from Two Hours after a Rainfall Event up to 24 hrs or the Next Event, Whichever Shorter (Using Hourly TSM Integration)	0.17	0.06	0.60	-0.56	-0.56
(21) Soil Moisture Increase in the Absence of Rainfall Event	1.88	0.64	0.37	0.12	0.45
(22) Soil Moisture Increase When Rainfall Event Not Recorded	0.00	0.00	0.00	0.00	0.00
(23) Balance (B) (I+ΔQ+ET(SM & Sy)-ΔS+19+21+22)	0.47	-0.17	0.05	-0.66	0.22
(24) Avg. Depth to Water Table (ADTWT)(ft)	1.90	2.00	2.17	3.89	3.12

Appendix F: (Continued)

Table 24. Annual water budget results form winter 2004 for USF3 and USF1.

Hydrologic Observations for Winter 2004		
Table (24)	11 Qtr- Derived Hydrologic Fluxes & Storages	
WINTER, 2004 (11 Qtr) (in/qtr)	USF3	USF1
(1) Interception Storage, SIc (in)/Event	0.05	0.05
(2) Total interception capture, EIc	0.69	0.69
(3) Saturation Rainfall Excess, SRE	5.05	1.74
(4) Total Rainfall Excess, TRE	6.02	4.47
(5) Net Runoff	1.88	0.90
(6) Infiltration, I	2.44	3.99
(7) Total Precipitation, P	9.15	9.15
(8) Total Lateral Flow, Q_{GW}	0.00	0.00
(9) Total Change in Lateral Flow, ΔQ_{GW}	0.00	0.00
(10) Total Observed Total Soil Moisture ET	-1.99	-3.62
(11) Adjusted TSM ET (with GPET)	-1.98	-2.64
(12) Difference Between Obs. & Adjusted TSM ET	-0.01	-0.98
(13) Deep Water TSM ET(DTWT > 1 FT BLS)	-1.33	-1.62
(14) Shallow Water TSM ET+ ET from DS (DTWT ≤ 1 FT BLS)	-4.80	-4.59
(15) Depression Storage ET (DS ET)	-4.14	-3.57
(16) Shallow Water TSM ET- ET from DS (DTWT ≤ 1 FT BLS)	-0.66	-1.02
(17)Total ET (Adj. TSM ET, DS ET& Ic)	-6.82	-6.90
(18) Total Change in Storage, ΔS	1.02	2.56
(19) Upstream Runoff Infiltration (Observed Infiltration Several Hours After a Rainfall Event)	0.39	1.03
(20) Depression Storage Infiltration/ET: Increase/Decrease Observed from Two Hours after a Rainfall Event up to 24 hrs or the Next Event, Whichever Shorter (Using Hourly TSM Integration)	-0.13	0.95
(21) Soil Moisture Increase in the Absence of Rainfall Event	0.18	1.16
(22) Soil Moisture Increase When Rainfall Event Not Recorded	0.00	0.00
(23) Balance (B) (I+ΔQ+ET(SM & Sy)-ΔS+19+21+22)	0.00	0.00
(24) Avg. Depth to Water Table (ADTWT)(ft)	1.10	1.17

12th Quarter Water Budget Components

Precipitation for this partially frontal storm period was measured at 10.62 in. (270 mm). This is lower than typical magnitude for this season. Total ET for this highly active plant growing season fluctuated in excess of 10.8 in. (274 mm) in the upland area while gradually increasing to about 14.6 in. (371 mm) near the stream region. Total ET near stations USF3 and USF1 fluctuated in the range of almost 7 to 14.9 in. (178 to 378 mm) respectively. With the exception of upland regions total ET was the dominant component of the water budget in this quarter. Relatively uniform infiltration volume was observed across the transect wells regardless of the landuse. Minimal TRE runoff and negligible SRE runoff were observed across the transect wells regardless of the landuse type. ADTWT was the deepest in this quarter while gradually declining toward the stream region. Zero DS ET was observed across the transect wells and minimal values were observed near USF3 and USF1. Lateral flows fluctuated from the upland while steadily declining to zero near the stream region. Moderate SM data were observed missing periodically for PS43 and USF3 while minimal SM data was observed missing for PS42, PS41 and USF1. No missing SM data were observed for station PS40. Observed quarterly results for all water budget components for PS43 through PS40 and USF3 and USF1 in this quarter are presented in Tables 25 and 26 respectively.

Appendix F: (Continued)

Table 25. Quarterly water budget results for spring 2004 for PS43-PS39.

Hydrologic Observations for Spring 2004					
Table (25)	12 Qtr- Derived Hydrologic Fluxes & Storages				
SPRING, 2004 (12 Qtr) (in/qtr)	PS43	PS42	PS41	PS40	PS39
(1) Interception Storage, SIc (in)/Event	0.05	0.04	0.08	0.07	0.07
(2) Total interception capture, EIc	0.95	0.77	1.44	1.29	1.29
(3) Saturation Rainfall Excess, SRE	0.02	0.04	0.00	0.00	0.00
(4) Total Rainfall Excess, TRE	0.88	1.30	1.52	0.59	0.60
(5) Net Runoff	0.88	1.30	1.52	0.59	0.60
(6) Infiltration, I	8.79	8.55	7.66	8.74	8.73
(7) Total Precipitation, P	10.62	10.62	10.62	10.62	10.62
(8) Total Lateral Flow, Q_{GW}	0.17	0.11	0.08	0.00	-0.06
(9) Total Change in Lateral Flow, ΔQ_{GW}	0.17	-0.05	-0.03	-0.09	-0.05
(10) Total Observed Total Soil Moisture ET	-9.87	-14.56	-12.90	-13.32	-13.24
(11) Adjusted TSM ET (with GPET)	-9.87	-14.56	-12.90	-13.32	-13.24
(12) Difference Between Obs. & Adjusted TSM ET	0.00	0.00	0.00	0.00	0.00
(13) Deep Water TSM ET(DTWT > 1 FT BLS)	-9.87	-14.56	-12.90	-13.32	-13.24
(14) Shallow Water TSM ET+ ET from DS (DTWT $\leq$ 1 FT BLS)	0.00	0.00	0.00	0.00	0.00
(15) Depression Storage ET (DS ET)	0.00	0.00	0.00	0.00	0.00
(16) Shallow Water TSM ET- ET from DS (DTWT $\leq$ 1 FT BLS)	0.00	0.00	0.00	0.00	0.00
(17)Total ET (Adj. TSM ET, DS ET& Ic)	-10.82	-15.33	-14.34	-14.61	-14.53
(18) Total Change in Storage, ΔS	2.91	-3.79	-3.13	-2.64	-2.64
(19) Upstream Runoff Infiltration (Observed Infiltration Several Hours After a Rainfall Event)	3.60	3.23	2.28	3.19	3.19
(20) Depression Storage Infiltration/ET: Increase/Decrease Observed from Two Hours after a Rainfall Event up to 24 hrs or the Next Event, Whichever Shorter (Using Hourly TSM Integration)	-0.46	-0.79	-1.68	-4.12	-4.12
(21) Soil Moisture Increase in the Absence of Rainfall Event	0.85	0.04	0.27	0.01	0.01
(22) Soil Moisture Increase When Rainfall Event Not Recorded	0.00	0.00	0.00	0.00	0.00
(23) Balance (B) (I+ΔQ+ET(SM & Sy)-ΔS+19+21+22)	0.33	-0.11	-0.06	-0.18	-0.11
(24) Avg. Depth to Water Table (ADTWT)(ft)	3.61	3.36	3.56	4.77	4.17

Appendix F: (Continued)

Table 26. Quarterly water budget results for spring 2004 for USF3 and USF1.

Hydrologic Observations for Spring 2004		
Table (26)	12 Qtr- Derived Hydrologic Fluxes & Storages	
SPRING, 2004 (12 Qtr) (in/qtr)	USF3	USF1
(1) Interception Storage, SIc (in)/Event	0.05	0.05
(2) Total interception capture, EIc	0.95	0.95
(3) Saturation Rainfall Excess, SRE	0.03	0.17
(4) Total Rainfall Excess, TRE	1.15	1.12
(5) Net Runoff	0.28	-0.19
(6) Infiltration, I	8.52	8.55
(7) Total Precipitation, P	10.62	10.62
(8) Total Lateral Flow, Q_{GW}	0.00	0.00
(9) Total Change in Lateral Flow, ΔQ_{GW}	0.00	0.00
(10) Total Observed Total Soil Moisture ET	-5.21	-12.79
(11) Adjusted TSM ET (with GPET)	-5.17	-12.63
(12) Difference Between Obs. & Adjusted TSM ET	-0.04	-0.16
(13) Deep Water TSM ET(DTWT > 1 FT BLS)	-4.68	-11.93
(14) Shallow Water TSM ET+ ET from DS (DTWT $\leq$ 1 FT BLS)	-1.37	-2.01
(15) Depression Storage ET (DS ET)	-0.87	-1.31
(16) Shallow Water TSM ET- ET from DS (DTWT $\leq$ 1 FT BLS)	-0.50	-0.70
(17)Total ET (Adj. TSM ET, DS ET& Ic)	-6.99	-14.89
(18) Total Change in Storage, ΔS	6.65	-0.29
(19) Upstream Runoff Infiltration (Observed Infiltration Several Hours After a Rainfall Event)	3.00	3.93
(20) Depression Storage Infiltration/ET: Increase/Decrease Observed from Two Hours after a Rainfall Event up to 24 hrs or the Next Event, Whichever Shorter (Using Hourly TSM Integration)	-0.12	-0.99
(21) Soil Moisture Increase in the Absence of Rainfall Event	0.35	0.03
(22) Soil Moisture Increase When Rainfall Event Not Recorded	0.00	0.00
(23) Balance (B) (I+ΔQ+ET(SM & Sy)-ΔS+19+21+22)	0.00	0.00
(24) Avg. Depth to Water Table (ADTWT)(ft)	1.93	1.80

Appendix G: Comparison of Observed Hourly SM+DS ET with Site PET

The hourly, monthly and quarterly comparison between site PET and observed and adjusted hourly, monthly and quarterly SM+DS ET, for grassland (PS-43) and Forest (PS-40), in 2002 and 2003 are shown in Figures 45 through 56. Recall, J&H model were utilized using FAWN (ONA) site solar radiation and temperature data to compute J&H PET. A pan factor of 0.7 was employed uniformly across the board and adjusted for research site rainfall records and interception capture for simulation of site PET. Results are presented in SI units.

Results in 2002- The hourly site PET dominates the profile for the winter and spring period for the grassland cover in 2002. The gap is not considerably during the wet period for the same year. For the monthly and quarterly scale the domination of the site PET over TSM+DS ET is prevalent for the grassland except for the months of November and December where considerably closer range was observed. The highest site PET was observed in the month of May and the highest TSM+DS ET were almost equal in May and July. Noteworthy that the DS ET contribution is considerable during wet period. Lowest TSM+DS ET demand is observed in winter season but Lowest Site PET is observed in December driven by unusual rainfall events. On quarterly basis is gap is the narrowest toward the end of the year believed to be associated with uncharacteristic rainfall events.

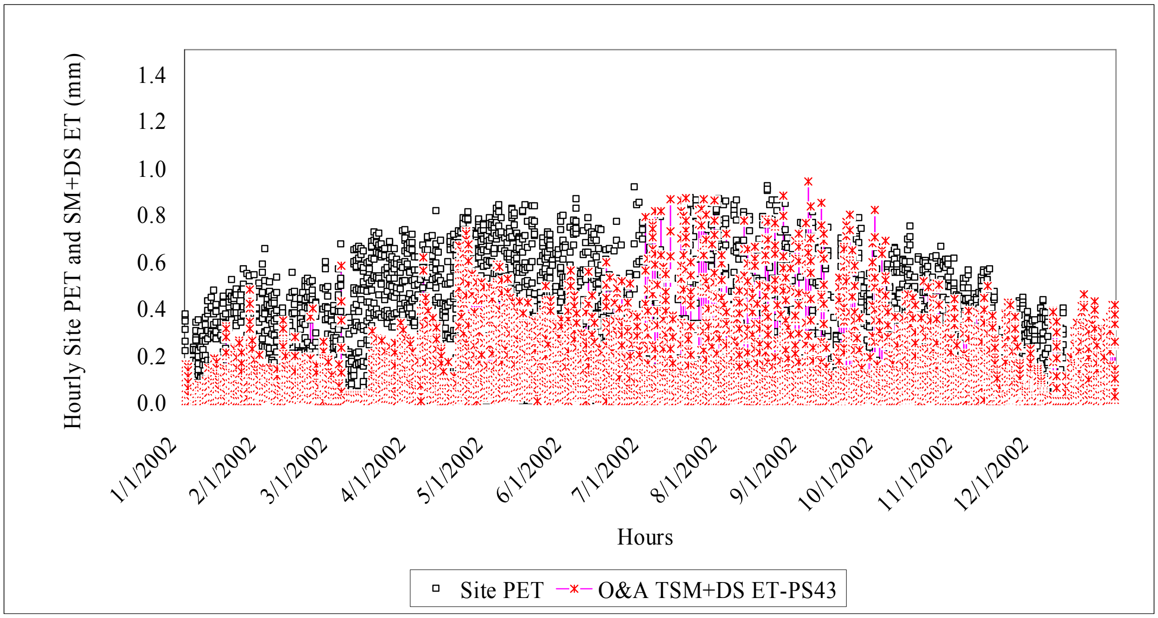

Figure 45. Hourly site potential ET vs. observed and adjusted total soil moisture and depression storage ET for grassland covers (PS43) in 2002.

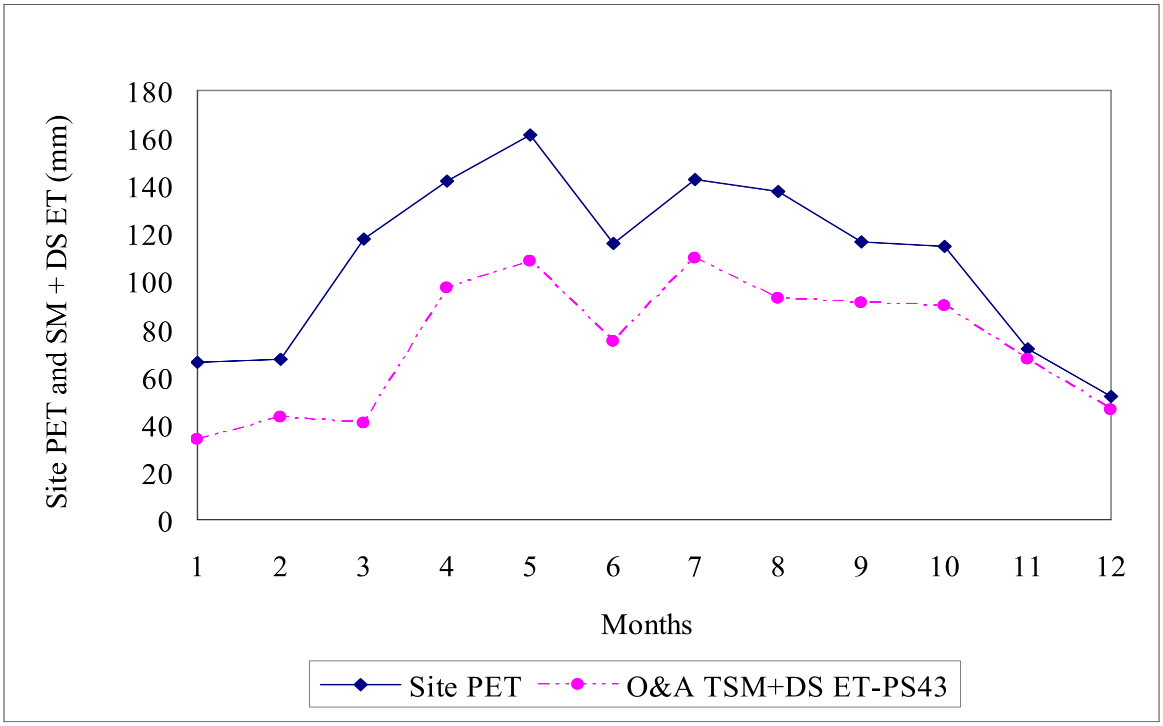

Figure 46. Monthly site potential ET vs. observed and adjusted total soil moisture and depression storage ET for grassland (PS43) in 2002.

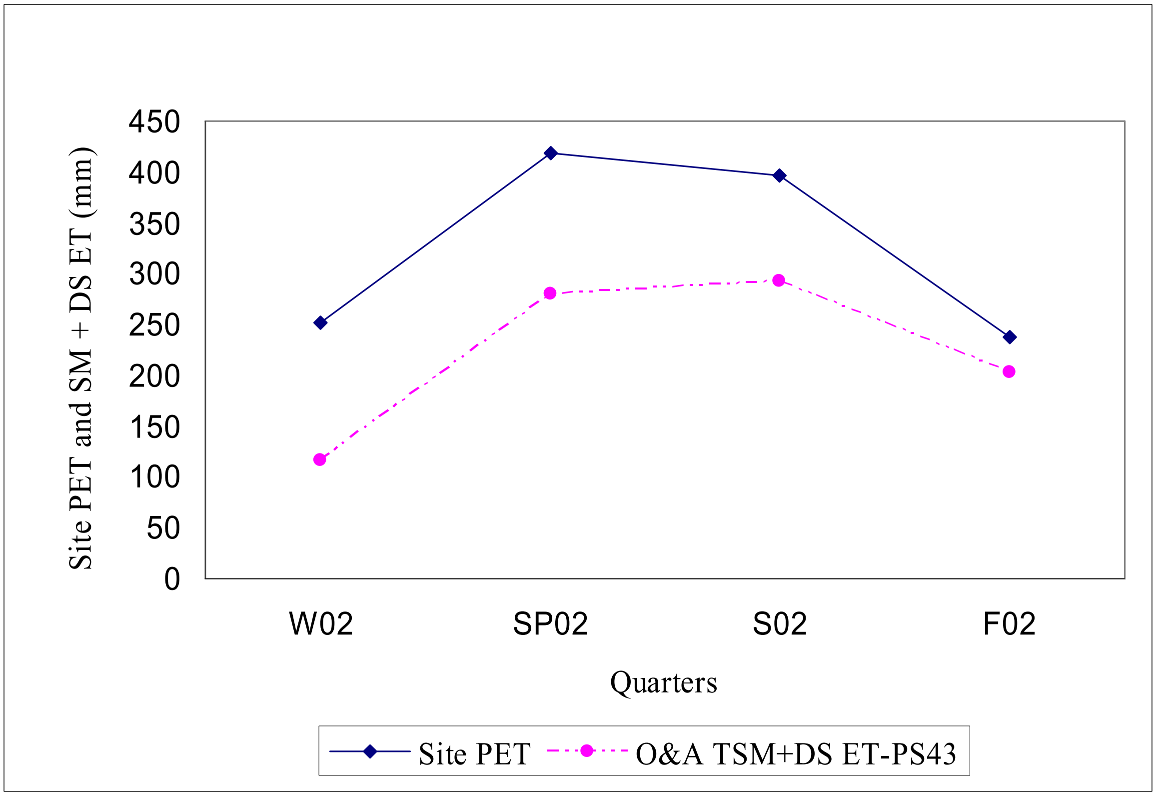

Figure 47. Quarterly site potential ET vs. observed and adjusted total soil moisture and depression storage ET for grassland (PS43) in 2002.

For forested wetland the hourly site PET dominates the TSM+DS ET profile during the winter and summer period. The magnitude of site PET and TSM+DS ET is nearly the same for the remainder of the year. The observed behavior during the fall season is attributed to significant and unusual rainfall events resulting in higher TSM ET. The highest TSM+DS ET is observed in August. On quarterly basis the domination of site PET is prevalent except for the fall season where the magnitude of TSM+DS ET is higher than site PET. The peak quarterly magnitudes were observed in the spring season. Lowest TSM+DS ET demand is observed in winter season.

Appendix G: (Continued)

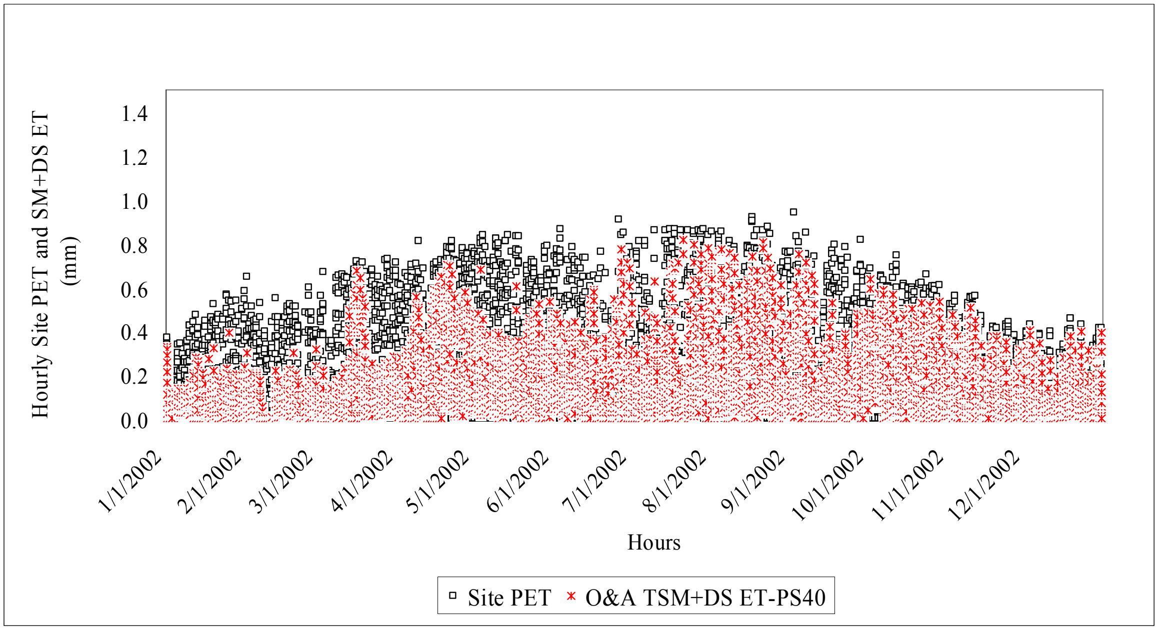

Figure 48. Hourly site potential ET vs. observed and adjusted total soil moisture and depression storage ET for forest wetland (PS40) in 2002.

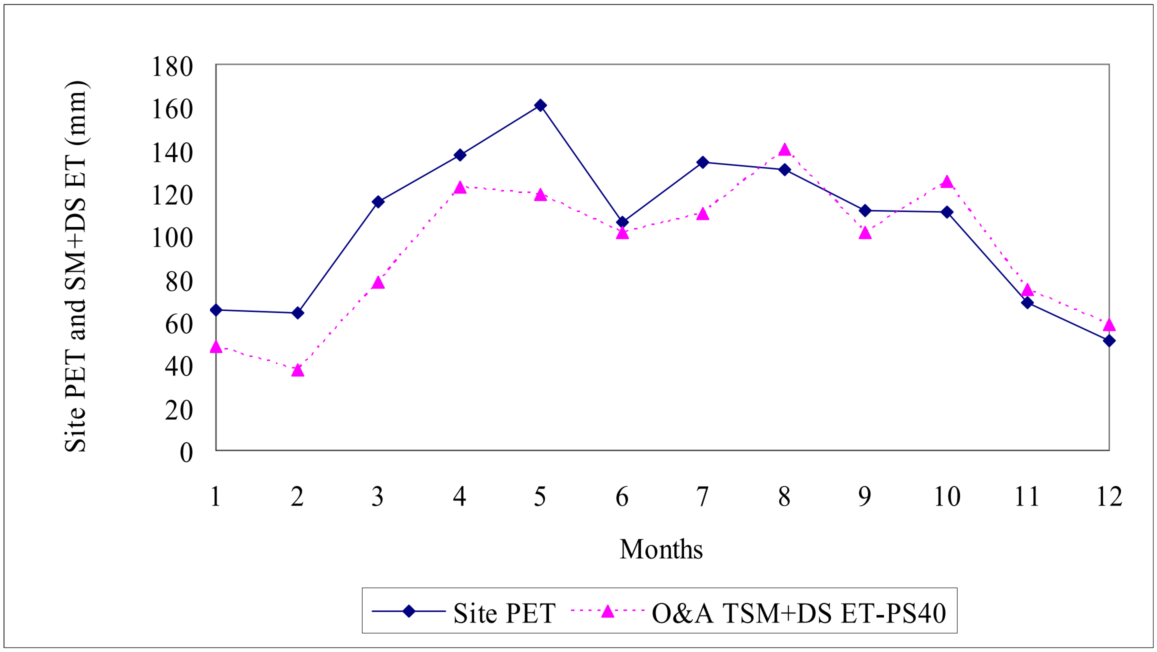

Figure 49. Monthly site potential ET vs. observed and adjusted total soil moisture and depression storage ET for forest (PS40) in 2002.

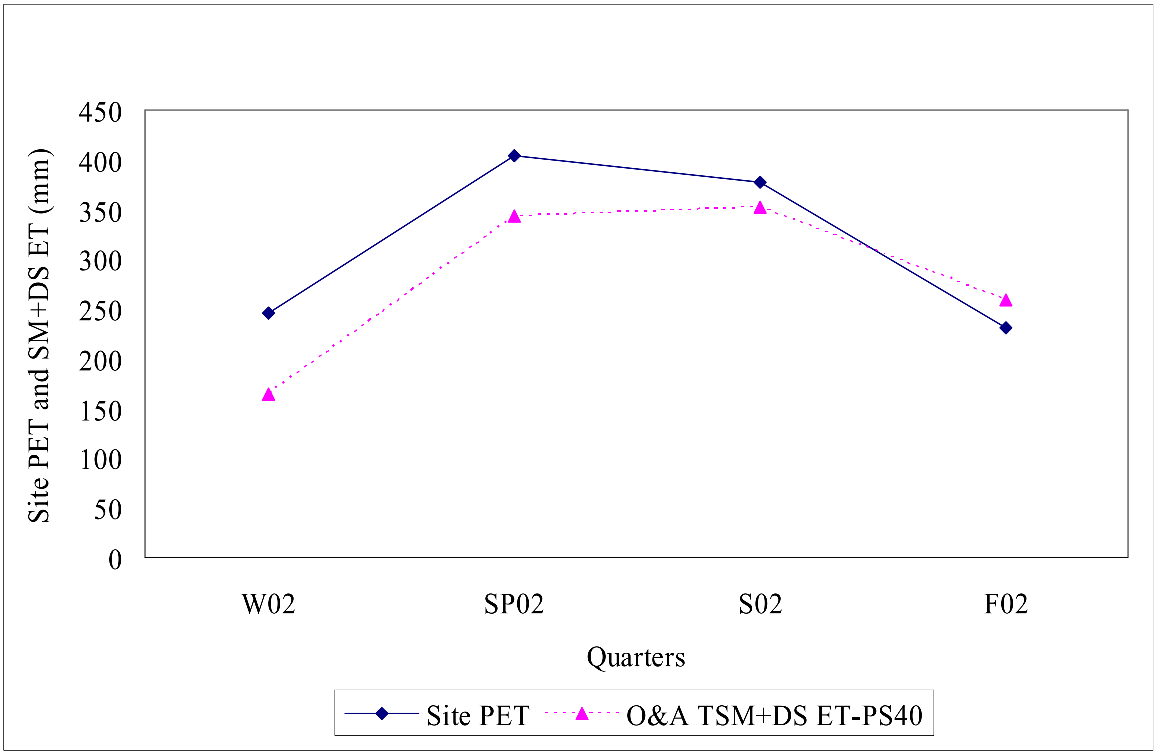

Figure 50. Quarterly site potential ET vs. observed and adjusted total soil moisture and depression storage ET for forest (PS40) in 2002.

Results in 2003- The hourly site PET dominates the profile for the grassland cover during early winter and the normal wet season in 2003. This observed behavior is attributed to SM availability during theses periods. Isolated higher values for TSM+DS ET were attributed to the use of hourly SMD directly following a rainfall event. On monthly basis the highest site PET and TSM+DS ET coincided in the month of May. The lowest monthly volumes of the two ET components are observed in December and February respectively. On quarterly basis the domination of site PET is prevalent for each quarter although the gaps are considerably narrower during the dry period.

The peak quarterly volume was observed in the spring season while relatively equal magnitudes were observed in the winter and fall of 2003 for the grassland cover.

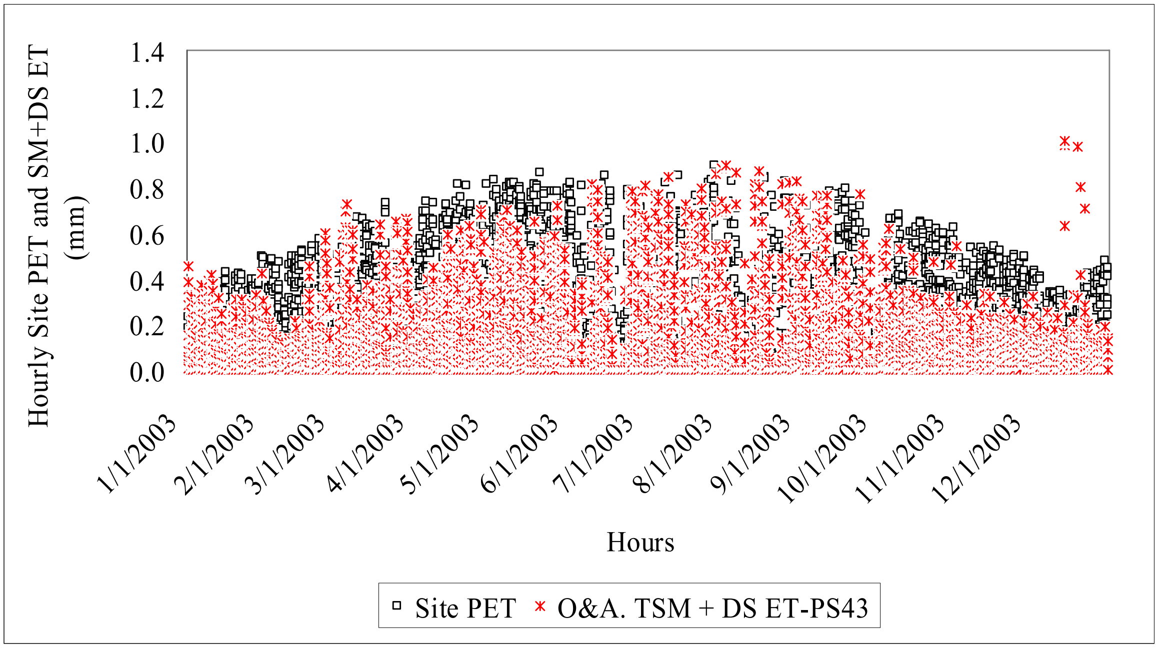

Figure 51. Hourly site potential ET vs. observed and adjusted total soil moisture and depression storage ET for grassland (PS-43) in 2003.

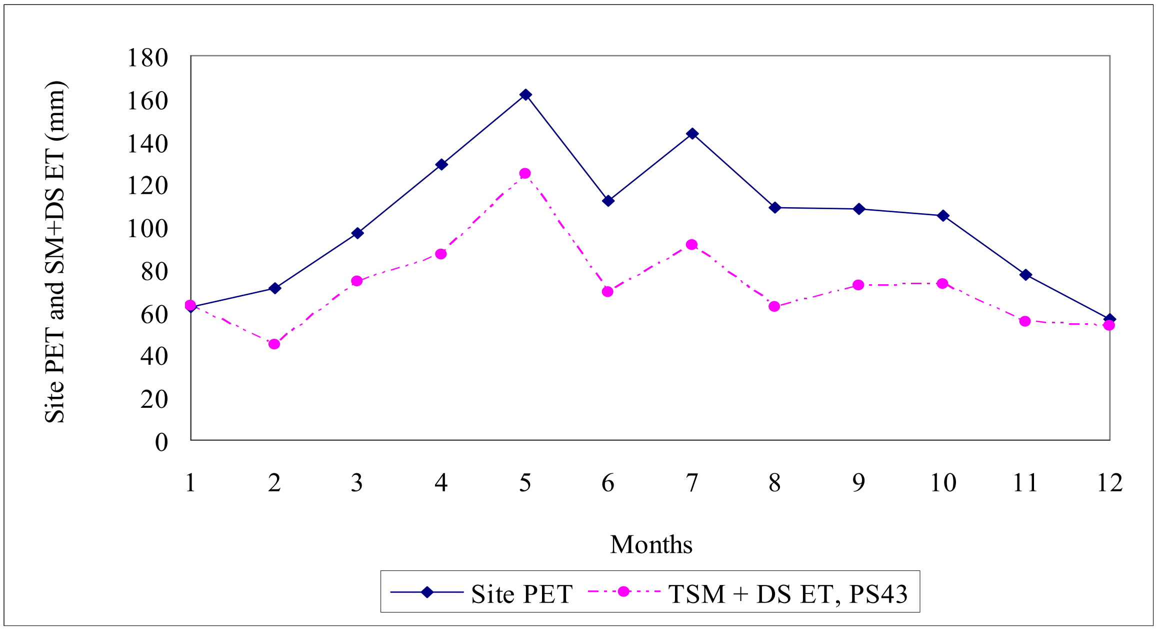

Figure 52. Monthly site potential ET vs. observed and adjusted total soil moisture and depression storage ET for grassland (PS43) in 2003.

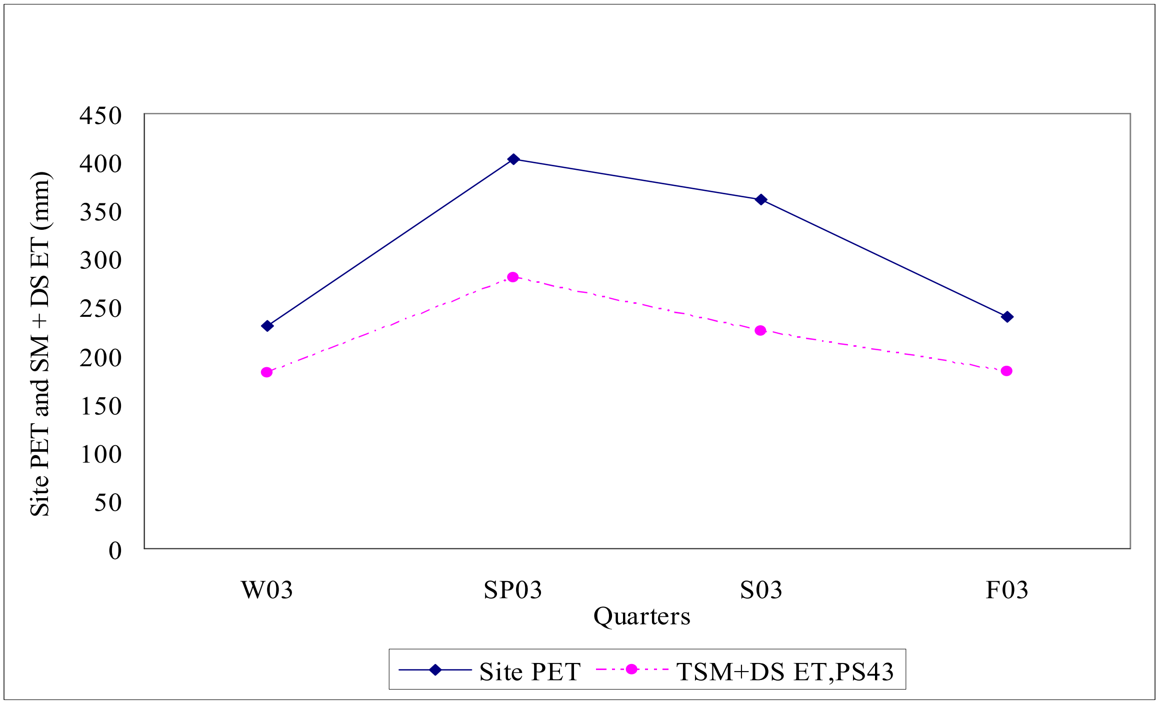

Figure 53. Quarterly site potential ET vs. observed and adjusted total soil moisture and depression storage ET for grassland (PS43) in 2003.

For forested wetland the gap between TSM+DS ET and site PET is uniformly narrow during 2003 period. Narrowest gap between the hourly TSM+DS ET and site PET is observed in the winter and the fall periods. Isolated higher values of TSM+ DS ET are attributed to the hourly fluctuations of SMD. Highest monthly site PET is observed in May while for TSM+DS ET the highest volume is observed in July. Higher TSM+DS ET in January is the residual effect of the significant rainfall events observed in the last days in December of 2002 resulting in wet antecedent SM condition and higher TSM+DS ET. On quarterly basis the domination of site PET is prevalent during the growing season and the wet period. Simulated site PET and TSM+DS ET matched closely in the winter and the fall period.

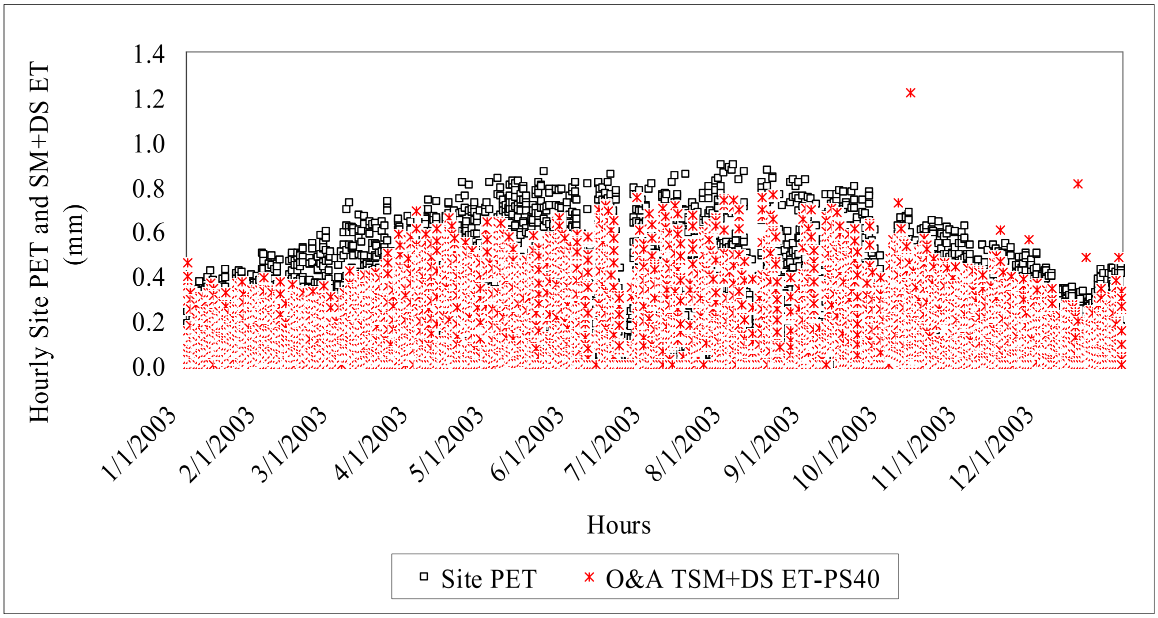

Figure 54. Hourly site potential ET vs. observed and adjusted total soil moisture and depression storage ET for forested wetland (PS-40) in 2003.

Appendix G: (Continued)

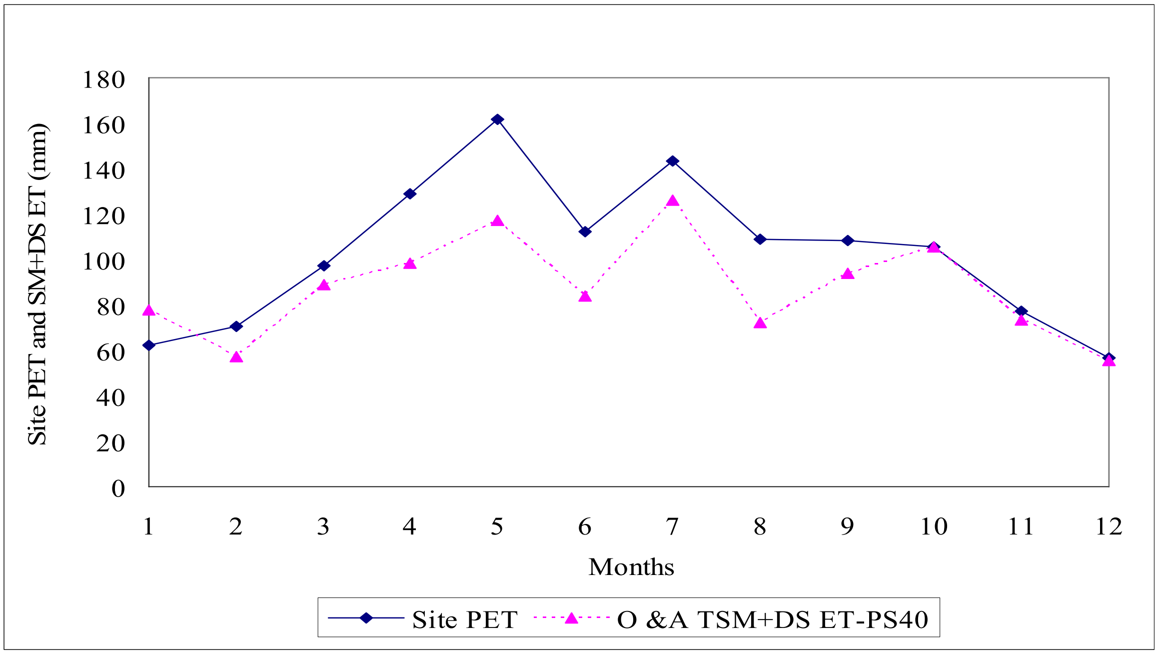

Figure 55. Monthly site potential ET vs. observed and adjusted total soil moisture and depression storage ET for forested wetland (PS40) in 2003.

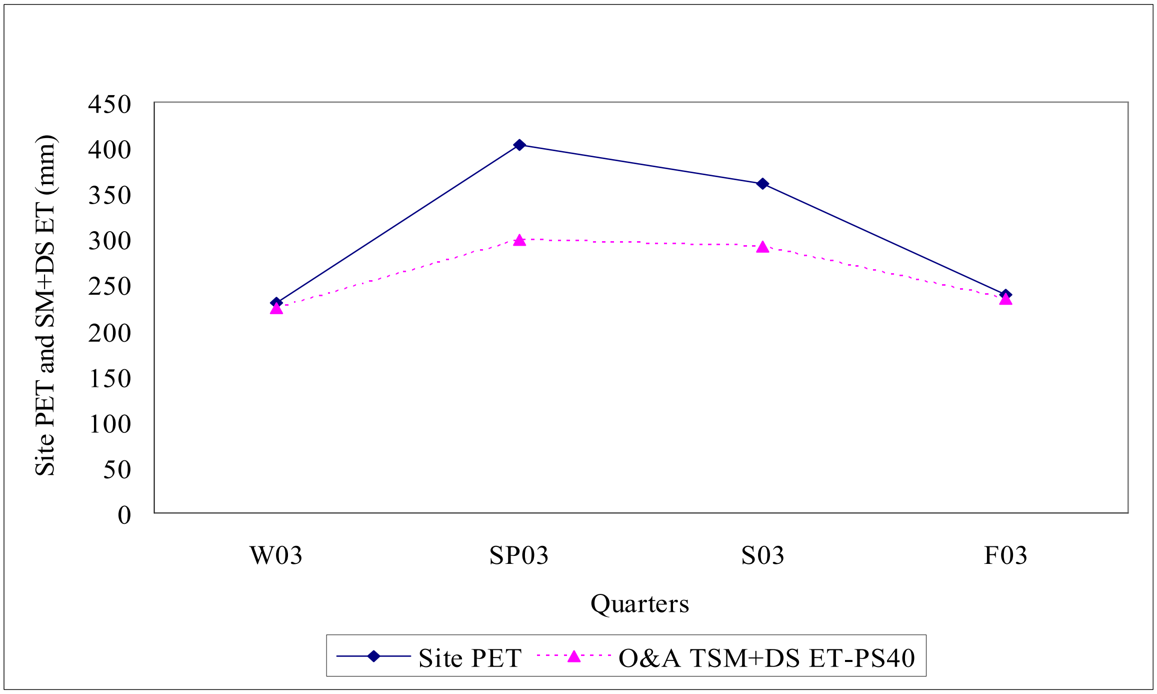

Figure 56. Quarterly site potential ET vs. observed and adjusted total soil moisture and depression storage ET for forested wetland (PS40) in 2003.

Appendix H: Sample of Observed Quarterly SM ET with Adjusted SM ET and GPET for Grass and Forested Land in 2003

Comparison of observed quarterly estimated TSM ET, Adjusted SM ET and GPET for grassland station (PS-43) and forested wetland (PS-42) 2003 are presented in Figures 57 and 58 respectively.

Recall for ET estimation all negative *(I-ET)* cell values in the numerical model were separated from the positive cell values by writing a simple algorithm in the model, for each time step (dt), and placed in a separate column corresponding to each station and averaged over a 12 hour period. Hourly ET were adjusted using the observed ET values from the SM data, while filtering the data such that observed ET values smaller than the minimum GPET values with central moving in 24 hour period with a 1.1 multiplier was used with GPET value averaged over 3 hour period as a substitute. It was explained earlier how GPET data were obtained.

In summer of 2003, 9th quarter, GPET depicted in Figure 57 dominates the profile for grassland cover. Isolated adjustments are observed for the grassland cover associated with observed TSM ET. The difference between the GPET and the observed and adjusted TSM ET may appear low. Recall the influence of DS ET is not included here.

In the summer of 2003, 9th quarter, GPET also dominates the profile for the forested wetland region. Graph for this landuse cover is depicted in Figure 58**.** TSM ET adjustments are more frequently observed for the forested wetland. Considerably narrowest gap between observed and adjusted TSM ET and GPET is observed for the

Appendix H: (Continued)

forested wetland region than grassland cover, in response to higher ET demand and in direct response to landuse change.

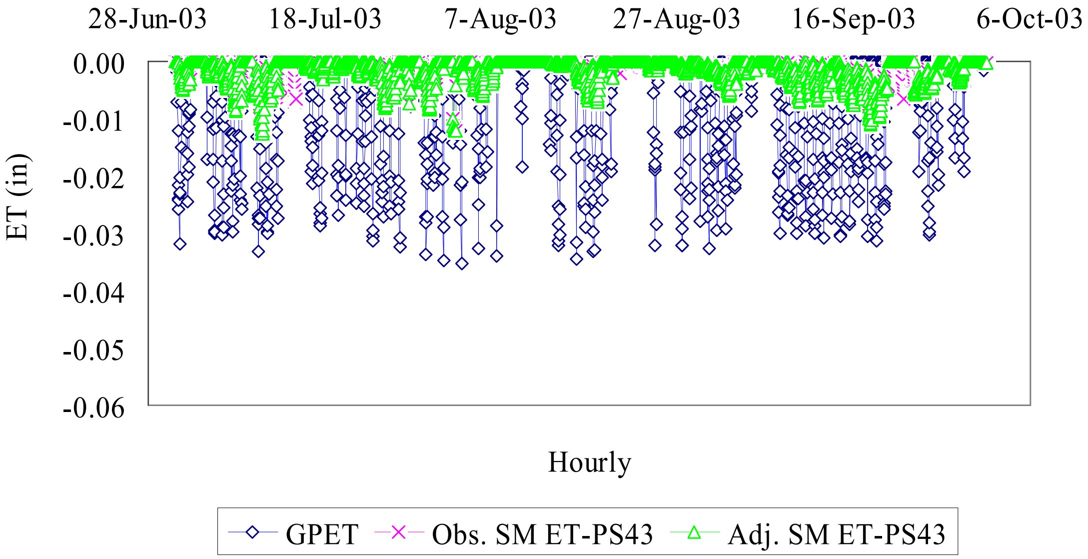

Figure 57. Quarterly ground potential ET (GPET) with observed and adjusted soil moisture and depression storage ET for grassland (PS43) summer 2003.

Appendix H: (Continued)

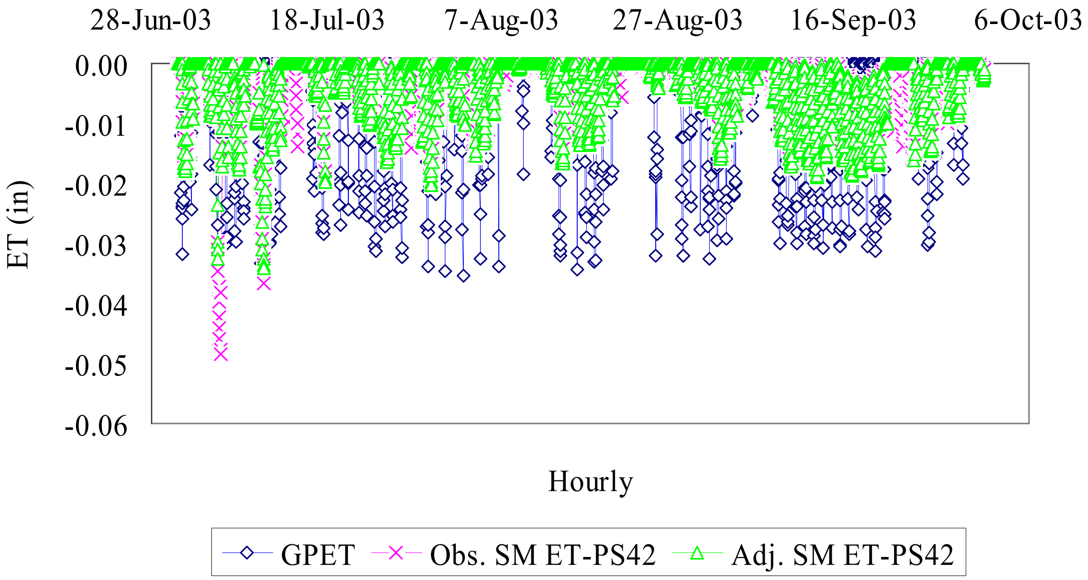

Figure 58. Quarterly ground potential ET (GPET) vs. observed and adjusted total soil moisture and depression storage ET for forested (PS42) in summer 2003.

ABOUT THE AUTHOR

Mandana Seyed Rahgozar was born in 1959 in Teharn, Iran. On February 23, 1977 she entered United States soil. She attended Rainsville State Jr. College in Rainsville, Alabama from 1977 to 1979 and obtained an AA degree. She attended Alabama A&M University in Huntsville, Alabama from 1979 to 1981 and obtained the bachelor's degree in Civil Engineering. She immediately moved to Tampa, Florida. After trying the private sector for a short while she was employed by Pinellas County Schools since 1982 as the district's Civil Engineer.

In 1991 she obtained her license/registration from Florida Board of Professional Engineers in the state of Florida. Shortly after she enrolled at the University of South Florida in Tampa, Florida in the Civil and Environmental Engineering Department where she obtained her Master's in spring of 1994 and immediately pursued the candidacy for Ph.D. program also in Civil and Environmental Engineering. She completed the program requirements in the fall of 2006.