Mike.

PET UPGRADES TO NWSRFS

PROJECT PLAN

Victor Koren
John Schaake
Qingyun Duan
Michael Smith
Shuzheng Cong

August 13, 1998

1. Introduction

Potential Evapotranspiration (PET) estimates are a required input to the soil moisture accounting procedures of the NWSRFS. PET estimates are needed for both calibration and operational applications. Alternative techniques are available to estimate PET, but different techniques produce different results. Accordingly each technique has its own unique climatology. Models calibrated to one PET climatology may not function well when forced for extended periods by PET values estimated by a different technique than the model was calibrated. The purpose of this plan is to:

a. improve the accuracy and reliability of the existing techniques ;
b. provide tools to reduce the required work effort to use them; and,
c. provide additional, improved techniques.

Different PET estimates may be used for operations than were used for calibration because there are potentially some practical advantages to having such differences. **But it is essential that the *climatology* of the operational estimates are the same as the climatology of the calibration estimates.**

2. Existing NWSRFS PET Options

NWSRFS usually estimates potential evaporation (free surface water evaporation, PE) first, and then evaporation demand (PET) for the SAC-SMA model as a product of PE and a vegetation adjustment factor (PE_{adj}).

NWSRFS has two present options to estimate PET. One is to use the product of monthly long-term averages of PE multiplied by adjustment factors that account for effects of vegetation, PE_{adj}. Monthly values of the PE_{adj} are estimated during calibration. Estimation of the long-term monthly PE is based on the maps of the annual and growing season (May to October) free water surface evaporation [NOAA Technical Report NWS 34, 1982; TR33]. When this option is used

NWSRFS requires one value for each month that is the product of the monthly average PE and the PE adjustment factor, PE_{adj}. Separate values of average monthly PE and monthly PE_{adj} are not used explicitly in NWSRFS. Only the product of the two is used.

The second option is to use surface observations (SAO data) to estimate daily potential evaporation using a program called SYNTRAN that has been available since about 1990 (Lindsey and Farnsworth, 1992). However, there is a bias between the PE climatology estimated by SYNTRAN and the PE climatology of the NOAA evaporation atlas. To correct for this bias, adjustment factors are applied to SYNTRAN estimates. These adjustments are not related to the vegetation adjustments; they are assumed to be constant for the year, they vary from site to site, and they can be as large as 40 percent. When this option is used, the daily PE time series and monthly PE_{adj} are both used as inputs. The PE_{adj} factors are defined during calibration.

Both of the above PET options are available in both operational and calibration modes. However, the SYNTRAN option requires daily cloud cover observations which are being phased out with the implementation of ASOS . Other alternative to use percent sunshine has been explored. Lindsley and Farnsworth showed that percent sunshine is an unbiased estimator of solar radiation. However, percent sunshine is not also in list of ASOS products.

There is another option to generate daily time series of PE in calibration mode. MAPE program can process pan evaporation data to generate basin averages of daily PE values. The appropriate pan coefficient (e.g., from map 4 in TR#33) is applied as a correction factor. The vegetation correction factor should be estimated and applied the same way as in both of the above options to derive a PET input to SAC-SMA

3. Limitations of Existing NWSRFS PET Options

All PET estimation techniques have limitations. Ultimately PET cannot be measured directly and the exact meaning of PET is a matter of definition. Some difference in PET values from different approaches can be expected simply because of differences (perhaps implicit) in definition. Such differences are most important if there is no temporal consistency between estimates at different locations. This can be very important if model parameters are based on one technique and another PET estimate is used without consistency adjustments to correct for differences from calibrated PET values, which may vary through the year.

Limitations in PET options may have scientific as well as practical aspects. This plan is intended to make both practical as well as scientific improvements to address the following difficulties.

3.1 Long-Term Average PE Estimates

The NOAA Evaporation Atlas (Farnsworth et al, 1982a) (TR33) gives annual and seasonal maps of free water surface evaporation. Monthly values may be determined using these maps by considering the monthly distribution of evaporation pan data (Farnsworth et al, 1982b) (TR34).

Application of the information in TR33 and TR34 is tedious and adequate procedures to make monthly estimates of long term average PE remain to be developed. Computer programs are described below that completely automate application of TR33 and TR34 to make PE estimates for the NWSRFS.

3.2 SYNTRAN PE Estimates

Two main problem areas with SYNTRAN are consistency of mean annual PE with TR33 and availability of cloud cover or percent sunshine data. SYNTRAN consistency may vary from month to month as well annually. Also, consistency adjustment factors are available as part of SYNTRAN for only a small portion of the total number of sites where SAO data are available, see Figure 1. The cumulative distribution function of SYNTRAN adjustment factors at 35 sites shown in Figure 1 is given in Figure 2.

Lack of operational cloud cover observations likely will preclude the SYNTRAN approach to be used operationally until some alternative way to account for the lack of cloud data can be found. One future option is to use satellite solar insolation measurements. Another might be to develop a technique that does not explicitly require cloud data and that empirically might compensate for this in terms of the effects of clouds, especially in summer, on air temperature, relative humidity and wind.

An additional problem is that wind speed measurements are made at heights that generally are above the surface height required for the PE calculation. Also the measurement heights may vary from site to site and from time to time at the same site. Station history data are available in printed form to permit appropriate adjustments to be made. However, available meta data are time-consuming to use and in practice may not be used properly.

3.3 Comparison of Long-Term and Short-Term PE Estimates

An example is presented in Figure 3 to illustrate the difference between daily PE climatological estimates and daily PE estimates based on hourly surface observations and radiation measurements. This figure is for the FIFE experimental site near Manhattan, Kansas. The smooth curve represents mean daily PE computed using procedures described below. The irregular curve represents daily PE values estimated using the Penman equation (as implemented in NCEP's Eta model) together with observations of 30-minute weather and radiation (long and shortwave) during the summer of 1987. NCEP's Eta model uses an aerodynamic wind function rather than an empirical wind function as typically used by hydrologists and as used by SYNTRAN. The aerodynamic wind function is needed to account for diurnal variations in the surface roughness coefficient for heat.

Clearly, there is more detail in the measurement-based PE values than in the climate-based values. This means that short term actual evaporation amounts are very sensitive to the observed weather and energy forcing as well as the current soil moisture. But, the daily PE anomalies are individually quite small as compared to the total moisture storage capacity. Therefore, the effects on streamflow of daily PE anomalies will be much less than on daily evaporation. But they still might be large enough to be worth representing operationally. The effects of anomalies in daily PE on model parameter values should be even less than the effects on daily streamflow. Hence it becomes questionable if much work is justified to prepare PE daily anomaly data for model calibration, especially given the current limitations of the SYNTRAN approach. This issue will be pursued under the long term objectives of this work plan.

3.4 PE Vegetation Adjustment Factors

PE adjustment factors must be estimated in model calibration. There are 12 factors and little existing scientific basis to calculate their values. Some guidance can be obtained from estimates of crop water requirements (Doorenbos and Pruitt, 1975). However, there is no a reasonable technique to get a representative areal estimates. The resulting estimates are likely to be highly dependent on human aspects of model calibration. This can be improved through use of AVHRR data.

3.5 Land Cover Heterogeneity: How to Treat Vegetation vs Bare Soil Processes

There are a range of scientific issues regarding how best to make areal estimates of evaporation. Many are being addressed as part of the research being done as part of the U.S. and World Climate Research Programs. Water evaporates differently from vegetation, bare soil and lakes. It evaporates differently from different types of vegetation. Improvements in evaporation estimates presumably would result from understanding and accounting for these differences. Many land surface modelers prefer to avoid the definition of potential evaporation and to estimate a stomatal resistance for use in the Penman-Monteith equation. Many prefer to continue to use potential evaporation, but there are differences in the appropriate definition of potential evaporation for vegetation (which may have a minimum stomatal resistance) and for lakes (where only atmospheric resistance is relevant) or bare soil. At present, NWSRFS implicitly lumps the effects of all of these issues into one composite PET value and one set of functions that considers only the effect of water deficit to compute evaporation from an "adjusted PET". Ultimately improvements in the entire vegetation/evaporation parameterization of NWSRFS should be made that consider the water and energy forcing of evaporation in a physically more appropriate way. This plan is directed only toward improvements in the PET estimates for existing soil moisture accounting schemes.

4.0 Objectives of this Plan

This plan outlines short-term and long-term objectives to improve the limitations discussed above. Short term objectives are to be met within a period of one year or less. The objectives are stated briefly in this section. The methodology and tasks required are discussed in more detail below.

4.1 Short Term Objectives

1. Develop software to generate basin average daily time series of PE using the annual and seasonal long-term PE maps (TR33) and the main characteristics (amplitude and phase angle) of the seasonal cycle of PE derived from analysis of data from TR34.. These daily time series can be used as a PE input into the calibration system or as a base line for SYNTRAN output adjustment to preserve the seasonal/monthly climate estimates.

2. ✓ Develop an *a priori* technique to generate initial estimates of long term average PE adjustment factors using NDVI data to account for the vegetation effects. The first step would be to use the long-term NDVI data to make climatological adjustment factors.

3. Develop digitized meta data for wind measurements for Mississippi Basin and NWRFC

4. Provide operational RFC access to and procedures for using operational NCEP PE estimates.

5. Develop software to calculate a basin average adjustment factor of SYNTRAN PE estimates using long-term MAPE time series derived from TR#33 (task 1).

4.2 Long Term Objectives

1. Develop an *a priori* technique to estimate monthly PE adjustment factors for a given year, taking into account inter-annual variability of NDVI data.

2. Develop techniques for using satellite solar insolation estimates that can be used to produce PE estimates that are consistent with TR33 climatology and that are consistent with PE estimates made with historical cloud cover data.. Imp

3. Improve the long term daily PE estimation technique in mountainous areas by developing or implementing where they are available (e.g., TR#33 results) local PE-Elevation relationships using the data from TR33 and a digital elevation model.

4. Develop digitized meta data for wind measurements for remainder of U.S. not covered by short term activities.

5. Provide a program to produce historical NCEP PE estimates for model calibration.

6. Develop long term climatology of NCEP PE estimates and procedures for estimating basin-specific adjustment factors to assure that operational PE estimates

agree with PE calibration climatologies locally.

7. Develop procedures for operational use of evaporation pan data to make PE estimates.

8. Analyze effect of different PET deriving methods and vegetation fraction adjustment on the SAC-SMA results over different regions of USA

5. Short-Term Products and Methodologies

5.1 Automated Long-Term Daily Climate-Based PE Estimates

5.1.1 *Product*

Computer program to produce mean areal values of:

1. Time series of daily mean PE values for one calendar year

2. Time series of monthly mean PE values for one year

3. Seasonal (May-Oct) and annual average PE values

4. Time series of daily PE values for any given period for input to NWSRFS in OH standard format

This computer program will have two options to define the basin location:

a. Basin boundaries

b. Basin centroid

5.1.2 *Methodology*

Long-term average daily and monthly time series of potential evaporation can automatically be estimated using data from TR33 and TR34.. Contours from the annual and seasonal free water evaporation maps in TR33 have been digitized and transformed to gridded fields. An analysis of the long-term monthly evaporation pan data from TR34 has demonstrated that almost all (more than 98 percent) of the mean monthly variance of pan evaporation is accounted for by a single annual harmonic component of a Fourier Series.

Accordingly, the first order Fourier expansion is used to approximate the long-term mean daily variability of PE

$$PE_i = PE_{avg}[1 + A_{PE}\sin(\frac{2\pi}{366}i + \phi)]$$

where PE_{avg} is the mean daily potential evaporation, A_{PE} is the amplitude of the seasonal cycle of PE, ϕ is a phase angle, and i is the Julian day. Data from TR33 and TR34 were used to estimate PE_{avg}, A_{PE} and ϕ at each pan location. Then these point values were used to make gridded fields of A_{PE} and ϕ for the contiguous 48 United States.

Mean daily climatological PE can be estimated at any point using four maps:

- annual PE
- seasonal (May-October) PE
- amplitude of the annual cycle of PE (A_{PE})
- phase angle of the annual cycle of PE (ϕ)

Basin averages of PE time series can be generated using the same type of software that is used in MAPX calculations or only a single time series can be computed using the basin centroid. The two results should be nearly identical, except possibly in mountainous areas. Because the effects of topography are not well represented in the present analysis, addition work will be done to replace the 4 gridded fields with high resolution gridded fields in which elevation effects are accounted for.

The seasonal total PE gridded value is not used as a direct input to the Fourier series equation so it serves as a check on the procedure. The difference between the gridded and computed seasonal PET is used in a second stage of analysis to make a minor adjustment to A_{PE} to assure that the final time series is constrained by TR33 data.

5.2 Estimates of Monthly PE Adjustments from NDVI Green Fraction

5.2.1 *Product*

Computer program to produce long-term basin average monthly values of vegetation fraction and PE vegetation adjustment factors.

5.2.2 *Methodology*

Monthly values of PE adjustment factor depend mainly on climatic regime and type of vegetation. Typical PE adjustment factors over some regions(basins) of the USA were empirically estimated by Eric Anderson as a result of calibration of the SAC-SMA model (the NWSRFS User's manual, section 'Initial soil-moisture parameter estimates by hydrograph analysis'). Monthly values of the PE adjustment factor for four regions (Southern mixed forest, Southwest, Northern mixed forest, and Southern Appalachian highlands) were taken from the User's manual (Figure 4).

Green vegetation fraction values (Gutman & Ignatov, 1997) over these regions were calculated as averages over an 'equivalent' rectangles that approximately covered each region. Monthly values of green vegetation fraction were extracted from NCEP global data sets. There is a strong correlation between the monthly PET adjustment factor, PE_{adj}, and the green vegetation fraction, V_{frc}, over selected four regions (see Figure 5). The two estimates have a correlation coefficient of 0.855.

This relationship can be used to estimate the seasonal cycle of the PE adjustment factor over any basin, globally. The interannual variation in the vegetation cover potentially can be accounted for operationally if NDVI data are available in an operational mode. A long term activity to develop this capability is included below.

5.3 Wind Measurement Meta Data

5.3.1 *Product*

ASCII wind sensor station history file, easy to read and interpret automatically

5.3.2 *Methodology*

Manually "decode" and transcribe NCDC Word Perfect station history file.

5.4 Operational PE Forecast Products from NCEP

5.4.1 *Product*

Procedures to acquire PE products from NCEP and to get basin average PE values from these products.

5.4.2 *Methodology*

Develop procedures for making NCEP PE products available to RFC's and write a program to read the products together with NWSRFS definition files to produce required NWSRFS PE products.

5.5 Basin average adjustment factor of SYNTRAN PE

5.5.1 *Product*

Program to estimate basin average value of SYNTRAN PE correction factor to adjust any monthly estimates to the climate map.

5.5.2 *Methodology*

Long-Term Daily Climate-Based PE Estimates (output of section 5.1) will be used in combination with SNTRAN time series of PE to calculate an annual adjustment factor averaged over selected river basin. Seasonal and monthly variability of the adjustment factor will be also available.

6. Long-Term Tasks and Methodologies

6.1 Annual Estimates of Vegetation PE Adjustment Factors

6.1.1 *Product*

Computer program to produce basin average monthly values of PE vegetation adjustment factors based on NDVI for the current month.

6.1.2 *Methodology*

Make tests to see if the methodology used to define long term average PE adjustment factors can be extended to give monthly values that vary from year to year and that lead to improved model performance as well.

6.2 Future Application of Satellite Solar Insolation Estimates

6.2.1 *Product*

Procedures for making estimates of solar insolation using cloud cover or percent cloudiness data consistent with satellite solar insolation estimates.

6.2.2 *Methodology*

During the period from about 1983 until when cloud cover measurements were discontinued, extend the work of Lindsey and Farnsworth (1994) and Thompson (1976) to get improved solar insolation estimates from historical cloud data before the satellite data existed.

6.3 Long Term Average PET Estimates for Mountainous Areas

6.3.1 *Product*

Procedures for estimating annual and seasonal (May-Oct) free water surface evaporation in mountainous areas that have much higher spatial resolution and better sensitivity to topography than the maps in the NOAA Evaporation Atlas.

6.3.2 *Methodology*

Develop evaporation-elevation relationships using the NOAA Evaporation Atlas and spatially averaged elevations from a digital terrain data. Apply these relationships to the high resolution terrain data to get high resolution evaporation estimates.

6.4 Digitized Wind Meta Data for Rest of U.S.

6.4.1 *Product*

ASCII wind sensor station history file, easy to read and interpret automatically

6.4.2 *Methodology*

Manually “decode” and transcribe NCDC Word Perfect station history file.

6.5 Historical NCEP PET Estimates

6.5.1 *Product*

Procedures to create time series of basin average PET estimates for input to NWSRFS that are consistent with the PET estimates used at NCEP.

6.5.2 *Methodology*

Develop a program to use SAO data and satellite solar insolation data to estimate the input variables required by NCEP’s PET procedures.

6.6 Climatology of NCEP PET Estimates

6.6.1 *Product*

Long-term climatological estimates of annual and seasonal PET that can be compared to PET estimates from the NOAA Evaporation Atlas.

6.6.2 *Methodology*

Use the program developed in activity 6.5 above, together with SAO and satellite data, to develop the NCEP PET climatology.

6.7 Future Applications of Evaporation Pan Data

6.7.1 *Product*

Procedures to use operational evaporation pan data to make operation estimates of PET.

6.7.2 *Methodology*

Estimate a transfer function (e.g. "pan coefficient") which may vary seasonally, using historical pan data and PET estimates, to convert pan evaporation measurements to PET estimates. Different transfer functions for the same evaporation pan could be developed for different PET estimation techniques.

6.8 Effect of different PET deriving methods and vegetation fraction adjustment.

6.8.1 *Product*

Comparative statistics and guidelines on use of different PET estimation techniques and NDVI data in streamflow simulations by the SAC-SMA model in different climatological regiongs.

6.8.2 *Methodology*

A number of river basins in different climatological regions will be selected to generate output time series from the SAC-SMA model using different PET inputs. Results of these simulations will be used to produce comparative statistics and graphics. Guidelines will be provided as to which PET methods and data interval (long-term or daily) should be used given climatology of the river basin and the type of vegetation.

7. Acknowledgments

This project plan was developed as an outgrowth of work done by the NOAA GCIP Core Project that was supported by NOAA's Office of Global Programs. Much of the work under this plan will be accomplished as part of the work of the GCIP Core Project.

8. References

Farnsworth, R K., E.S. Thompson, and E. L. Peck, 1982a, Evaporation Atlas for the Contiguous 48 United States, NOAA Technical Report NWS 33, U.S. Department of Commerce, NOAA/NWS, Washington D.C.

Farnsworth, R. K., E. S. Thompson, and E. L. Peck, 1982b, Mean Monthly, Seasonal, and Annual Pan Evaporation for the United States, NOAA Technical Report NWS 34. U.S. Department of Commerce, NOAA/NWS, Washington D.C.

Gutman, G, and A. Ignatov, 1997,. Derivation of green vegetation fraction from NOAA/AVHRR for use in numerical weather prediction models. Manuscript available from Garic Gutman at ggutman@nesdis.noaa.gov.

Lindsey, S. D., and R. K. Farnsworth, 1992, Use of daily potential evaporation in the National Weather Service River Forecast System. OH Technical Memorandum

Thompson, E. S., 1976, Computation of Solar Radiation from Sky Cover, Water Resour. Res., 12(5), pp859-865.

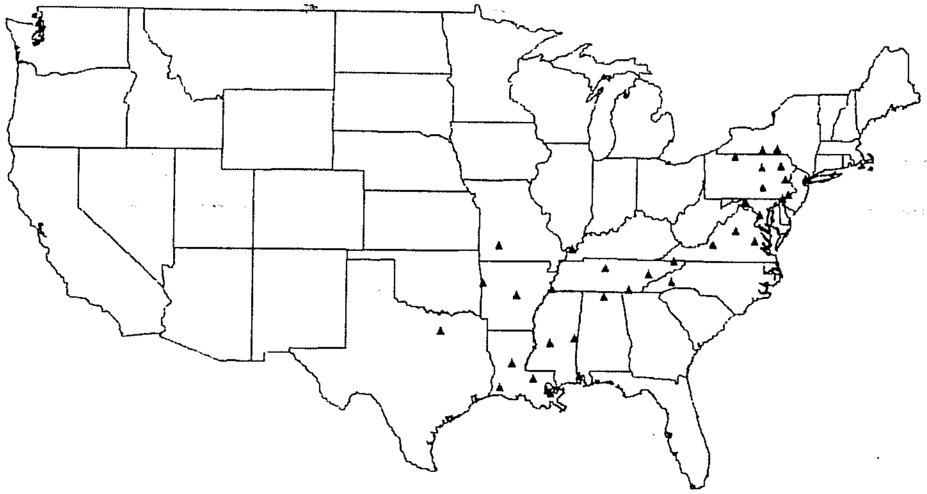


Figure 1 - LOCATIONS WHERE SYNTRAN PE ADJUSTMENT FACTORS HAVE BEEN ESTIMATED

Fig 2 - SYNTRAN PET Adjustment Factors

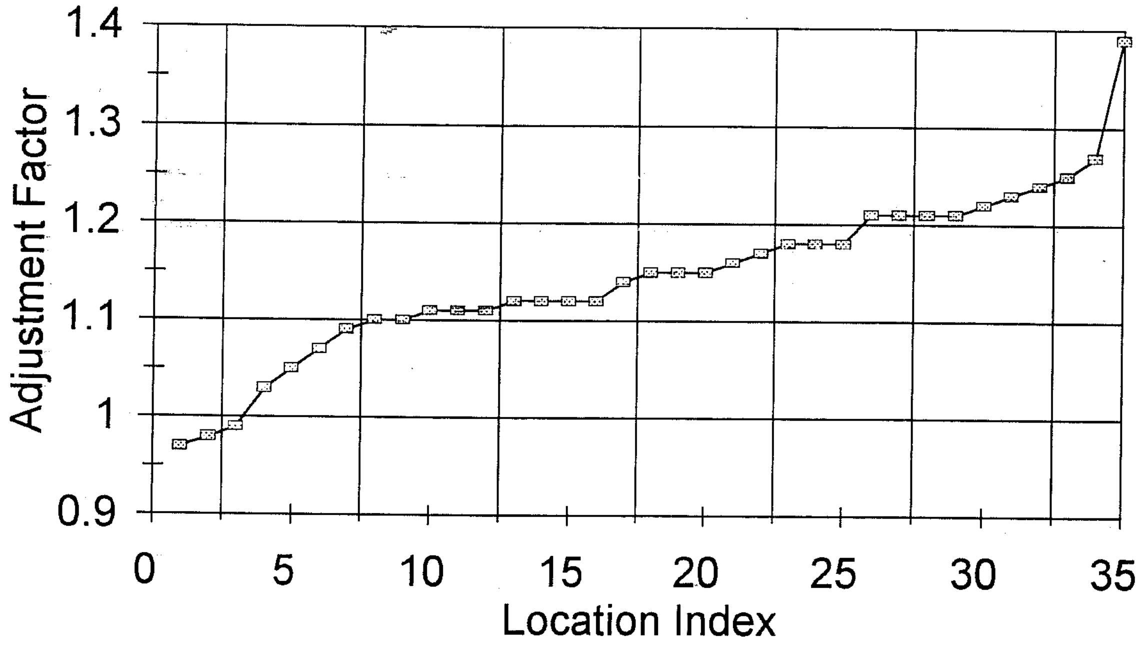


Figure 3 - Comparison of PET Estimate

FIFE Experiment - Manhattan, KS

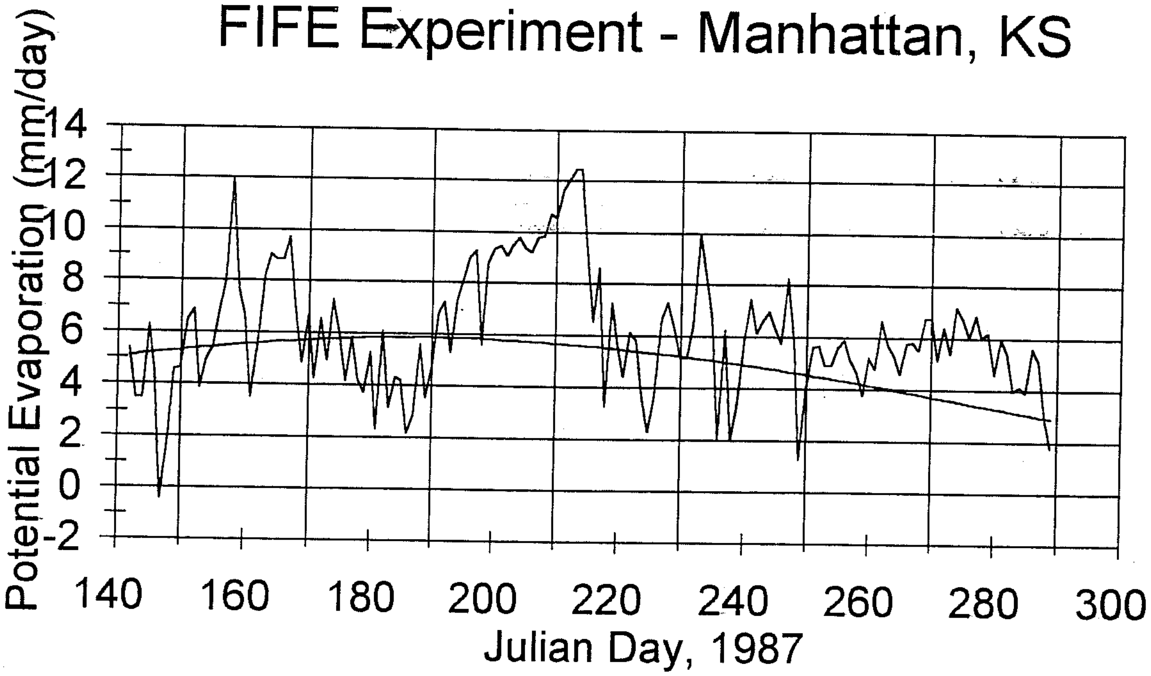
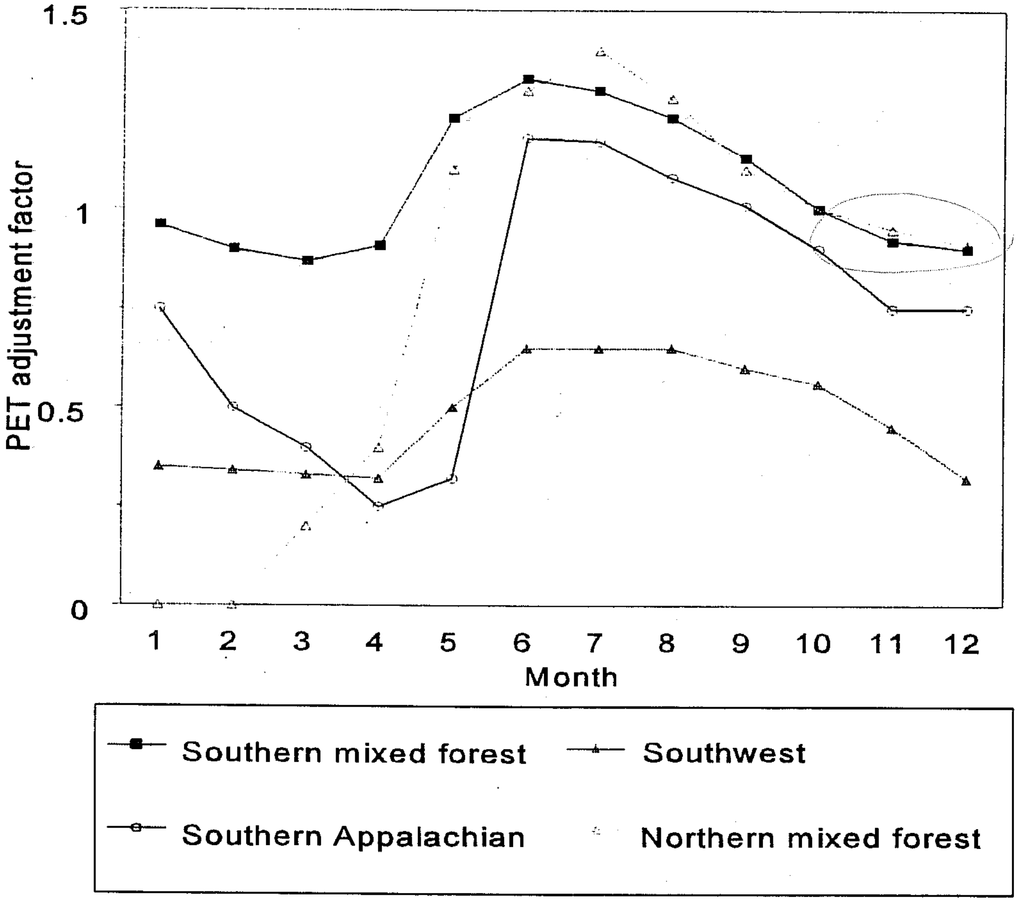


Figure 4 - SAC-SMA PET adjustment factor over four regions of the USA



?

Figure 5 - PET adjustment factor versus vegetation fraction over three regions of the USA