ERE445/645
HW#6
Due Thursday April 21st, 2016 by 5 pm

This assignment combines elements from many of the previous homework assignments. In this assignment, you are to develop a lumped parameter rainfall-runoff model for the West Branch of the Delaware River at Hale Eddy, NY. The procedure we will employ is discussed below, and is also outlined in Haith's (1987) GWLF model. This procedure uses the SCS curve number runoff technique to determine runoff, with snowpack, unsaturated zone, and saturated zone mass balances. Evapotranspiration is to be determined using Hamon's method with average monthly values for daylight hours. In this assignment, assume the following constants:

Baseflow Recession Coefficient = K_b = 0.924
Initial unsaturated storage is at field capacity = FCAP = 10 cm
Curve number for average moisture conditions = CN2 = 65
Initial antecedent moisture conditions = 0 (no rain or snowmelt in the previous 5 days)
Initial snow accumulation = 0
Initial saturated zone storage = 0.265 cm
No deep groundwater seepage

Further extensions and uses of this model are discussed in the following papers. You are only programming the hydrologic component of this model.

Haith, D.A. (1985). An Event-based Procedure for Estimating Monthly Sediment Yields, *Transactions of the ASAE,* 107(EE1), 121-137.

Haith, D.A., and Shoemaker, L.L. (1987). Generalized Watershed Loading Functions for Stream Flow Nutrients, *Water Resources Bulletin,* 23(3), 471-478.

Estimating Surface Runoff, Snow pack and Snowmelt

As in HW#5, you are to use the SCS runoff model with Haith's smoothed curve number approach to estimate the surface runoff, SR_t, on day t. The SCS runoff method is to employ an area-weighted curve number to estimate surface runoff. This model will be interfaced with a snow accumulation/snow melt model. In the SCS runoff model the precipitation term, P_t, is to be replaced by $R_t + M_t$, where R_t is the rain on day t and M_t is the snow melt on day t. In this model, we must keep track of the snow accumulation at the beginning of each day, SN_t, as well as the 5-day antecedent precipitation, $AM5_t = \Sigma(R_i + M_i)$, i = t-5 to t-1. R_t, M_t, and SN_t depend on both daily average temperature (T_t) and precipitation (P_t):

If $T_t \le 0$:	$SN_{t+1} = SN_t + P_t$	(cm)
	$R_t = 0$	(cm)
	$M_t = 0$	(cm)

If $T_t > 0$:	$R_t = P_t$	(cm)
	$M_t = \text{Minimum}\{SN_t, K\ T_t\}$	(cm)
	$SN_{t+1} = SN_t - M_t$	

K = constant = 0.45 (from B.A. Stewart, et al., 1975, Control of water pollution from cropland, volume 1, EPA-600/2-75-026a. U.S. EPA, Washington, D.C.)

If the $M_i > 0$ on any day (i.e. there is snow melt), then the curve number should be set to CN3 (wettest conditions). You are to estimate the curve number based on antecedent moisture conditions, and then estimate daily rainfall, snow, snow melt, snow pack, and runoff for each day.

Infiltration, Soil Moisture, Evapotranspiration and Percolation

This model accounts for unsaturated zone water storage. The model is:

$$UNSAT_{t+1} = UNSAT_t + I_t - ET_t - PERC_t$$

where:

$UNSAT_t$	=	Unsaturated zone storage at beginning of day t
I_t	=	Infiltration on day t
ET_t	=	Evapotranspiration on day t
$PERC_t$	=	Percolation on day t

The infiltration is estimated as the quantity of rain (R_t) and snowmelt (M_t) that is not surface runoff (SR_t):

$$I_t = R_t + M_t - SR_t$$

I_t includes interception, depression storage, and infiltrated waters. In homework 5 and 6, Hamon's method was employed to estimate the ***potential*** evapotranspiration (E_t).

$$E_t = 0.021\ N^2\ e_{st}/(T + 273) \qquad \text{if } T > 0$$
$$E_t = 0 \qquad \text{if } T \le 0$$

where

E_t	=	potential evapotranspiration (cm/day)
N	=	number of hours of daylight on day t
e_{st}	=	saturated water vapor pressue (mb) on day t
T	=	mean air temperature (°C) on day t

In practice the potential evapotranspiration is adjusted to account for the impact of crop water usage. This is accomplished by multiplying potential evapotranspiration by a crop cover coefficient (KU) to obtain an estimate of the actual evapotranspiration:

$$ET_t = \text{Minimum}(KU^*E_t, USAT_t)$$

The values of KU are in the following table (taken from Haith for upstate NY). Note that ET_t cannot exceed the amount of available unsaturated zone soil moisture at the beginning of the day.

Month	KU = Crop Cover Coef
October	0.97
November	0.72
December	0.61
January	0.78
February	0.82
March	0.82
April	0.79
May	0.89
June	0.91
July	0.93
August	0.98
September	1.03

Percolation only occurs when the field capacity of the unsaturated zone is exceeded. Thus we first calculate:

$$UNSAT_{t+1} = UNSAT_t + I_t - ET_t$$

and

If $UNSAT_{t+1} \leq 10 = FCAP$ $\quad PERC_t = 0$

If $UNSAT_{t+1} > 10$ $\quad PERC_t = UNSAT_{t+1} - FCAP = UNSAT_{t+1} - 10$
$\quad UNSAT_{t+1} = FCAP = 10$ cm

Thus UNSAT will always be in the range from 0 to 10 cm.

Groundwater Discharge

Percolated waters enter the saturated zone storage (SAT_t). In this model we are assuming there are no losses to a deep groundwater system, thus the only loss of water from the saturated zone is via discharge of baseflow to the stream. The baseflow discharge is estimated as a function of groundwater (saturated zone) storage at the end of the previous day:

$$SD_t = (1 - K_b)SAT_t$$

where: $\quad SD_t \quad = \quad$ Subsurface discharge to stream on day t

K_b	=	Baseflow recession constant
SAT_t	=	Saturated zone (groundwater) storage at beginning of day t

Thus the mass balance for the saturated zone is:

$$SAT_{t+1} = SAT_t + PERC_t - SD_t$$

Streamflow

The final estimated streamflow (Q_t) on day t is estimated as a combination of surface runoff and groundwater discharge:

$$Q_t = SR_t + SD_t$$

Deliverables

Using the model described above with a daily time step, you are run your model for the 1941 to 1960 water years. You are to submit the following:

a) The commented main script that was developed to create the model, as well as a script of functions employed by your main script.
b) Determine the Bias and Nash Sutcliffe Efficiency (NSE) for annual average daily streamflow and monthly average streamflows. Report these values.
c) Manually adjust the **CN2 and Kb values** to maximize the NSE of monthly average streamflows. Report the original and new CN2 values, as well as the new Bias and NSE for both annual average daily streamflow and monthly average streamflows.
d) A scatter plot containing the predicted (from parts a) and c)) and observed (from HW1) annual average daily streamflow versus water year.
e) A scatter plot of both predicted (from parts a) and c)) and observed (from HW3) average daily streamflow for each month averaged across the 20 years (the month should be on the x-axis).
f) A line plot with day on the x-axis and lines for observed daily streamflow and the predicted daily streamflow for parts a) and b) for the 1960 water year.