Problem Set 2
The Surface Water Balance

1. Sherlock Holmes surveyed the three suspects. "The guilty one," he said, "is the one from a region with lots of rivers – a region that produces plenty of runoff. You can tell that from the distinct bootprints left at the scene of the crime."

"None of the suspects will tell us anything," Watson said. "However, we do know this much from examining their personal effects – letters, telegrams, local newspapers, and so on." Watson handed Holmes a piece of paper. Here's what it said:

Suspect A's hometown: The Bowen ratio, computed from annually averaged latent and sensible heat fluxes, is 3. The annually-average net radiation is 160 W/m^2. The annually-average rainfall is 1.5 mm/day.

Suspect B's hometown: Budyko's dryness index, computed from annual mean precipitation and net radiation, is 0.3. The annual mean precipitation is 6 mm/day, and the Bowen ratio, again computed from the annual mean surface fluxes, is 1.

Suspect C's hometown: The total rainfall for the year is 550 mm. The latent heat flux from interception loss is 10 W/m^2 on average for the year, and the sum of transpiration and bare soil evaporation is 30 W/m^2 on average for the year. Snow does not fall here.

"Assuming that these numbers represent true climatological annual values," Holmes said, "we can ignore changes in storage in all of our balance calculations. Therefore, only one suspect lives in a place with high runoff. That suspect is…" Who? (Quantify the climatological runoff in each suspect's hometown.)

2. In a simple soil column model, suppose you represent the hydraulic conductive K with the equation

$$K(w) = K_s w^{(2b+3)},$$

soil moisture potential ψ with the equation

$$\psi(w) = \psi_s w^{-b},$$

and the downward moisture flux q between soil layers 1 (top) and 2 (bottom) with the equation

$$q = K_{layer\ 1} [1 + (\psi_{layer\ 1} - \psi_{layer\ 2})/d],$$

where K_s is the hydraulic conductivity for a saturated soil, ψ_s is the soil moisture potential for a saturated soil, d is the distance over which the flux occurs (i.e., the effective depth for determining the ψ gradient) and w is the degree of saturation (i.e., the water content of a soil layer divided by the maximum possible soil moisture content). The value of d for your model is 0.5m

a. You know that the average value of w in soil layer 1 is 1.0 and that the average value of w in soil layer 2 is 0.9. Using the table of values below, compute q for a sandy loam.

b. Now compute q for a silty clay. What percent of the flux from (a) does this represent?

c. Now assume that w in soil layer a is 0.5, and w in soil layer 2 is 0.4. (Note that the difference in w remains the same.) Recompute q for a silty clay. What percent of the flux from (a) does this represent?

d. Given that we don't often know exactly what the soil type is in a region and that we don't model the soil moisture (w) with precision, what do these results say about the reliability of computed subsurface flow?

3. a. The annually-averaged precipitation in a region is 2 mm/day, and the annually-averaged net radiation is 120 W/m^2. If you know nothing else, but you do have access to the Budyko equation, what would you estimate the annually-averaged evaporation rate to be?

b. What is your associated estimate of annually-averaged runoff?

c. Suppose that because of global climate change, the annually-averaged precipitation in the region increases by 0.1 mm/day, while the net radiation stays the same. By how much does your estimate of annually-averaged evaporation change?

d. By how much does your estimate of annually-averaged runoff change?

e. The fraction E/P of the total precipitation goes into evaporation. How does this fraction compare with the fraction of the precipitation increment that goes into evaporation ($\Delta E/\Delta P$)? That is, is the incremental rainfall partitioned in the same way as the original climatological rainfall?

f. Finally, someone gives you some additional information. Now, you learn that the seasonal cycles of net radiation and precipitation are exactly in phase. That is, both cycles are roughly sinusoidal, the maxima of the two cycles occur in the same month, and the minima of both cycles occur at the same time, 6 months later. Would you expect the evaporation to be greater than, the same as, or less than the original estimate you computed with the Budyko equation?