CEE6400 Physical Hydrology

Homework 1. Hydrologic data, conservation Laws and Reservoir Yield

Date: 8/29/16
Due: 9/12/16

Objective. The objective of this homework is to gain experience working with hydrologic data, quantifying uncertainty variability and pattern.

General guidance. Whenever you hand in a homework which involves program codes and/or spreadsheet work, you need to describe your work briefly using text that explains what you did. For example you might write. The daily flow was downloaded from web site …. Then Excel was used to compute …, using the formula …. The result is …. If you give a computer program it is helpful to include comment statements and descriptive variable names.

1) Dingman ch 1 problem 2 (i) to (iv) only.

(When this question mentions section A.3 refer to section A.4 in Dingman 2nd edition if you need to. Look for conversion factors online or on the inner cover of Dingman 2nd edition)

2. The following equations are taken from the hydrologic literature. The units in which the equation quantities were originally measured are given as the "old" units. In this exercise, we want to convert the equations to use with a "new" set of units, using the steps below. "[1]" designates a dimensionless quantity. Conversion factors can be found in table A.2.
   a. Check each equation for dimensional and unitary homogeneity.
   b. For equations that are not homogeneous, change the appropriate constants so that the equation is correct when using the new units as described in section A.3.
   c. The modified equation should be in exactly the same form as the original, with only the appropriate constant values changed. The constants should have the same number of significant figures as in the original.
   d. Check your results by substituting values as described in section A.3.

i. $I = 0.00042 \cdot H + 0.00026 \cdot H \cdot P$

Symbol	Definition	Old Units	New Units
I	interception	mm	in
H	height of grass	mm	in
P	precipitation	mm	in

ii. $B = 0.00061 \cdot p \cdot \frac{(T_s - T_a)}{(e_s - e_a)}$

Symbol	Definition	Old Units	New Units
B	Bowen ratio	[1]	[1]
p	atmospheric pressure	mm	in Hg
T_s	surface temperature	°C	°F
T_a	air temperature	°C	°F
e_s	surface vapor pressure	mb	in Hg
e_a	air vapor pressure	mb	in Hg

iii. $R_n = 0.83 \cdot K_{in} - 54$

Symbol	Definition	Old Units	New Units
R_n	net radiation	cal/cm^2 · d	W/m^2
K_{in}	incident solar radiation	cal/cm · d	W/m^2

iv. $E = \frac{3.64}{T_a} \cdot \frac{u_a}{\left[\ln\left(\frac{z_m}{z_0}\right)\right]^2} \cdot \left(e_a^* - e_a\right)$

Symbol	Definition	Old Units	New Units
E	evaporation rate	cm/d	mm/d
T_a	air temperature	K	°C
u_a	wind speed	km/d	m/s
z_m	measurement height	cm	m
z_0	roughness height	cm	m
e_a^*	saturation vapor pressure	mb	kPa
e_a	actual vapor pressure	mb	kPa

2) Refer to Figure 2.20 and Tables 2.5 and 2.6.

   a) Calculate the average residence time of water in the land phase of the hydrologic cycle.

   b) Assume that surface flow in Figure 2.20 is the flux through rivers and lakes, and calculate the average residence time in rivers and lakes.

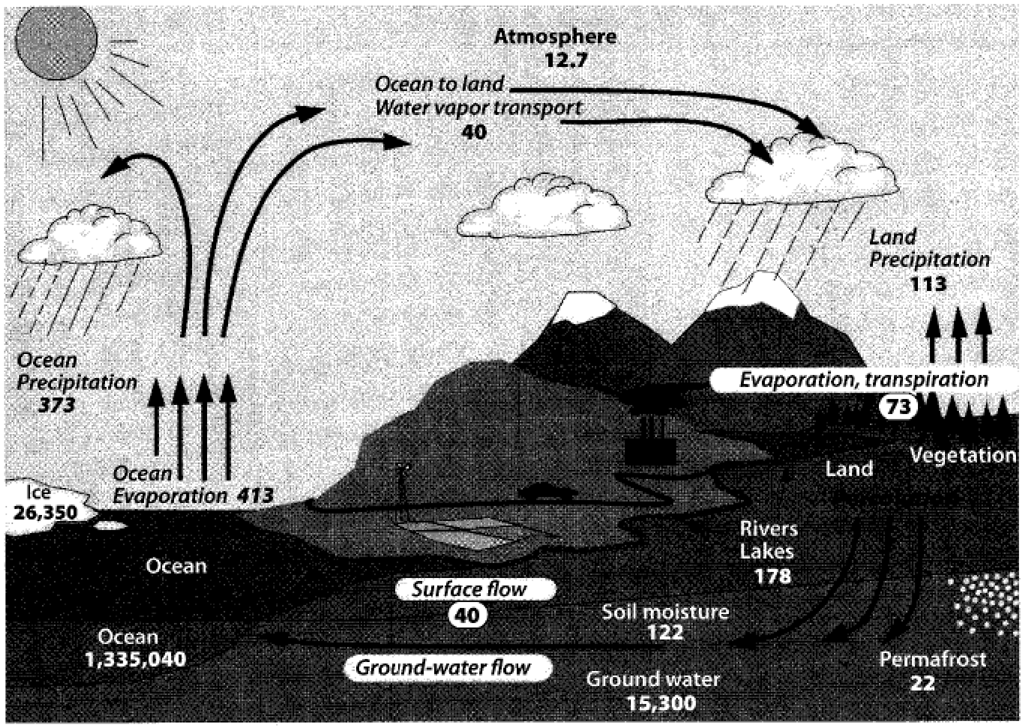

Figure 2.20 The global hydrologic cycle. The volume (10^3 km^3) of water found in each main type of global reservoir is shown; the rates (10^3 km/yr) of flow through the system for annual fluxes are italicized [Trenberth et al. (2007). Estimates of the global water budget and its annual cycle using observational and model data. *Journal of Hydrometeorology* 8:758–769, reproduced with permission of American Meteorological Society].

Table 2.5 Major Global Water Stocks.

Global Stock	Area (km^2)	Volume (km^3)	Percent of Total Water[5]
Oceans	361,300,000[1]	1,335,040,000[2]	96.95
Ground water	134,800,000[1]	15,300,000[2]	1.11
Soil moisture	82,000,000[1]	122,000[2]	0.0089
Glaciers and permanent snow	16,227,500[1]	26,350,000[2]	1.91
Antarctica	13,980,000[1]	21,600,000[1]	
Greenland	1,802,400[1]	2,340,000[1]	
Arctic islands	226,100[1]	83,500[1]	
Mountains	224,000[1]	40,600[1]	
Permafrost	14,600,000[3]	23,100[4]	0.0017
Rivers and lakes	150,858,700[1]	178,000[2]	0.013
Fresh lakes	1,236,400[1]	91,000[1]	
Salt lakes	822,300[1]	85,400[1]	
Rivers	148,800,000[1]	2,120[1]	
Marshes	2,682,600[1]	11,470[1]	
Biologic water	510,000,000[1]	1,120[1]	0.00008
Atmosphere	510,000,000[1]	12,700[2]	0.00092
Total	510,000,000[1]	1,377,387,000[5]	

[1] Data from Shiklomanov and Sokolov (1983).
[2] Updated values from Trenberth et al. (2007).
[3] Center of range (12,210,000 to 16,980,000 km^2) given by Zhang et al. (2000).
[4] Center of range (10,800 to 35,460 km^3) given by Zhang et al. (2000).
[5] Based on Trenberth et al. (2007) estimates.

Table 2.6 Stocks and Annual Fluxes for Major Compartments of the Global Hydrologic Cycle.

Stock	Volume (10^6 km^3)	Sources	Input Flux (10^3 km^3/yr)	Sinks	Output Flux (10^3 km^3/yr)
Oceans	1,335	Precipitation	373	Evaporation	413
		Runoff	40		
Atmosphere	0.0127	Land evapotranspiration	73	Land precipitation	113
		Ocean evaporation	413	Ocean precipitation	373
Land	42.1	Land precipitation	113	Land evapotranspiration	73
				Runoff	40
Total	1,377				

Source: Data from Trenberth et al. (2002).

3) Dingman ch 1 problem 7.

7. The table below gives the drainage area, average precipitation (determined from measurements at meteorological stations), and average streamflow (measured near the mouths) of four large rivers.

Watershed	Area, A (km^2)	Average Precipitation, P (mm/yr)	Relative Error, ε_P (%)	Average Streamflow, Q (m^3/s)	Relative Error, ε_Q (%)
Connecticut River, USA	20,370	1,100	10	386	5
Yukon River, Canada & USA	932,400	570	20	5,100	10
Euphrates River, Iraq	261,100	300	10	911	10
Mekong River, Thailand	663,000	1,460	15	13,200	5

a. Using equation (1.21) and assuming no ground-water inputs or outputs, use this information to compute the estimated long-term average evapotranspiration, ET, for each watershed.

b. How well do your calculated ET values conform to those shown for the same watersheds on figure 2.27?

c. Use the information in the table, equations (1.36) and (1.40), and example 1B1.6 to compute the 95% absolute and relative uncertainties in your ET estimates.

$$\mu_{ET} = \mu_P - \mu_Q. \qquad \textbf{(1.21)}$$

This is equivalent to Dingman 2nd edition 2-16 to see the text explanation.

The approach to measurement errors is described in Dingman 2nd edition pages13 to 17.

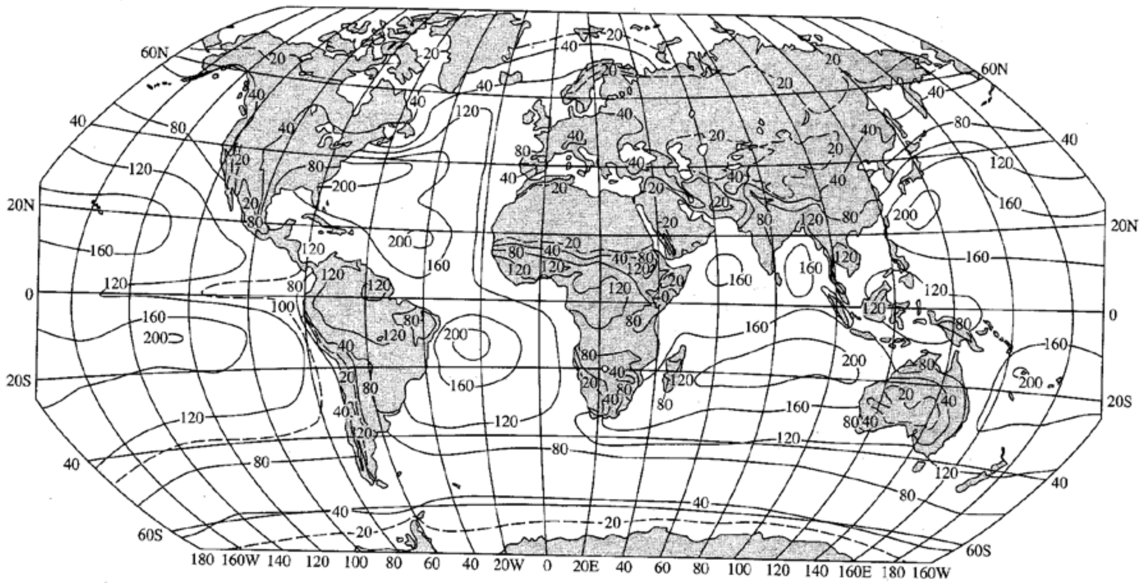

Figure 2.27 Global distribution of average oceanic evaporation and continental evapotranspiration (cm/yr) [Peixoto and Oort (1992). *Physics of Climate*. New York: American Institute of Physics. With kind permission of Springer Science+Business Media].

Identify a USGS streamflow gauging station of interest from http://waterdata.usgs.gov, that meets the criteria that you can delineate the watershed using streamstats (Dingman Ch 1, problem 6) and that has at least 20 years of record current until the end of the 2015 water year (Sept 2015). This may take a bit of hunting around.

4) Dingman ch 1 problem 6 for the stream gauge you identified.

6. Section 1.7.2.2 describes the USGS StreamStats (http://water.usgs.gov/osw/streamstats) application that delineates watersheds for user-selected basin outlets and provides data on watershed characteristics and streamflow statistics.

   a. Access this program and select a state for which the application is "fully implemented."

   b. Under "Interactive map," click on "General information" and review the list of basin characteristics provided.

   c. Return to the previous page and click on "Interactive map." Set the map scale at 1:24,000.

   d. Use the "Navigation" tool to locate the outlet of a watershed (e.g., where a stream enters a larger stream or a lake).

   e. Using the "Watershed delineation from a point" tool (●+), click on the outlet and wait until the application delineates the watershed.

   f. Click on the "Basin characteristics" tool (to the right of the delineation tool) to get information on watershed area, etc.

5) Download daily data for a period of 20 years or more for the stream gauge you selected. Prepare a time series plot of the data you downloaded. The USGS has developed a tool

dataRetrieval for retrieval of data directly into R that simplifies data retrieval and analysis (if you know R). I encourage you to learn R and to experiment with this tool. See

a) R bare essentials http://hydrology.usu.edu/dtarb/cee6400/RBareEssentials.html

b) dataRetrieval https://github.com/USGS-R/dataRetrieval/

6) For the series plotted in the question above compute the average annual flow, peak flow and annual seven day minimum flow. Plot your results similar to figure 1.16.

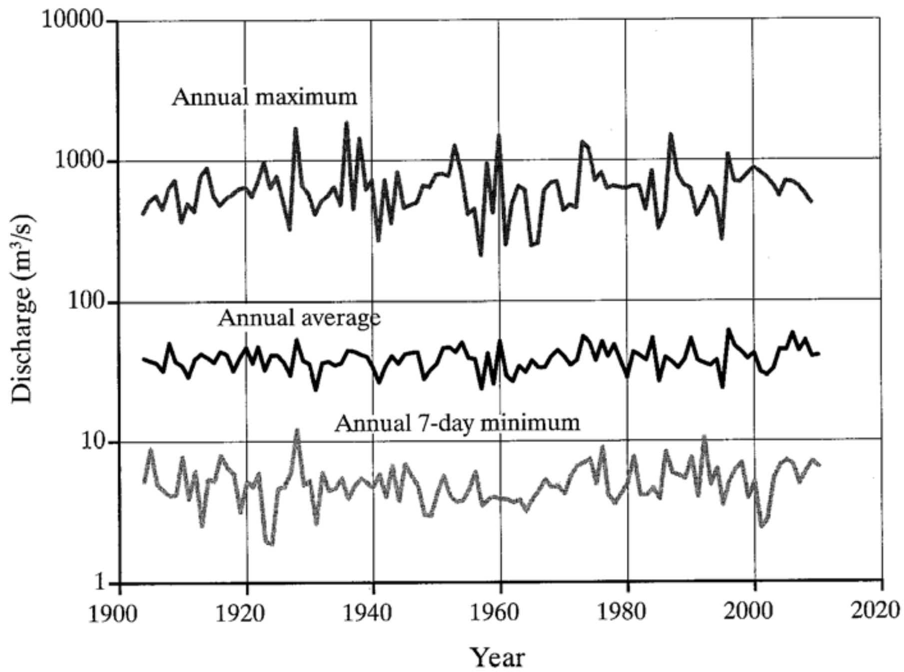

Figure 1.16 Traces of the annual maximum daily streamflow, annual average daily streamflow, and annual minimum 7-day average streamflow for the Pemigewasset River, New Hampshire.

7) Plot the flow duration curve (like Figure 1.17) for the daily streamflow at the gauging station you selected. associated with each daily flow value for the data from problem 3. Report the daily flow that has a 90% probability of being exceeded.

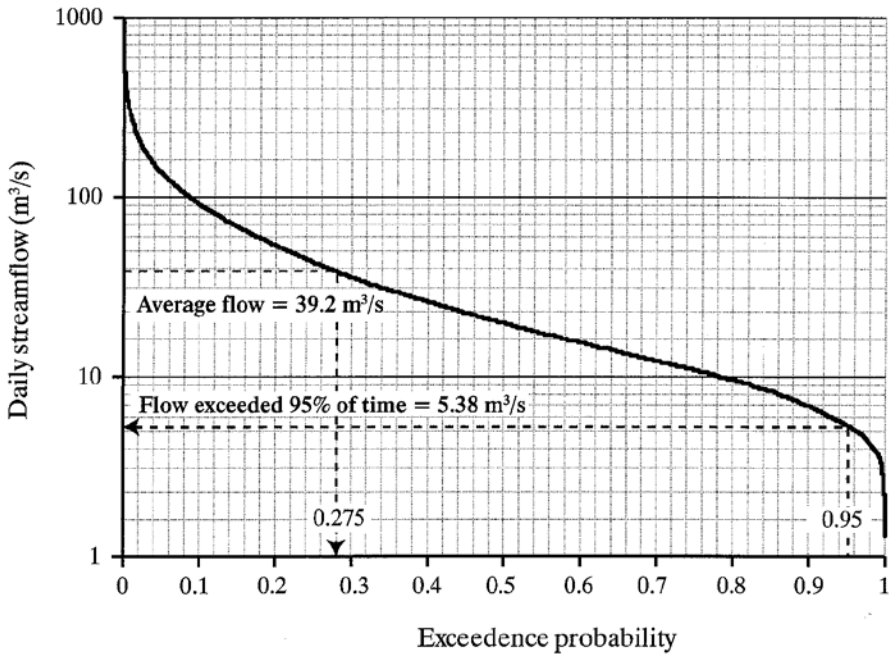

Figure 1.17 Flow-duration curve for the Pemigewasset River, New Hampshire. Note that the average flow, 39.2 m^3/s, is exceeded only 27.5% of the time. The flow that is available 95% of the time is 5.38 m^3/s, so the "available water resource" for this watershed is only about 14% of the average flow.

Refer to Dingman 2nd edition appendix C, Box C-1 for formulae to calculate exceedence probability (frequency).

8) Monthly mean streamflow is defined as the average of streamflow within each specific month (e.g. average of daily flows in August 2012). The mean of monthly streamflows is defined as the average of monthly mean streamflow across all years for a particular month. For the data obtained at your selected gauge, compute the monthly mean streamflow and then the mean of monthly streamflows. Plot a graph of the mean of monthly streamflows. This provides an indication of the seasonality associated with the hydrologic cycle.