Names: **ESS 315**

Lab #6, Floods and Runoff

Part I –Flood frequency

A **flood** is any relatively high flow of water over land that is not normally under water. Floods occur at streams and rivers but can also be caused by high rainfall or snowmelt as well as high tides along seashores, high groundwater levels, dam failures, and high water levels in lakes. Floods happen naturally in rivers as a response to hydrologic, meteorologic and topographic factors. Dams, levees, channelizing rivers, development of agricultural, urban, and suburban areas, and deforestation also effect floods.

In this section of the lab you will become familiar with the nature of river floods, the problems that are created by flooding, and potential solutions.

Discharge is defined as the rate of stream flow at a given instant in terms of volume per unit time at a given location. Discharge can be calculated from the equation:

$$Q = A * V$$

where Q= discharge (in cubic feet per second, *cfs*, or m^3/s)
A = cross-sectional area of the wetted channel (width of the channel at a given location multiplied by the depth of the water at that location)
V= velocity of the flow (in ft/s or m/s)

Flood frequency (the average occurrence of flooding of a given magnitude, over a period of years) is based on the maximum discharge for the year at a given point. Recurrence intervals or return periods are generally used to characterize flood frequency. A recurrence interval is the average time interval (in years) between the occurrence of two floods with the same water level. It can be calculated from the equation:

$$T = \frac{(n+1)}{m}$$

where T = Recurrence Interval (years)
n = the number of years of record
m = is the order of the annual flood discharges from the greatest (1), to the smallest for the number of years of record

One way to view flood data is to plot it on a flood frequency graph with discharge plotted on the vertical axis and recurrence interval on the horizontal axis. Drawing a best fit line allows you to extrapolate the average number of years that will pass until a given magnitude flood occurs again. The longer the number of years of flood records, the more likely it is that floods with extremely large discharges have been recorded. The annual probability of exceedence is calculated from the recurrence interval as:

$$P = \frac{1}{T}.$$

P is the likelihood that in a single year the annual maximum flood will equal or exceed a given discharge. This means that a flood with a recurrence interval of 10 years has a 10% chance of occurring in any year while a 100 year flood has the probability of occurring 1% chance of occurring in any year.

Flood Frequency in the Seattle/Tacoma Area

The data below are slightly modified from U.S. Geological Survey information. During lab, the TA will assign you to calculate flood frequency using just one of the four data sets.

Mercer Creek Data Set 1				**Mercer Creek Data Set 2**			
Year	**Peak Flood Discharge (cfs)**	**Rank**	**Recurrence Interval**	**Year**	**Peak Flood Discharge (cfs)**	**Rank**	**Recurrence Interval**
1957	180			1979	518		
1958	238			1980	414		
1959	220			1981	670		
1960	210			1982	612		
1961	192			1983	404		
1962	168			1984	353		
1963	150			1985	832		
1964	224			1986	504		
1965	193			1987	331		
1966	187			1988	228		
1967	254			1989	664		

Green River Data Set 1				**Green River Data Set 2**			
Year	**Peak Flood Discharge (cfs)**	**Rank**	**Recurrence Interval**	**Year**	**Peak Flood Discharge (cfs)**	**Rank**	**Recurrence Interval**
1941	9310			1976	4490		
1942	10900			1977	9920		
1943	12900			1978	6450		
1944	13600			1979	8730		
1945	12800			1980	5200		
1946	22000			1981	9300		
1947	9990			1982	10800		
1948	6420			1983	9140		
1949	9810			1984	10900		
1950	11800			1985	7030		
1951	18400			1986	11800		

Use your data set to estimate the likely discharge for a 100-year flood by following these steps:

1.) Rank the peak flood discharges for the data set in order of magnitude. Start with 1 for the largest and end with 11 for the smallest.

2.) Use the formula for recurrence interval given above to determine the recurrence interval for each of the 11 floods.

3.) Plot the discharge and recurrence interval for each of your 11 floods on the provided piece of semi-logarithmic graph paper with discharge plotted on the vertical axis and recurrence interval on the horizontal axis. Place the paper so that the logarithmic scale is on the horizontal axis.

4.) Draw a best-fit straight line on your graph that extends to the right hand side of the graph.

Questions:

What is the predicted discharge (in cfs) for a 100-year flood based on your data?

Compare this discharge with the other group working on the other set of data for the same river. How does your prediction of 100 year flood discharge compare with the answer that they got?

What possible human activities in the watershed could have caused the difference in predicted floods that result from the two sets of data?

After you finish your interpretation your stream, talk to a group that worked on a different river. How do their data compare to yours? What human activities did they suggest for the changes in flood predictions they discovered?

Based on the flood predictions for all four data sets, what does the contrast in predicted flood discharges imply about the usefulness of the 100-year flood as a legal designation for these two streams?

Part II: Runoff prediction

When it rains, some of the water infiltrates the ground and soils, where it can be used by plants or recharge the groundwater system. When precipitation rates exceed the soil's capacity to absorb water (the infiltration rate), the remaining water flows along the ground surface as "runoff." Urbanization greatly increases the proportion of impermable ground surfaces (parking lots, roads, buildings), and thus can change surface water (i.e., stream) discharge patterns.

The purpose of this exercise is to introduce you to two commonly used methods of predicting changes in precipitation runoff caused by urbanization. You will use the **Rational Runoff** and the **Soil Conservation Service (SCS)** methods to calculate: 1) discharge rates under existing conditions, and 2) predicted discharge rates once the basin has been developed.

The Situation

Assume that you are planning a residential development in an area of northern King County, near Duvall. The drainage basin encompasses approximately **100 acres** of gently rolling (3-5% slopes) farm land (mostly **pastures**). The maximum length of the catchment is 10,000 feet. The current soil survey map shows that the catchment is underlain entirely by "Alderwood soils," which represent the single most common soil in the Puget Lowland (see attached description).

Your proposal calls for constructing **60** single-family dwellings within the drainage basin, each on **half-acre** lots. The remainder of the basin is to be left in agriculture. Downstream of the proposed development is a community with facilities (i.e. storm drain network, holding ponds, etc.) designed to accommodate floods up to the 100-year event. Your question: will present facilities be overwhelmed if another 100-year event occurs after development?

Method 1: The ***Rational runoff formula***

$$Q=CIA$$

where Q = discharge (cubic feet per second (cfs))
C = rational runoff coefficient, from Table 1
I = rainfall intensity (inches per hour)
A = area of catchment (acres)

To use the rational runoff formula, we must know what storm duration produces an equivalent recurrence of flooding. The rational runoff formula assumes that the maximum travel time for runoff in the basin (the **time of concentration**) is the correct duration of storm to evaluate. Assume that the time of concentration for your basin is 30 minutes. Looking in a U.S. Weather Service table, you see that the 100-year 30-minute rainfall intensity is **1.25 inches/hour**. From the description of Alderwood soils, determine what the Rational Runoff Coefficient should be from the Rational Runoff Coefficient Table (Table 1).

Using the rational runoff formula (Q=CIA), calculate the peak runoff rate expected from this design rainfall. Watch your units (feet, inches, acres, etc.)! HANDY TIP: 1 inch per hour from one acre ~ 1 cfs

a.) from the undisturbed basin

b.) from the same basin after development

c.) what assumptions of the method are your calculations based on?

d.) How good are these assumptions?

Method 2: SCS method

Steps for using the SCS method (the required map, chart, and tables are provided):

1. Use the **Classification of Soil Type Table (TABLE 2)** to determine the soil classification (A, B, C, or D).

2. Use the **Western Washington Runoff Curve Numbers Table (TABLE 3)** to look up the curve number for the pre-development land use.

3. The curve number that you determined for step 2 should be considered "normal" soil conditions and corresponds to Antecedent Moisture Condition (AMC) II. Use the **AMC Table (TABLE 4)** to estimate curve numbers for dry and wet soil conditions as well. For example, if the curve number for AMC II is 60, it will be 40 for AMC I and 78 for AMC III. You may need to interpolate.

4. Locate your site on the laminated **100-year, 24-hour Precipitation Maps**, and determine the 100-year 24-hour precipitation amount.

5. Plot each of the three curve numbers against the 24-hour precipitation on the **Curve Number Chart**. This will give you the storm runoff (in inches) for each of these conditions.

6. Use the following equation to find the *average* discharge (Q); express the result in cubic feet per second (watch your units!):

$$Q = \frac{Storm\ runoff\ x\ site\ area}{storm\ duration}$$

Write your discharge here: __________________

Now, use the SCS method to predict the ***volume*** of runoff from the same basin under 100-year storm conditions. In this region of the country, it has been observed that the best correlation between rainfall recurrence interval and flood recurrence interval occurs at about the 24-hour storm duration. Therefore, you should always use the 24-hour rainfall totals with the SCS method. Note that to calculate ***peaks***, you would need a simulated distribution of rainfall.

Using the SCS method and a 24-hour, 100-yr storm, calculate the runoff volume:

a.) for the site before development

b.) for the site after development

c.) Discuss the differences between these values and those obtained using the rational runoff method.

d.) Briefly, what could be done to minimize the effects of the proposed development?

ALDERWOOD ASSOCIATION SOIL DESCRIPTION

Moderately well drained, undulating to hilly soils that have dense, very slow permeable glacial till at a depth of 20-40 inches; found on uplands and terraces.

Alderwood soils are moderately well drained gravelly sandy **loams** that are 24-40 inches deep over consolidated glacial till. They have convex slopes that are dominantly 0-30% but range to as much as 70%. Slopes of more than 15% are generally no more than 200 feet long.

The soils of this association are well suited to pasture and timber production but are poorly suited to cultivated crops. Urban development is occurring rapidly. Limitations for homesites are moderate and slight on most of this association but are severe on Kitsap soils.

The Alderwood series formed under conifers, in glacial deposits. The annual precipitation is 30-60 inches, most of which is rainfall between October and May. The mean annual air temperature is about 50^{o} F. The frost-free season is 150-200 days. Elevation ranges from 100-800 feet.

In a representative profile, the surface layer and subsoil are very dark brown, dark-brown, and grayish-brown gravelly sandy loam about 27 inches thick. The substratum is grayish-brown, weakly consolidated to strongly consolidated glacial till that extends to a depth of 60 inches or more.

Alderwood soils are used for timber, pasture, berries, row crops, and urban development. They are the most extensive soils in the survey area.

Permeability is moderately rapid in the surface layer and subsoil and very slow in the substratum. Roots penetrate easily to the consolidated substratum where they tend to mat on the surface. Some roots enter the substratum through cracks. Water moves on top of the substratum in winter. Available water capacity is low. Runoff is slow to medium, and the hazard of erosion is moderate.

TABLE 1: Rational Runoff Coefficient, C

URBAN AREAS	C
Streets: asphalt	0.70-0.95
concrete	0.80-0.95
brick	0.70-0.85
Drives and walks	0.75-0.85
Roofs	0.75-0.95
Lawns: sandy soil, gradient ≤ 2 %	0.05-0.10
sandy soil, gradient ≥ 7 %	0.15-0.20
heavy soil, gradient ≤ 2 %	0.13-0.17
heavy soil, gradient ≥ 7%	0.25-0.35
The values listed above can be used, together with areas of each type of surface measured from a map or aerial photograph, to compute weighted average values of *C*. Alternatively, the following overall values apply to most North American urban areas.	
Business areas: high-value districts	0.75-0.95
neighborhood districts	0.50-0.70
Residential areas: single-family dwellings	0.30-0.50
multiple-family dwellings, detached	0.40-0.60
multiple-family dwellings, attached	0.60-0.75
suburban	0.25-0.40
apartment buildings	0.50-0.70
Industrial areas: light	0.50-0.80
heavy	0.60-0.90
Parks and cemeteries	0.10-0.25
Playgrounds	0.20-0.35
Unimproved land	0.10-0.30
RURAL AREAS	
Sandy and gravelly soils: cultivated	0.20
pasture	0.15
woodland	0.10
Loams and similar soils without impeding horizons: cultivated	0.40
pasture	0.35
woodland	0.10
Heavy clay soils or those with a shallow impeding horizon:	0.50
shallow soils over bed rock: cultivated	
pasture	0.45
woodland	0.40

TABLE 2: Classification of Soil Types

CLASSIFICATION	TYPE OF SOIL
A (low runoff potential)	Soils with high infiltration capacities, even when thoroughly wetted. Chiefly sands and gravels, deep and well drained.
B	Soils with moderate infiltration rates when thoroughly wetted. Moderately deep to deep, moderately well to well drained, with moderately fine to moderately coarse textures.
C	Soils with slow infiltration rates when thoroughly wetted. Usually have a layer that impedes vertical drainage, or have a moderately fine to fine texture.
D (high runoff potential)	Soils with very slow infiltration rates when thoroughly wetted. Chiefly clays with a high swelling potential; soils with a high permanent water table; soils with a clay layer at or near the surface; shallow soils over nearly impervious materials.

TABLE 3: Western Washington Runoff Curve Numbers

LAND USE DESCRIPTION		HYDROLOGIC SOIL GROUP			
		A	B	C	D
Cultivated land- winter condition		86	91	94	95
Mountain open areas- low growing brush and grasslands		74	82	89	92
Meadow or pasture		65	78	85	89
Wood or forest land- undisturbed		42	64	76	81
Wood or forest land- young second growth or brush		55	72	81	86
Orchard- with cover crop		81	88	92	94
Open spaces, lawns, parks, golf courses, cemeteries, etc.					
good condition- grass cover on 75 % or more		68	80	86	90
fair condition- grass cover on 50-75 %		77	85	90	92
Gravel roads and parking lots		76	85	89	91
Dirt roads and parking lots		72	82	87	89
Impervious surfaces, pavement, roofs, etc.		98	98	98	98
Open water bodies- lakes, wetlands, ponds, etc.		100	100	100	100
Residential					
Average lot size	Average % Impervious				
1/8 acre or less	65				
¼ acre	38				
1/3 acre	30				
½ acre	25	78	83	89	94
1 acre	20				

TABLE 4: Antecedent Moisture Condition

CN For Antecedent Moisture Condition I	*CN* For Antecedent Moisture Condition II	*CN* For Antecedent Moisture Condition III
100	100	100
87	95	98
78	90	96
70	85	94
63	80	91
56	75	88
51	70	85
45	65	82
40	60	78
35	55	74
31	50	70
26	45	65
22	40	60
18	35	55
15	30	50
12	25	43
9	20	37
6	15	30
4	10	22
2	5	13

For the purposes of this lab we will assume an antecedent moisture condition II. Ordinarily we would determine the correct antecedent moisture condition by finding out the 5-day rainfall total and using the following table

Antecedent Moisture Condition Class	5-Day Total Antecedent Rainfall (Inches)	
	Dormant Season	Growing Season
I	Less than 0.5	Less than 1.4
II	0.5-1.1	1.4-2.1
III	Over 1.1	Over 2.1

Runoff Curve Number Chart