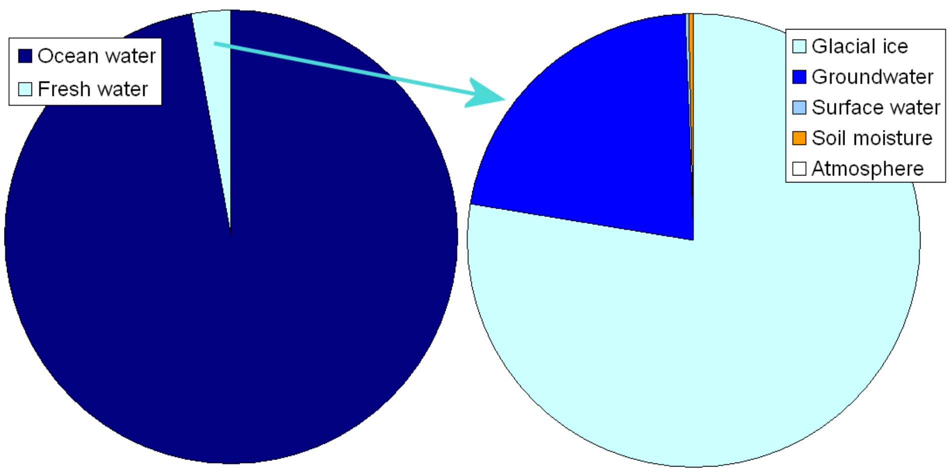
GEOL-304

Surface hydrology and its relationship to hydrogeology

Hydrology is the study of water in general, while hydrogeology is the study of the physical and chemical interactions of water, especially groundwater, with geological materials (rock and unconsolidated sediments). Most hydrology courses are generally limited to surface water. While this course is hydrogeology, there are a few aspects of surface hydrology that we need to review before we get deeper into hydrogeology. One of those is the important relationships between surface water (e.g., precipitation, streams, lakes, etc.) and groundwater.

Water on the earth

Over 97% of the earth's water is salty ocean water. Most of the rest is glacial ice. Surface and groundwater make up about 0.62% of the water on the earth, and the vast majority of this is groundwater—water that exists within pores and cracks from the surface down to a depth of 4000 m.



Proportions of the earth's water in the various reservoirs. Most freshwater is stored as ice, while most liquid freshwater is groundwater.

Although only 0.001% of the earth's water supply is in the atmosphere at any moment, this does not give a realistic representation of the importance of atmospheric water because of the rapid rate of transfer of water through the atmosphere. Each year about 505,000 km^3 of water is evaporated into the atmosphere, and the same volume is precipitated from the atmosphere as rain and snow. This is almost 3 times the total volume of water stored in rivers, lakes and the soil at any one time.

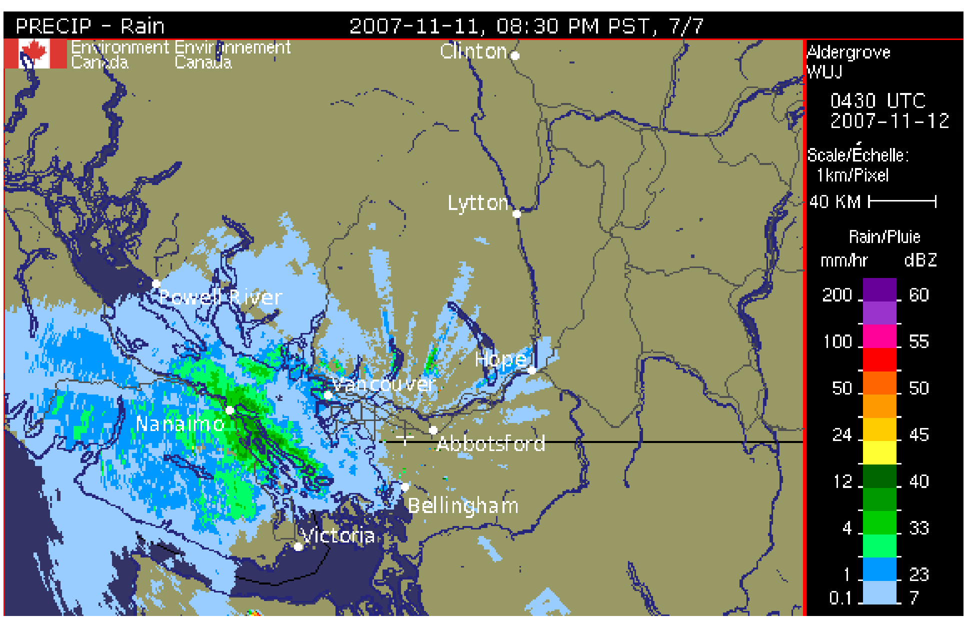
The hydrological cycle - precipitation and runoff

Some of the components of the hydrological cycle are shown on Figure 2.10 in Fetter. Water that flows on the surface is known as **overland flow**. Water that percolates essentially vertically down into the soil is known as **infiltration**. Water that flows along some permeability boundary within the soil or between the soil and the bedrock is known as **interflow**. The upper limit of the zone of saturation is the water table, and water within the saturated zone is **groundwater**.

Rainfall rates and amounts are measured using a standard rain gauge, like the one shown below. This one is read manually, although automated rain gauges are widely used.

A standard 8-inch manual rain gauge.

From: http://www.piercecollege.com/offices/weather/8inch_rain_gauge.html



Radar rainfall rate estimates for southwestern British Columbia at 8:30 PM on Nov. 11, 2007. The highest rates are in the Nanaimo area, and are between 4 and 12 mm/hr. The radar instrument for this map is located near Abbotsford.

Some of the precipitation that falls on the land infiltrates almost immediately into the ground, while the rest—overland flow— runs off the surface and flows directly into streams (or into storm sewer systems in urban areas). For any area it is possible to estimate the volume of water that will flow directly into streams and sewers using the runoff coefficient equation.

$$Q = 0.278(CiA)$$

Equation for estimating runoff volume (Q) based on precipitation rate and the area and landcover characteristics of a drainage basin

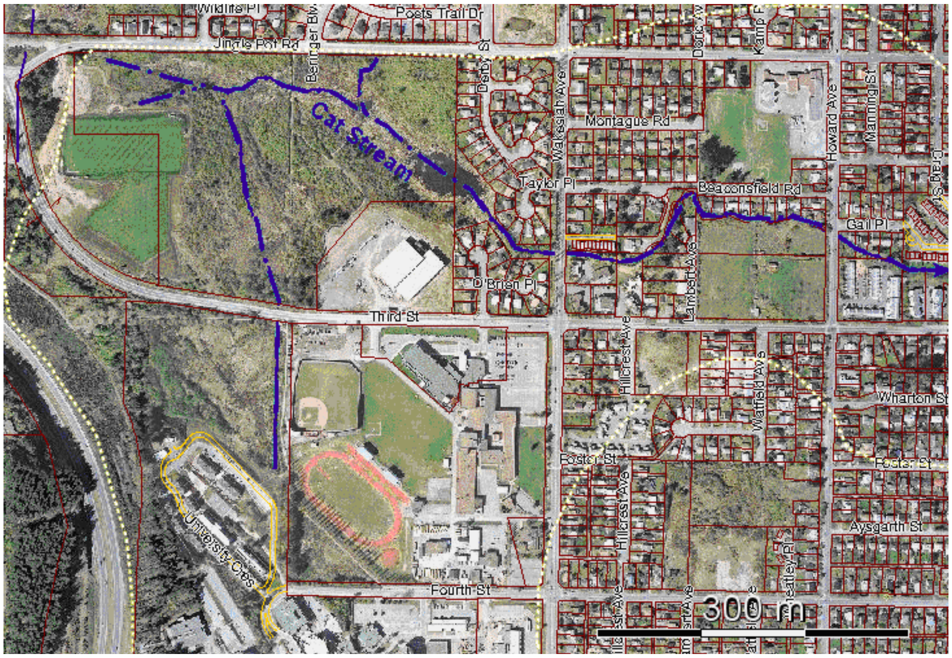
- Q: the volume of overland flow draining off the land (m^3/s)
- C: runoff coefficient (values range from 0 to 1 – see table below)
- i: rainfall rate (mm/hr) (values range up to 100 mm/hr under normal conditions in BC)
- A: area of drainage basin (km^2)

Some values of the coefficient C for the runoff equation are given in the table below. Depending on the type of surface the proportion of runoff can range from 5% for some natural surfaces to 95% for some paved surfaces. Since the great majority of British Columbia is rural (forest or range) rather than urban (streets and buildings), the average runoff coefficient is probably less than 25%, meaning that approximately 75% of the rainfall infiltrates into the ground to become groundwater.

Simplified table of runoff coefficients

Ground cover	**Runoff coefficient, C**
Lawns	0.05 - 0.35
Forest	0.05 - 0.25
Cultivated land	0.08-0.41
Meadow	0.1 - 0.5
Parks, cemeteries	0.1 - 0.25
Pasture	0.12 - 0.62
Residential areas	0.3 - 0.75
Business and industrial areas	0.5 - 0.95
Asphalt streets	0.7 - 0.95
Brick streets	0.7 - 0.85
Roofs	0.75 - 0.95

From: http://www.lmnoeng.com/Hydrology/rational.htm



The drainage basin of the Cat Stream near to VIU. Based on rainfall rate data and a characterization of the different land-cover types it is possible to predict the volume of flow at a particular point on the stream for a particular period.

Stream flow measurement

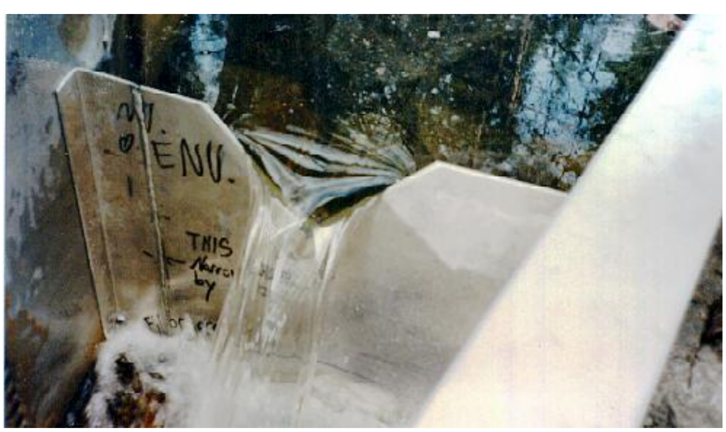
Stream discharge rates can be measured using weirs (either V-notch or rectangular), although in larger streams where weirs are not practical discharge is estimated using a combination of velocity and cross-sectional area measurements.

The standard tool for discharge measurements in small streams is the 90° v-notch weir (see photos below). Discharge is proportional to the height of water above the tip of the V:

Equation for estimating discharge using a 90° v-notch weir.

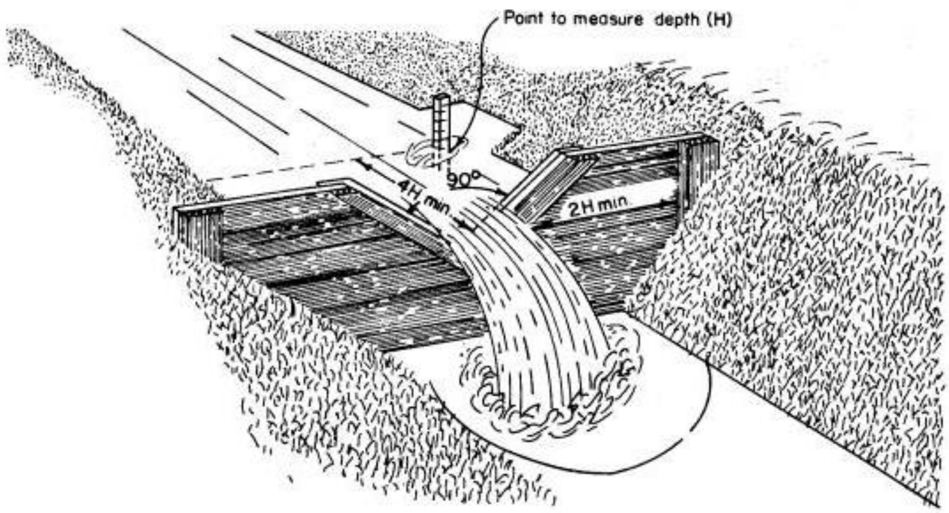
$$Q = 1.379\, H^{5/2}$$

- Q= discharge (m^3/s),
- H= height of backwater above the tip of the V (m)



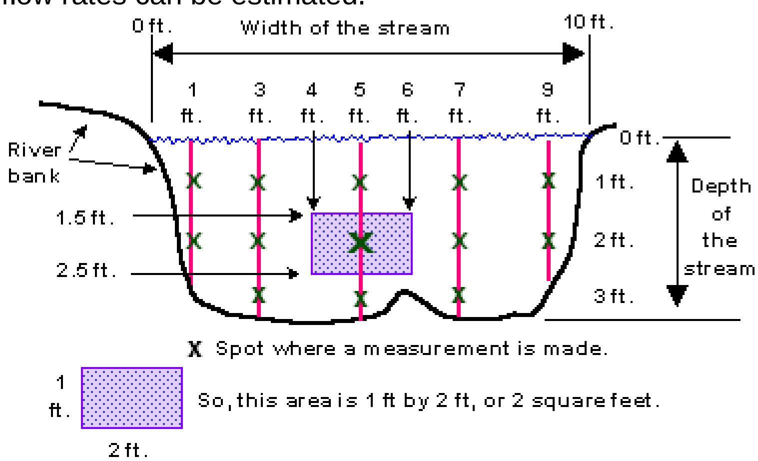
BC Min. of the Env.

90° v-notch weir



90° v-notch weir showing recommended dimensions for the width and the depth measuring point

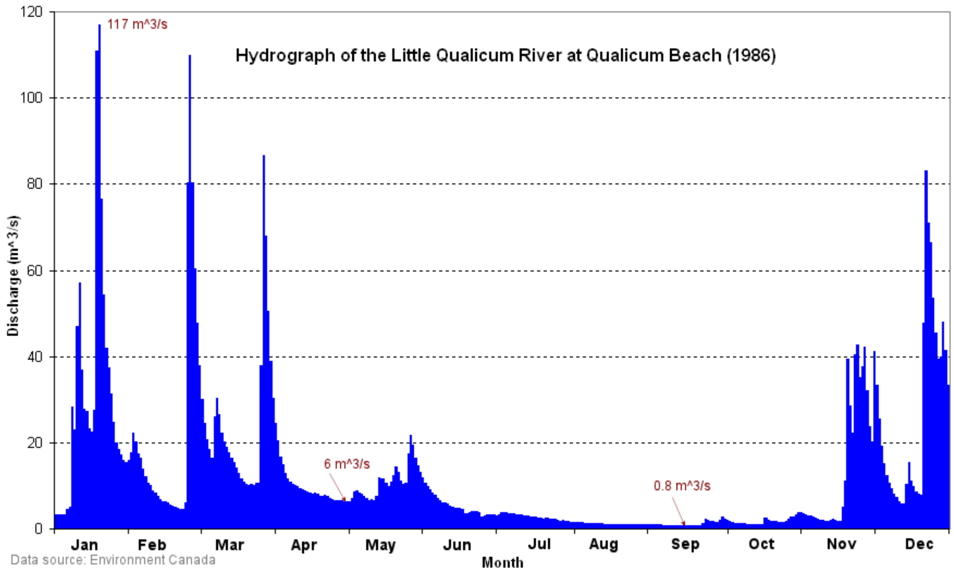
For large streams, where installation of a weir is impractical, it is necessary to characterize the shape of the river channel and then to measure the flow rates at several points within the channel to calculate the flow rate. This exercise is done at various stages of river height, and a relationship is derived for flow rate versus river height. Then by monitoring the stream's height—either manually or automatically—the flow rates can be estimated.



An example pattern for measuring flow velocities at various points within a stream channel.

Source: USGS
http://ga.water.usgs.gov/edu/measureflow.html

A one-year hydrograph for the Little Qualicum River at Qualicum Beach is shown below. The flow rate ranges over more than two orders of magnitude from 0.8 m^3/s to 117 m^3/s, and, as is typical of this region, flows are highest from November to March and lowest from April to October.



Flow rates (m^3/s) for the Little Qualicum River at Qualicum Beach for 1986

Data source: http://www.wsc.ec.gc.ca/hydat/H2O/index_e.cfm

The hydrograph of any stream can be divided into two main components, the baseflow and the overland flow. Overland flow only exists in the few days following a major rainfall event, and its duration is a function of the area of the drainage basin:

Equation for estimating the duration of overland flow based on the area of a drainage basin.

$$D = 0.827A^{0.2}$$

- D = duration of overland flow in days
- A = area of drainage basin in km^2

For example, the Little Qualicum River has a 237 km^2 drainage basin, so the typical duration of overland flow within the entire basin is 2.47 days (59 hours). The Fraser River has a 232,000 km^2 drainage basin, giving an overland flow period of nearly 10 days.

Except in areas and at times where snowmelt is a factor, the baseflow component of a stream's flow is entirely fed by groundwater. Baseflow will be relatively low if the water table is low (as it is in the summer on Vancouver Island) or relatively high if the water table is high.

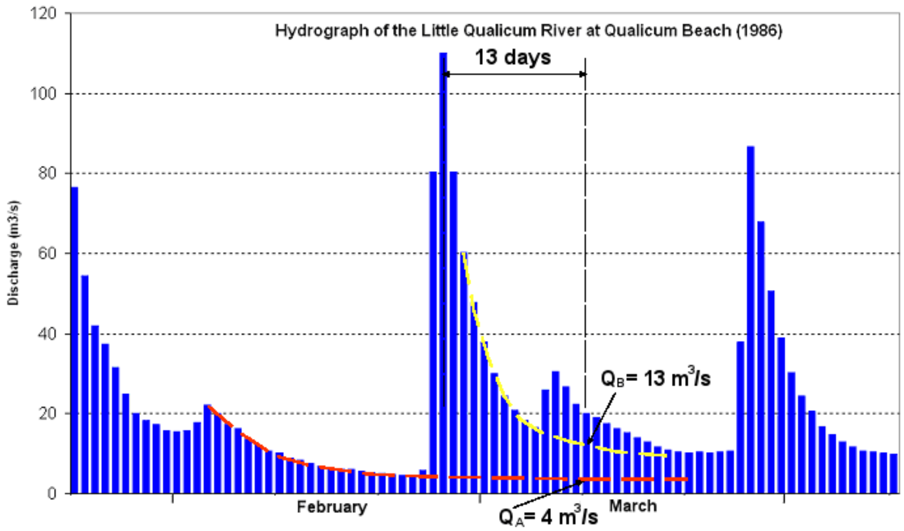
It is possible to use a stream hydrograph to estimate the amount of groundwater recharge that is produced by a rainfall event. One way to do this is the Rorabaugh method, which is based on the offset of the baseflow following a significant precipitation event. The equation is:

Rorabaugh equation for estimating the volume of groundwater recharge produced by a precipitation event

$$G = 2(Q_B - Q_A)t_1 / 2.3026$$

- G = the volume of water recharged to the aquifer
- Q_b = the baseflow at a specific time (t_c) after the precipitation event (m^3/s)
- Q_b = the baseflow that would have existed without the precipitation event (m^3/s)
- t_1 = the time that it takes for discharge to decrease by a factor of 10 (s)
- ($t_c = 0.2144 \times t_1$)

An example is given below. In this case it was estimated that t_1 is 63 days (= 5.44×10^6 s) so t_c is 13 days. The baseflow (Q_B) related to the major precipitation event at the end of February is 13 m^3/s. The baseflow at the same time from the previous recharge event (Q_A) is 4 m^3/s.



Hydrograph for the Little Qualicum River for the period from mid-January to mid-April 1986 with interpreted baseflow curves

Putting these numbers into the Rorabaugh equation gives a total recharge volume from the late February rainfall event of:

$$G = 42.5 \times 10^6 \ m^3$$

Since the area of the drainage basin is 237 km^2 (or $237 \times 10^6 \ m^2$), the depth of recharge from this rain event is:

$$42.5 \times 10^6 \ m^3 / 237 \times 10^6 \ m^2 = 0.18 \ m \text{ (or 18 cm)}$$

Since the porosity of the aquifers within the drainage basin are unlikely to be any more than about 20%, this would be equivalent to a water-table rise of something in the order of 1 metre.