Streamflow

Note: Streamflow, flowrate, discharge refer to the same thing and may be used interchangeably throughout the text.

Hydrologists find it extremely useful to be able to measure or estimate the rates of streamflow. It is important to be able to estimate the rate at which water is needed vs. the rate at which it can be supplied to users. In flood prediction, estimating the flow rate in a stream due to a rainstorm is critical in determining if a stream will overtop its banks, therefore necessitating residential evacuation of the area. Estimating the runoff rate that storms would likely cause in a stream will help the hydrologist determine how high to build levees or other flood protection projects. Estimating flow rates is also useful in determining erosions rates in streams and rivers as well as sedimentation rates in reservoirs.

Since streamflow is so important in hydrologist's work, it is important to understand what streamflow is, how it is measured, and how it can be predicted. Much time has been spent in devising ways of measuring actual flow rates and ways of predicting future flow rates. Flow rates can be measured and predicted in numerous ways, depending on the information the hydrologist has available to him or her.

A stream flow rate (Q), or discharge, is defined as the volume of water that passes a given point within a given time period.

$$\text{Flow rate, } Q = \text{Volume/Time}$$

$$= ft^3 / sec$$

Flow rates are most commonly expressed in units of ft^3/sec, gal/mm, and m^3/s, but may be expressed as any volume unit divided by a time unit. The customary unit of ft^3/sec is often written in short hand as cfs, short for the words cubic feet per second. Likewise, the customary unit of gal/min is often written as gpm, short for the words gallons per minute. The metric unit of m^3/sec is less often written in shorthand but would be written as cms, short for cubic meters per second.

Another common unit used for flow rate includes Mgd (Million gallons per day). For example, 50 Mgd is equal to 50 x 10^6 gal/day.

Perhaps you wanted to know the flow rate of water coming out of your kitchen sink so you could determine if you need to get a water saving spigot. You could use a watch and a bucket to determine the flow rate. Using the watch, you could time when you started to collect water flowing from the spigot into your bucket and then when you stop collecting water. You could determine the volume of water you collected in that time period by measuring the total volume of water collected in your bucket. If you took that volume of water collected and divided it by the time it took to collect that water, you would get the flow rate of water coming out of the spigot.

Specifically, let's say that you let the water run and collect in a bucket for exactly 2 minutes. When you measured the amount of water you collected within that 2 minute period, you measured 3.5 gallons. The flow rate coming out of the spigot is then:

Flow rate = Volume/Time = 3.5 gallons/2 minutes
= 1.75 gallons/minute

Looking back at the definition of flow rate, 3.5 gallons is the volume of water that passes a given point (the outlet of the spigot) within a given time period of 2 minutes. However, more simply, this can be divided out or reduced to give us a rate of 1.75 gallons of water passing the opening of the spigot every time a minute goes by. Functionally, the flow rate tells us that every minute we have the tap on, we will be using or wasting 1.75 gallons of water. This is useful to know especially in efforts to conserve water.

Hydrologists sometimes find it useful to know simply know the volume of water, but it is often more useful to know the rate of water flow. For example, if we told someone we collected 3.5 gallons of water from the kitchen spigot, they would probably say "so what?" because that doesn't really tell them anything. However, if you told the person that you collected 3.5 gallons of water in 2 minutes, then they could make sense of that 3.5 gallons. The time factor gives more meaning to the measurement. That person could now make sense of the information, because knowing the volume of water per time can help determine if he/she needs to get a water saving spigot or not.

Likewise, if we knew that the total volume of water that went into a stream because of a particular storm was 8.4 x 107 ft^3, it wouldn't tell us much. However, if we knew how long it took for that volume of rain to fall, it would help us tremendously. Because if 8.4 x 107 ft^3 of water fell into a stream within a 24 hour time period, the flow rate in the stream would about 1000 cfs, but if 8.4 x 107 ft^3 of water fell into a stream within a shorter time period, say within 3 hours, the flow rate in the stream would be 8,000 cfs. Thus, the time factor included in a flow rate usually makes it more useful to a hydrologist than just knowing a volume alone.

Different Types of Flow Rates

Flow rates are often simply referred to as flow. For instance, hydrologists will usually say the flow was 5,000 cfs, rather than saying the flow rate was 5,000 cfs, but they are referring to the same thing, the volume per time. Other times, however, they refer to flow rates simply as rates. Another more common way hydrologists refer to flow (or flow rates) is discharge. So alternatively, it could be said that the discharge was 5,000 cfs. In summary, flow rate and discharge rate (or flow and discharge) are basically equivalent ways of expressing that the measurement stated is an expression of a given volume of water passing a certain point within a given time period.

Although any flow or discharge is an expression of volume/time, that flow rate can be characterized for many different situations. For instance, immediately after a storm, the total flow in a stream may be 7,000 cfs, but that stream may usually have a flow of only 1,000 cfs. Therefore, the streamflow is 7,000 cfs (the total amount of flow in the stream), but the runoff rate (water running off the land and into the stream due to the precipitation of the storm) would be 6,000 cfs. The baseflow (the amount of flow that is always in the stream) would be 1,000 cfs.

$$\text{Streamflow} = \text{runoff rate} + \text{baseflow}$$
$$7{,}000 \text{ cfs} = 6{,}000 \text{ cfs} + 1{,}000 \text{ cfs}$$

So flow can be the total flow, or it can be broken down into its constituent parts: the portion of the streamflow that is due to precipitation, and the portion that is due to baseflow, but they are all volume/time. The point is just that flow can be characterized differently depending on where it comes from and what it is representing and there are various words we can use to characterize those differences.

Hydrologic Phenomena and the Description of Flow Rates

The topography (pattern of land elevations) of the land surrounding a stream is one factor that helps determine the amount of water contributing to streamflow. Water flows naturally by gravity from high points in elevation to low points. Therefore, tops of the ridges serve to separate drainage basins. Precipitation that falls a little to one side of the ridge will roll down one side of the mountain and into one stream. Precipitation that falls a little to the other side of the ridge will roll down the other side of the mountain and flow into a different stream. These ridges, or high points in elevation, are called drainage divides. The ridges control which direction water will drain. These drainage divides define a drainage basin, or watershed. A drainage basin is the area of land which drains its water into a particular river or stream. The drainage basin of a particular river is often alternately referred to as the river's watershed.

Although it is less common in Arizona, many streams flow even if there hasn't been rainfall in a while. This flow could be due to snowmelt or groundwater that is close enough to the surface that it intersects with the stream bed, thus contributing its water to the stream's flow. The flow is expected to be in the stream regardless of any particular rainfall event and is called **baseflow**. Baseflow is streamflow which is due to events not associated with a particular storm. Baseflow continues before and after storm events.

When a storm does occur, some water infiltrates into the soil, but a large portion of the precipitation usually flows over the land or runs off the land until it reaches a stream channel and contributes that water to the flow of that stream. This flow of water is called **overland flow**, or more commonly, **runoff** flow. A relatively small amount of the stream's flow is due to channel precipitation which lands directly into the stream. This precipitation usually contributes a negligible amount of flow to a stream unless the stream channel is very wide.

In summary, the total flow in a stream (streamflow) can be separated into its individual components that contribute to it.

$$\text{Streamflow} = \text{Baseflow} + \text{Runoff}$$

How to Determine Flow Rates

As discussed previously, the flow rate, or discharge, can be expressed as the volume passing a given point in a given amount of time (vol/time). It can be determined by multiplying the velocity of the stream by its cross-sectional area.

$$Q = V * A$$

where Q = Discharge (ft^3/s, m^3/s)
V = velocity (ft/s, m/s)
A = cross-sectional area (ft^2, m^2)

The cross-sectional area of the stream is the area of an infinitely thin, vertical slice of the stream, which all the water flows perpendicularly through. FIGURE 1 pictorially shows the cross-sectional area of a stream with a uniform width and height. For an irregular shaped stream, it is much more difficult to determine the cross-sectional area of flow. We won't be too concerned here with how the cross-sectional area of the stream is determined in irregular shaped streams, only that it is usually a complicated and time-consuming process that one does not like to have to do very often. For the purposes here, we will be dealing with regular shaped channels where the cross-sectional area can be easily figured out.

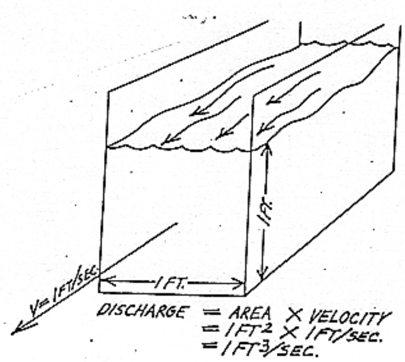

Figure 1 Discharge measurement in cubic feet per second. *Manning, 1997.*

From the formula, you can see that the velocity and cross-sectional area of the stream affect the flow rate of the stream. It is important, therefore, to obtain accurate measurements of those two parameters. Measuring the cross-sectional area of the stream can include a lot of human error and can be difficult especially it is a natural irregular channel. You must also be careful where you measure the velocity to get the most accurate value. The velocity of a stream is different depending on where you measure it (See next paragraph for details). Water is fastest when it is farthest away from any physical boundaries, or sides of the channel. Therefore, the velocity is greatest near the center of the channel, near the surface. The best way to get the velocity is to take several measurements at different points in the stream and average them. The average velocity for the entire stream will also depend on the roughness of the channel bottom and the slope of the channel. The rougher the bottom the more friction is exerted on the water and the slower the water will travel.

For any given point in a stream, the velocity changes with depth. The velocity decreases for water closest to the bottom of the stream, or the stream bed. Water that is in direct contact with the stream bed is actually not moving at all. Water just a little above that non-moving water slides by that water and starts moving with a small velocity. Water that is a little above that water moves a little faster and so on, so that water that is farthest from the stream bed (or ground surface) is moving the fastest. However, water that is closest to the surface, has a slightly lower velocity than that in the middle because of the increased exposure to air resistance. Therefore, as far as depth is concerned, the fastest moving water is located at a position far enough away from the stream bed to feel the least frictional resistance, yet is far enough from the surface that it feels the least air resistance. FIGURES 2 and 3 show how the velocity of water changes with depth.

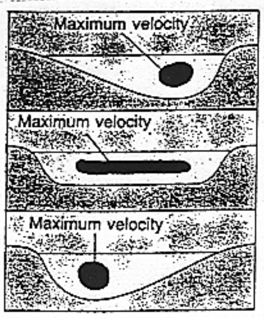

Figure 2 Maximum stream velocity in relation to channel shape. *Lutgens and Tarbuck, 1989.*

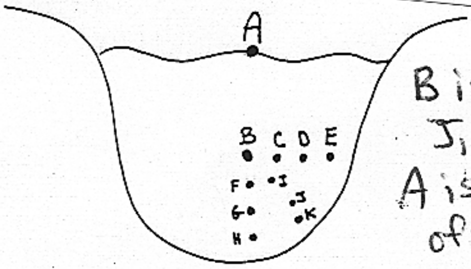

Figure 3 Velocity change with distance from banks.

B is faster than F, J, and E.
A is faster than all of the points.

Manning's Equation - Finding a Peak Flow Rate

During particularly high flows, it may be difficult to impossible to physically measure the velocity of the stream. In this case an empirical equation can be used to determine the expected peak flow rate. This equation is called **Manning's Equation.** In order to use Manning's Equation, certain characteristics of the stream channel must be known. Manning's Equation is defined as

$$Q = \left(\frac{1.49}{n}\right) * A * R^{\frac{2}{3}} * S^{\frac{1}{2}}$$

$$Q = \frac{(1.49 * A * R^{0.667} * S^{0.5})}{n}$$

where
Q = peak flow rate (cfs)
n = channel roughness factor
A = cross-sectional area of the stream (ft^2)
R = hydraulic radius (ft)
S = slope of the "energy surface" (unitless)

Hint: When performing the calculations, remember order of operations. Do the exponents first, so do $R^{0.667}$ and $S^{0.5}$ first. Then multiply those answers together, then multiple that by A and 1.49. Then take that answer and divide it by the value of n.

The cross-sectional area of the stream is usually available from records of previous survey data for the stream.

The hydraulic radius, R, is defined as the cross-sectional area divided by the wetted perimeter (A/P). The wetted perimeter is the length of the surface of the channel that is wetted by water as you travel down one bank, into the channel, and then back up the other bank. FIGURE 4 shows an example of how the wetted perimeter is found.

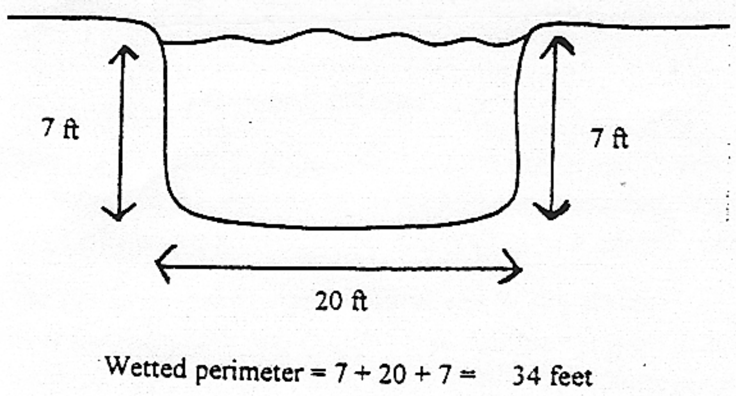

Figure 4: Wetted perimeter.

Channel roughness coefficients, "n", are unitless numbers ranging from between 0 and 1.0, which describe the roughness, or the texture, of the stream bed See FIGURE 5 for examples). The larger the value of "n", the more sluggish the channel is. Relatively high values of "n" may be due to grass, weeds, or rocks which are prominent in the channel bed causing the flow to be slowed (resulting in a low Q). Relatively low values of "n" would be characteristic of smooth channels with few obstructions and perhaps a concrete-lined channel. The flow in these clear channels would be relatively larger than in channel with a high value of "n". For example, if the channel is smooth and lined with concrete, "n" would be about 0.012 - 0.029. For an earth channel stones and weeds, "n" may have a value of between 0.035 - 0.112. The channel roughness coefficient is usually the greatest source of error in determination of the peak flow rate using Manning's Equation.

The slope of the energy surface is the slope that the water surface would have ideally if there were no constrictions in the channel and the channel were uniform. The slope can be determined in the field once the flood waters have receded. Here, we will assume that the slope of the energy surface is equivalent to the slope of the channel bottom.

REMEMBER: Q is volume per time so the units are usually ft^3/sec or (cfs), as long as A and R use feet and seconds. Make sure to put units in your answer.

FIGURE 5

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Table A-18 Values of *n* for the Manning Formula [Eq. (4-7)]

Channel condition	*n*†
Plastic, glass, drawn tubing	0.009
Neat cement, smooth metal	0.010
Planed timber, asbestos pipe	0.011
Wrought iron, welded steel, canvas	0.012
Ordinary concrete, asphalted cast iron	0.013
Unplaned timber, vitrified clay, glazed brick	0.014
Cast-iron pipe, concrete pipe	0.015
Riveted steel, brick, dressed stone	0.016
Rubble masonry	0.017
Smooth earth	0.018
Firm gravel	0.020
Corrugated metal pipe and flumes	0.023
Natural channels:	
Clean, straight, full stage, no pools	0.029
As above with weeds and stones	0.035
Winding, pools and shallows, clean	0.039
As above at low stages	0.047
Winding, pools and shallows, weeds and stones	0.042
As above, shallow stages, large stones	0.052
Sluggish, weedy, with deep pools	0.065
Very weedy and sluggish	0.112

† Values quoted are averages of many determinations; variations of as much as 20 percent must be expected, especially in natural channels.