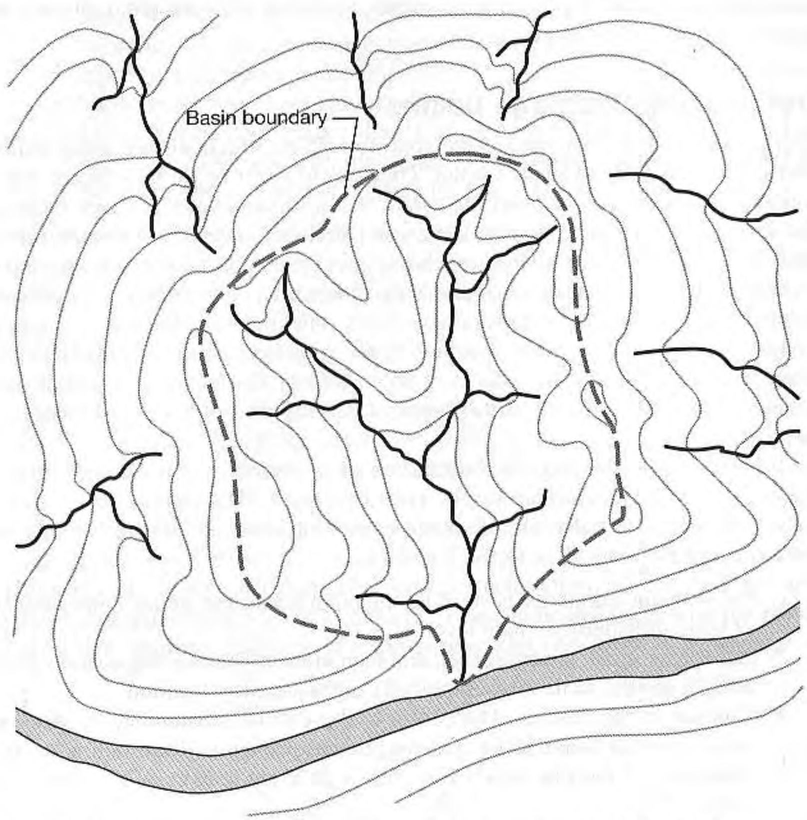


Fig. 3.7 Use a topographic map to make a first approximation of the basin boundaries.

To field-check the map, again begin at the mouth of the stream. Walk uphill, initially walking along the steepest uphill path. Move slowly, at each step checking. "If a drop of rain fell to my left and ran overland to a stream, would it flow into my stream, or somewhere else? What if it fell to my right?" If you are walking along the drainage divide, then the right and left sides should give different answers to this question. Look behind yourself frequently to check yourself. Survey flags may be helpful; position them at the basin boundary and periodically review them as you proceed.

Bear in mind that especially in urbanized areas, drainage pipes and sewers may drain an area that topographically would appear to be part of one basin, while actually conveying the water into a different basin. Roadways and other embankments or structures may divert natural flow paths, rerouting the water to another basin. Local governmental engineers, sewage-treatment plant operators, and highway

engineers can provide information on these structures or conveyances. Other confounding features are sinkholes, especially in karst regions, and glacially formed kettles and "potholes." In regions where these features appear, especially if they make up a significant fraction of a basin, it might be necessary to do a smaller-scale study.

Streams

Why Is This Stream Here?

In a field study of an area that includes a stream, ask the question, "Why is this stream here?" The answer may illuminate flow paths of water through the area. Obviously, streamflow follows topographically low areas. But what feeds the stream? Why is there water in the stream? Why doesn't the water soak into the stream bed? If the stream is intermittent, why is it so? If it is perennial, what keeps the water flowing? Does the stream flow in a single course, or is it a braided stream (i.e., one with many separate channels)? Why?

Sometimes the source of a stream is a single point: a spring, industrial outfall, or drainage pipe. Alternatively, the source might be runoff: water flowing across the ground surface to the stream, or baseflow: ground water discharging into the stream through its bed, all along the length of the stream. An ephemeral stream, which flows only in association with a storm event, probably has only runoff and perhaps some shallow ground water flow as a source. A perennial stream is ground-water-fed and flows even in times of drought.

What keeps the water in the stream? Gaining streams gain more and more water as they flow downstream, both from tributaries and from ground water discharge into the stream. Losing streams have less discharge as they go downstream, because water infiltrates the stream bed and becomes ground water. If water does not infiltrate into the stream bed, it is for one of two reasons: Either the permeability of the stream bed is too low to allow it or the ground water gradient is such that water flows in to the stream, not out of it. Intermittent streams contain water along parts of their course, but not along others, as soil and hydrogeologic conditions change (Fig. 3.8).

Field observations

Several stream parameters may be measured in the field. While working in and around streams, safety should be of primary importance. Before wading into any stream, test the bottom to determine what the footing is like. If the current is too fast to allow you to keep your balance easily, it is unsafe to work in the stream. Do not even consider using ropes or harnesses unless specialized, advanced training in this specific area has been completed. Such devices in the hands of a novice can be deadly.

Field observations about a stream should include the general topographic setting and condition of the floodplain. Note the character of the stream banks and bed. What are the sediments and rocks like? Describe the vegetation.

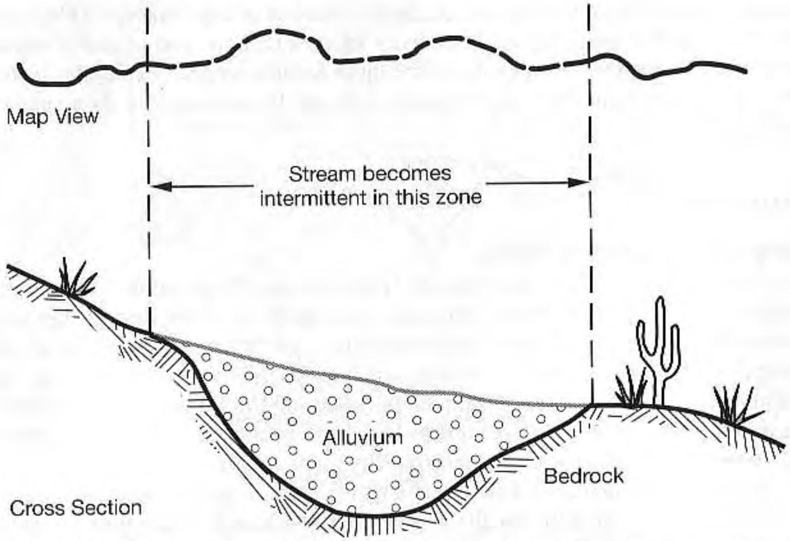


Fig. 3.8 One of many possible situations giving rise to an intermittent stream.

Observations about the following are appropriate in a field study of a stream:

- General topographic setting
- Site-specific topography and relief (a sketch or profile may be helpful)
- Character of the floodplain and floodplain development. (For example, is there a floodplain? How wide is it relative to the stream's width? What is its cross-sectional geometry?)
- Description of the stream banks and bed
- Sediment and rock exposed in cuts and in the stream bed
- Soils on the bank and washover deposits
- Vegetation: plant species, density, and condition
- Evidence of animal activity in the stream on its banks (e.g., tunneling, burrowing, and dam building)
- Field observation of moisture content of the floodplain soils (dry, moist, or saturated)
- Depositional features (sand bars, debris, or high-water marks)
- Erosional features (scouring, exposed tree roots, unstable vegetation, or building foundations that are undercut)
- Human development (buildings, roadways, bridges, railroads, dams, diversion structures, drainage pipes, rip-rap, levees, and spillways)
- Evidence of flooding (high-water marks, debris in trees, muddy or silty coating on vegetation and structures, and dead aquatic animals on banks)
- Bank stability (undercutting, trees with roots exposed hanging over the water, evidence of soil creep, slides or washouts, unvegetated scars of mass movements)

Width

The width of a stream changes as discharge changes. Discharge changes from moment to moment, day to day, and season to season, depending on rainfall, snowmelt, and ground water interactions with the stream. Because width and discharge may change significantly, any stream-width measurement should be correlated with a discharge measurement made at the same point.

The width of an unchannelized stream may vary significantly along its course and as discharge varies. As a result, depending on the objectives of the field project, several measurements may be needed. For small streams, measurements of width may be made easily with a fiberglass or steel tape measure. Measure perpendicular to the flow direction and to the stream banks. If the stream is wide, the tape may sag, resulting in a measurement that is too high, so pull it taut. Also, if the tape drops into the water, the current will pull it, again resulting in an inaccurate measurement. The approximate width of larger streams may be measured on a map. Keep in mind, however, that a change in discharge may significantly affect the width. If a stream is inaccessible by wading, a bridge over the stream may be the only point at which a width measurement may be safely made.

Distance-finding equipment that uses light or laser beams may be used on wider streams. Surveying equipment also may be used. If it is impossible to measure distance in one sighting, a bridge or island may serve as a triangulation station.

For instructions on using triangulation, refer to the *National Handbook of Recommmended Methods for Water-Data Acquisition* (USGS, 1980).

The channels of a braided stream (one with many separate channels) shift rapidly. Because of this, it may be most useful to consider the width of the entire set of channels, depending on the purpose of the study.

Depth

Like width, the depth of a stream varies with varying discharge. In addition, depth typically varies across the stream from bank to bank, and may vary considerably even along short longitudinal distances. Meandering streams are generally deeper on the outside of a curve and shallower on the inside. "Pool" areas generally are deeper than "riffles." Even in a straight stretch of a seemingly regular stream, the bed may be thoroughly irregular and may contain bars and channels. If depth is a critical factor, as it is in any estimation of discharge, sufficient measurements should be taken to characterize it. Stream beds change as deposition, erosion, and flooding occur, so depth measurements may be valid for only a short time, depending on the stream processes.

In small streams, depth may be measured with a plastic or metal graduated rod (plastic meter sticks are particularly handy for this). If a long enough measuring rod is available, it may be lowered into the stream from a bridge or platform. A calibrated, weighted line also may be used for this purpose, but unless the weight is heavy, the current is likely to pull the weight and line downstream, giving an inaccurate reading. A portable crane (a "bridge crane") and a cable reel may make it easier to handle the heavy weight in these locations. Streamlined weights with fins may be used to minimize the effect of the current.

When measuring near bridge abutments, large rocks, or other obstructions, be aware of eddy currents that might distort the water surface. These currents change and, in some cases, even reverse flows. Avoid measuring in these areas; if this is impossible, increase the number of measurements made.

A weighted line also may be used to make depth measurements from a boat. In this case, it is important to know the exact location of the measurement. This may be found by sighting with a compass or surveying instrument to two fixed landmarks or by stretching a graduated cable across the river, and making measurements at a set interval. A surveying instrument may be set up on the banks of the stream, and the boat may be directed (by visual signals or by radio communication) to the precise measuring spot. A global positioning system (GPS) unit may be used in some cases, but this method is not precise enough to warrant its use except in very wide rivers. Depth-sounding equipment may be used, especially if the stream is deep; versions of these instruments are sold in some sporting goods stores as "fish finders."

Because river depth may vary significantly from bank to bank, longitudinally along the river, and at different stages of water elevation, it is important to take many measurements to get an accurate cross-sectional view of the stream. When measuring across the width, especially if the width and depth measurements are to be correlated with discharge measurements at the same points, make at least twenty measurements. Depending on the irregularity of the stream bed and the purpose for which the measurements are to be made, it may be necessary to take more.

Depth may change over time as the stream moves, erodes, and deposits sediments. When discharge changes, depth changes; depths should be correlated with a discharge measurement.

Gradient

The gradient of a stream is the change in elevation of the water surface between two points divided by the horizontal distance traveled by the water. The gradient of a stream changes along the course of the stream, and the overall gradient commonly is different from the gradient measured along discrete reaches of the stream (Fig. 3.9).

The gradient of a relatively short section of a stream may be measured using simple surveying instruments (transit or alidade, meter stick, measuring tape). The gradient measures the change in slope of the water *surface,* and the simplest place to make this measurement is where the water-surface elevation equals the land-surface elevation, or at the water's edge. If the stream has a very rapid current, there may be a "banking" effect on a curve, wherein the water level is higher on the outside of the curve than the inside. When this condition occurs, either avoid the problem by making the measurement at another place in the stream or make two measurements, one on either bank.

Two people are needed to make accurate measurements of gradient. One holds a graduated rod (e.g., a meter stick or stadia rod) so that its bottom end sits precisely at the surface of the water. The easiest way to achieve this is by setting the rod precisely at the water's edge. Attempts to hold the rod level with the stream

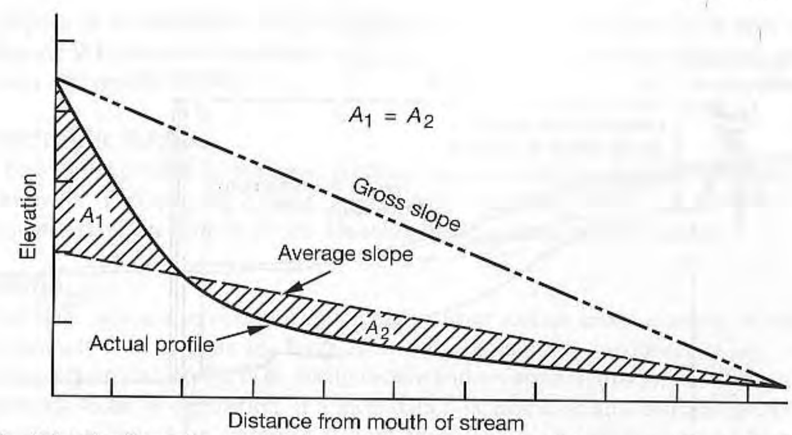


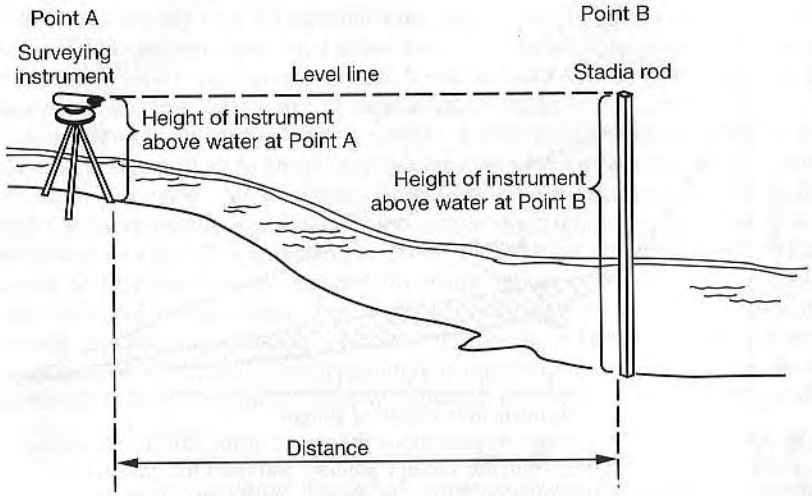
Fig. 3.9 Gradient of a stream changes along the course of the stream. The overall (gross) gradient is different from the average gradient and from the gradient at a discrete section of the stream (after Viessman, Lewis, and Knapp, 1989).

surface while standing in the middle of the stream probably will not be successful. Another person takes a surveying instrument (such as an alidade, transit, or theodolite) some distance upstream or downstream; the direction is a matter of convenience. The height of the instrument above the water surface is measured. A level line is then sighted to the stadia rod, and the reading on the rod is noted. Distance from the instrument to the stadia rod is measured, by tape or accurate map distance. The gradient is calculated as shown in Fig. 3.10.

If the gradient is very low, it may be difficult to measure it in the way described, because change in elevation will be small over a large distance, and accuracy of the method will suffer. Gradient may be estimated from gaging station information collected and published by the USGS by comparing the gage height and datum at two stations, and measuring the map distance along the flow path between them. Alternatively, elevation of the water surface may be surveyed at two points and referenced to benchmarks. However, because stream level may change during the time the measurements are being made, they should be made simultaneously, or they should be repeated several times, alternating between upstream and downstream locations.

Cross-Sectional Area

The cross-sectional area of a stream is the area of the stream perpendicular to flow. It varies along the course of the stream, and it varies as a function of current velocity and discharge. It should be estimated by first constructing an accurate cross section of the stream, based on width and depth measurements. Once the cross section is complete, the area of the stream may be calculated by using any standard method, four of which are described here:



$$\text{Slope} = \frac{\left(\begin{array}{c}\text{Height of instrument}\\ \text{above water at Point B}\end{array}\right) - \left(\begin{array}{c}\text{Height of instrument}\\ \text{above water at Point A}\end{array}\right)}{\text{distance}}$$

Fig. 3.10 To calculate gradient along a discrete segment, position a surveying instrument at the water's edge at Point A and a stadia rod at the water's edge at Point B. Measure distance between the points. Calculate gradient as the change in elevation over the distance.

1. Trace the cross section onto graph paper and count the number of grid blocks enclosed in the area.
2. Consider the area as being composed of many trapezoids. Each trapezoid is defined by the water surface, the stream bed, and two measurements of depth made along the transect across the stream. Calculate the area of each trapezoid by summing the two depth measurements and dividing by 2 and then multiplying by the width of the section. Sum the areas of the several trapezoids to get the total cross-sectional area of the stream.
3. Use a planimeter, an instrument that measures areas on maps.
4. Use a computer-assisted drafting program that has the capability of measuring areas enclosed within irregular shapes.

Wetted Perimeter

The wetted perimeter (WP) is the length of a line along the part of the stream bed that is under water, in a direction perpendicular to flow. The WP of a stream always is greater than its width. This is especially the case if the stream is narrow and deep. See Fig. 3.11 for examples. WP is best measured by constructing an accurate, to-scale cross section of the stream based on width and depth measurements, then measuring the WP on the cross section. Braided streams may be treated as the sum of many individual channels, or as one channel, depending on the purpose of the study. WP varies with stage and stream width, which vary with discharge; WP should be correlated with a discharge measurement made at the same point and time.

Hydraulic Radius

The hydraulic radius is the cross-sectional area of a stream divided by the wetted perimeter. This quantity is used in estimating stream discharge with the Manning Equation (see the section on the Manning equation later in this chapter).

Stage

The stage of a stream is the elevation of the water surface above a datum. A datum commonly used is mean sea level. However, a datum may be chosen at any local point, selected carefully to be easily visible and permanent, that is, not affected by erosion, scour, or deposition. If a local datum is used it should be referenced to a nearby benchmark to correlate it with mean sea level. Buchanan and Somers (1968) gave a thorough description of the design and use of instruments used by the USGS to measure and record stage. Also see USGS (1980) and Herschy (1995), for more information.

Gages used to measure stage may be of the recording or non-recording type. Nonrecording gages simply show the relative elevation of the water surface; an observer must read and record the elevations manually. A common type of non-recording gage is a staff gage. A staff gage is essentially a large-scale ruler, affixed to a permanent object and referenced to a datum (Fig. 3.12). The observer notes the height of the water surface as indicated by the ruler. Staff gages should be installed at locations unlikely to be affected by scouring or by floating debris. Installation of a staff gage in a stream with a significant current will cause eddy currents about the gage. For this reason, if the measuring side of the gage faces upstream or downstream, the readings will be anomalously high or low. Instead, the staff gage should face neither upstream nor downstream, or it should be placed

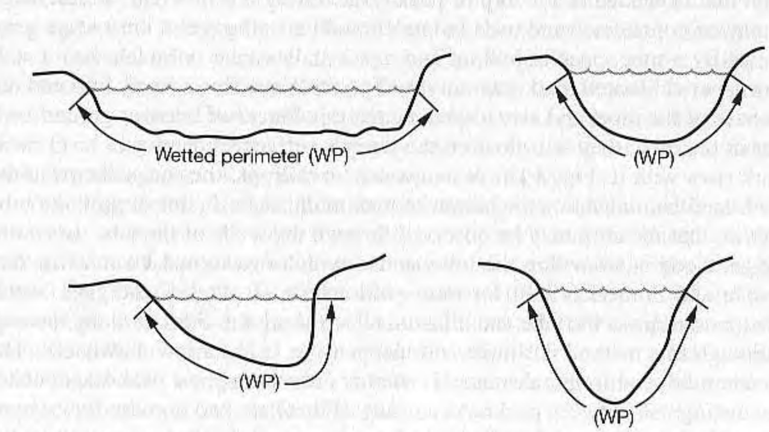


Fig. 3.11 Wetted perimeter of a stream always is larger than stream width. WP may be much larger than the width if the stream is narrow and deep.

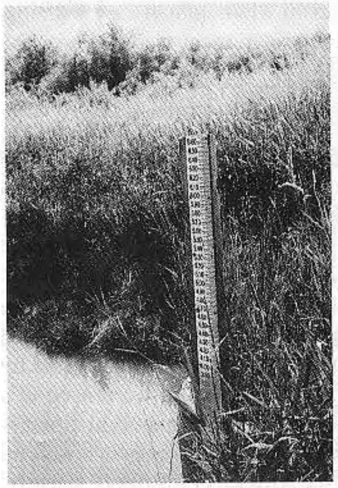


Fig. 3.12 A staff gage.

in a location where strong current will not interfere with the reading. Alternatively, the staff gage may be placed in a stilling well. A stilling well is a pipe or other structure that allows free flow of water into and out of the well, but that "stills" the water so that gage readings are accurate. The well must not obscure the observer's view of the staff gage.

Staff gages are relatively inexpensive and durable. If read on a daily basis at the same time of day over a long period, they can give a good indication of flow conditions over that period. However, they are not capable of yielding a good record of brief flow events unless the observer stays nearby to read the gage at short time intervals.

If all that is needed is a record of peak stage during a flow event, a crest stage gage may be constructed and used in tandem with a staff gage. A crest stage gage is essentially a tube, open at bottom and top, installed near or attached to a staff gage or other calibrated marker or surveyed point. Water flows freely into and out of the base of the tube, and air escapes out the top. Pieces of burnt or ground cork are put in the tube; they will float on the water's surface. When water level rises, the cork rises with it (Fig. 3.13). When water level drops, the cork adheres to the sides of the tube, indicating the height of maximum stage. In one design, the tube is clear, so that the cork may be observed through the walls of the tube. In another design, a rod is set within the tube, and is withdrawn to make a reading. See Buchanan and Somers (1968) for more information. To "reset" the gage, water may be poured down the tube and allowed to run along the sides or along the rod.

Although this method is simple and inexpensive, it has a few drawbacks. The gage cannot be read from a distance. It records only the highest peak stage, and it cannot distinguish between peaks. As a result, if there are two or more flow events between readings, it may be unclear which event caused the highest stage. Finally, the gage must be read manually.

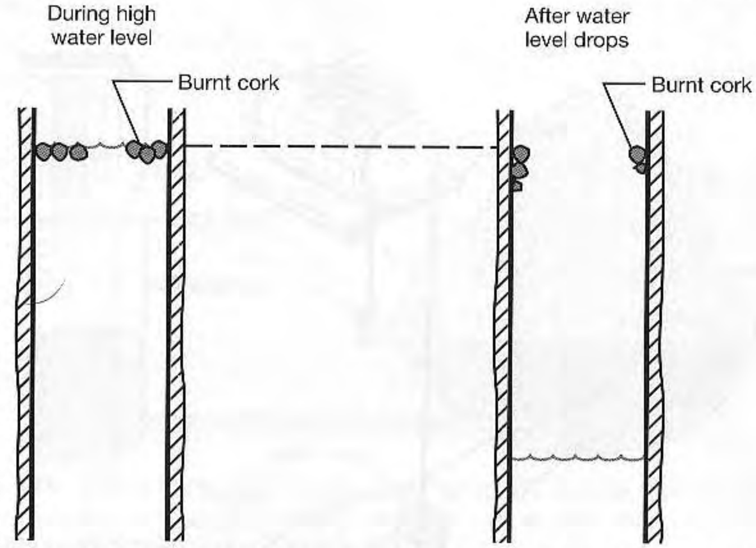


Fig. 3.13 An inexpensive maximum ("crest") stage gage. Pieces of burnt cork floating in a tube adhere to the sides of the tube when water level drops.

Continuous-recording gages are much more expensive than staff gages, but offer significant advantages. They provide continuous water-level measurements; no observer is required in the field. The gage records measurements for periodic retrieval or automatically transmits them to a base office.

Several designs of continuous-recording gages are available. The simplest is the mechanical float recorder, or "Stevens-type" gage. In this design, a pulley and cable are set up, with a float attached to one end of the cable and a counterweight attached to the other end. The float floats on the water surface; when the water level rises and falls, it rises and falls, too (Fig. 3.14). This turns the pulley, which is attached to a recording device. The recording device may be a strip chart recorder, on which charts must be changed daily, weekly, or monthly by the operator. Or it may be a device that digitally encodes that data for later downloading, either by an operator at the site or via remote telemetry.

A stilling well is used to allow measurement of water level unaffected by current, and to protect the float from debris. The well may be located within the stream or on the bank; the latter option may involve excavation and/or drilling (see Fig. 3.15). The well may be made of any material that can be worked and that will protect the float from debris, but will still admit water. For example, a stilling well may be made of corrugated pipe, stainless steel, PVC, or even (under conditions of low velocities and little debris) clothes dryer vent pipe into which holes have been cut to allow water to flow freely in and out.

A stilling well should be constructed such that it functions no matter what the height of the water within the well. Intake pipes or holes in the casing should be

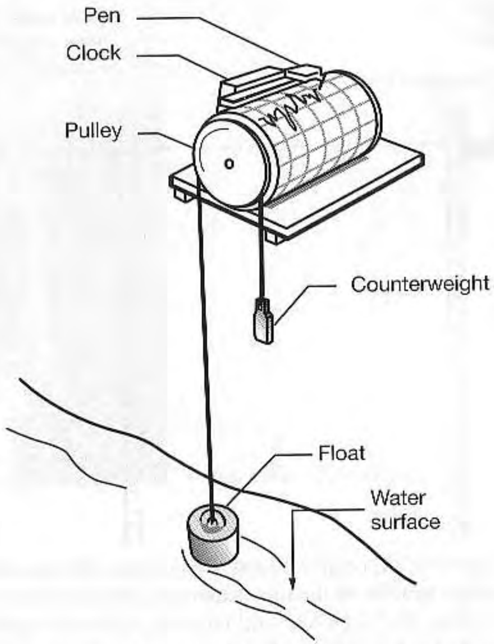


Fig. 3.14 A continuous-recording gage. The float stays at the water's surface, rising and falling with changes in water level. This causes the chart recorder to rotate under a pen. At the same time, the clock drags the pen along the recorder drum at a steady rate, providing a continuous record of water-level changes with time. Measurements also may be recorded digitally.

placed at many elevations so that flow can be admitted to the well at any stream stage. The holes must be large enough to allow water to flow freely in and out, but small enough to protect the gage from debris and to damp out surges or waves.

A continuous recording gage is installed on a platform. The platform may be located in the stream or at its edge. Wherever it is located, it must be accessible for servicing; responsive to changes in stream level; and secure from erosion, flood debris, boaters, and vandals. Construction of the platform must be secure, even in floods, and it must be sturdy enough to allow a person to climb onto the platform to service the gage. To determine how high to make the platform, check the levels of previous high flows in historical records of the U.S. Geological Survey (USGS) or Federal Emergency Management Agency (FEMA), interview local residents, or look for high water marks or other evidence of flooding high above the stream bed.

The entire gage must be elevated high enough on its platform to keep it dry in case of flooding. A "doghouse" of sheet metal or plywood should be constructed around the gage, with hinges to allow for access, and a secure lock to keep out vandals. In areas where the gage may inspire a round of target practice by vandals with guns, a more secure installation may be required. In more expensive and secure

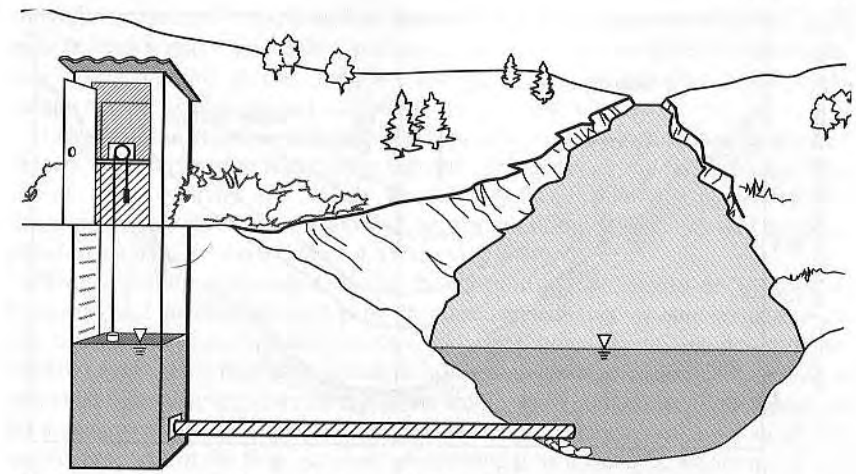


Fig. 3.15 Stilling wells may be located within the stream or on the bank; this may involve drilling or excavating the bank. Intake tubes are subject to siltation and must be maintained regularly (after Manning, 1997).

installations, the gage may be placed in a locked shed constructed of relatively thick metal.

Velocity

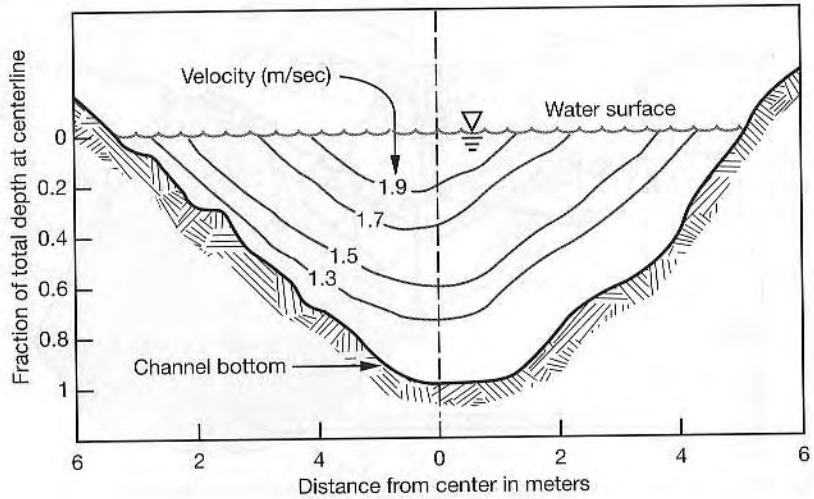
Velocity of a stream varies from top to bottom of the flow profile, across the stream from bank to bank, and along the flow course of the stream (Fig. 3.16). Velocity varies as a function of discharge and cross-sectional area, and stream-velocity measurements should be reported with discharge measurements made at the same time and same point in the stream. Buchanan and Somers (1969) provided detailed information on measurement of velocity and discharge at USGS gaging stations. More information is also available in USGS (1980), Dunne and Leopold (1978), and Herschy (1995).

Velocity may be estimated by direct or indirect methods. Direct methods include using a float, current-velocity meter, or tracers.

Float Method

The float method is the simplest and most rapid of the three direct methods, though it has significant disadvantages. In this method, a float is dropped in the stream and timed as it travels a given distance. Velocity is the distance traveled divided by the time it takes to travel that distance. Because the float is at the surface of the water, this method does not give a representative measurement of the average stream velocity.

The float may be anything that floats and is easily visible, but some floats work better than others. It is tempting to simply use sticks of wood or leaves picked up off the ground near the stream. However, it may be difficult to see a stick in the



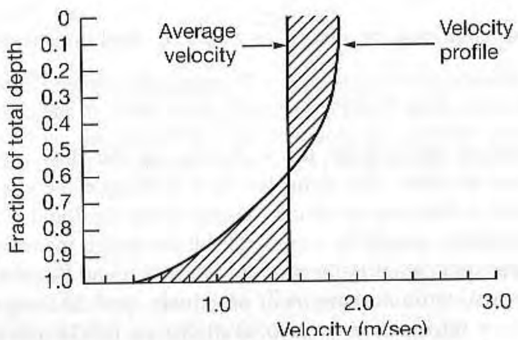


Fig. 3.16 Velocity of a stream varies from top to bottom of the flow profile and across the stream from bank to bank (after Ward and Eliot, 1995).

water, or to be sure it is the "right" stick. Also, sticks and leaves tend to hang up on debris, and they may float so close to the top of the water that they are affected by wind. Leaves, especially, may be severely affected by wind blowing across the water surface. Because velocity in a stream varies from top to bottom, an object that floats too close to the top allows one to measure only the velocity near the top. This is faster than the average velocity. Fishing bobbers are visible, but float too close to the surface and are affected by wind. Oranges constitute a good float. Oranges float somewhat below the surface, are visible, roll around obstructions, and if lost, generally pose little environmental problem.

Depending on the width of the stream, it may be necessary to divide the stream into sections or "channels" and run the test in each (Fig. 3.17). Several repetitions

should be conducted in each section. Beware of using too many sections; the float may be drawn into a single flow path no matter where it is released. If this is the case, using multiple sections will not add meaningful information. A few trials should reveal the utility—or lack thereof—of multiple sections.

Length of the segment tested should be chosen based on accessibility, convenience, and precision required. The segment chosen should be relatively straight and of regular gradient, and, ideally, free of debris. The longer the segment tested, the more precise the measurement will be. Length of the segment should be measured by using a measuring tape or a surveying method.

Two operators are needed to run the float test. One should be positioned upstream, and the other, downstream. Distance between them should be measured. The upstream operator releases the float and starts the clock, and the downstream operator catches the float and signals to stop the clock. The float must be released upstream of the starting line, so that it has ample opportunity to become entrained by and move with the current. The operator should stand out of the way of the anticipated path of the float, to avoid obstructing it as it floats downstream.

When the float crosses the starting line, the upstream operator starts the clock, which might be a stopwatch, a digital watch, or a watch with a sweep second hand. The float is allowed to travel downstream toward the other operator, who raises a hand (or communicates via radio) when the float nears the finish line and brings the hand down sharply when the float crosses the line. The upstream operator stops the clock when the signal is given. The downstream operator catches the float and, ideally, returns it to the upstream operator so that the test can be repeated.

The test should be repeated several times (at least three) in every section or "channel" of the stream. Section widths should be measured so that an average

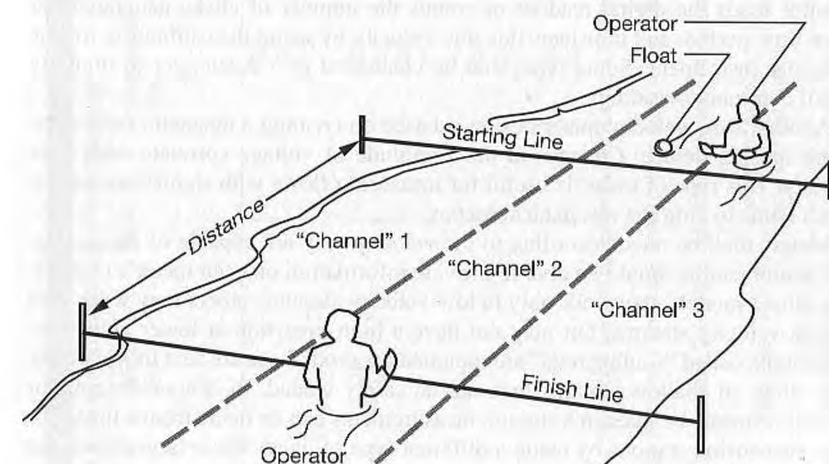


Fig. 3.17 The float test. It may be necessary to divide the stream into sections or "channels" and run the test in each. Here, operators will perform several trials in each of three channels.

velocity may be calculated. If discharge is to be estimated, then depths should be measured as well, so that a good estimate of cross-sectional area in each section can be determined.

A sample of calculations is given in Table 3.1.

Trials should be repeated in each section until at least three trials are made with no errors. Errors should be described in the "Notes" column of the data table, as shown in the table. If a measurement is inexplicably and significantly (more than 10%) higher or lower than the other measurements in that section, another trial should be run.

The float method is generally limited to use in streams that are accessible by wading. It may be used for some other streams by operators standing on the banks. The upstream operator throws a float into the water, waits until it crosses the starting line, starts the clock, and watches for the downstream operator's signal that the float crossed the finish line. However, the inaccuracies in throwing the float and in the angles introduced by observing the start and finish lines from the banks introduce significant error. This method is suitable for approximate estimates of surface velocity.

Current-Velocity Meter

A current-velocity meter is an instrument used to take measurements of stream velocity at a particular point in a stream. A common design features a propeller or set of cups mounted on a shaft. The shaft may be oriented horizontally or vertically. The propeller or cups catch the current and spin on the shaft at a rate proportional to current velocity (Fig. 3.18). These meters are battery-operated; each rotation of the shaft generates an electronic signal that may be digitally displayed or may generate a clicking sound in a set of headphones worn by the operator. The operator reads the digital readout or counts the number of clicks generated per given time period, and translates this into velocity by using the calibration for the particular instrument. Some types can be connected to a datalogger to digitally record continuous readings.

Another flow velocity meter design is based on creating a magnetic field within the sensing device. Changes in the amplitude of voltage correlate with flow velocity. This type of meter is useful for measuring flows with significant debris, which tends to clog the mechanical meters.

Meters may be rated according to the velocity they are capable of measuring. The manufacturer should be able to provide information on each meter's capabilities. Some models may work only in low-velocity streams; others may work well in high-velocity streams, but may not have a high precision at lower velocities. Small units called "wading rods" are mounted on a rod; these are best for relatively slow flows in shallow streams that can be safely waded. In deeper streams, or when it is unsafe to wade in a stream, measurements can be made from a bridge or from suspension stations by using a different type of gage. These larger units can be suspended from a cable that is manipulated by a portable crane and cable reel. In these situations, a streamlined, heavy sounding weight with fins is attached to the cable to hold the gage in place against the pull of the current.

TABLE 3.1
Sample Calculations for the Float Method

Section of Stream	Width[a] (ft)	Trial	Distance[a] (ft)	Time[a] (sec)	Surface Velocity (ft/sec)	Average Surface Velocity in this Section (ft/sec)	Weighted Surface Velocity (ft/sec)	Notes
1	11	1	100	23.5	4.26	4.20	1.32	
		2	100	25.0	4.00			
		3	100	23.0	4.34			
2	10	1	100	22.0	4.55	4.61	1.32	
		2	100	21.3	4.69			
		3	100	21.7	4.61			
		4	100	21.7	4.61			
3	14	1	100	25.1	3.98	3.98	1.32	
		2	100	—	—			Float caught in branch
		3	100	25.2	3.97			
		4	100	25.1	3.98			

Surface Velocity = sum of weighted velocities = 4.23 ft/sec

Average Velocity = (multiply uncorrected velocity by 0.85 to account for variation of velocity with depth in stream) = 3.59 ft/sec

Weighted Surface Velocity is calculated by weighting sectional values according to the width of the section:

$$\text{Weighted velocity} = \frac{\text{width of section}}{\text{total stream width}} \times \text{Velocity measured in that section}$$

[a]Indicates measurements that must be taken in the stream. Others may be calculated on dry land.

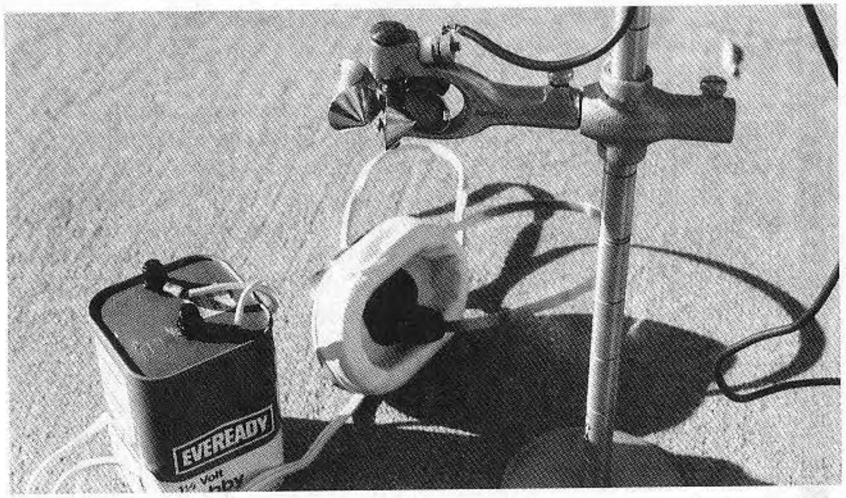


Fig. 3.18 A current-velocity meter. The cups catch the current and spin on the shaft at a rate proportional to current velocity. Each rotation causes a clicking sound in the headphones.

Preparing for the Test. In some situations, it may be worthwhile to conduct two trips to the site: one to prepare for the test and one to actually perform the test. If stream conditions are likely to change significantly, the second visit should be conducted soon after the first. For both site visits, take into the field the velocity meter(s) and spare batteries, a depth-measuring device, a measuring tape or some other device for determining stream width, a "tag line" (see what follows) and means to anchor it, tape or surveyor's flags, a calculator, and a field notebook and pencils. If measurements are to be conducted from a bridge or suspension station, take a portable crane, cable and reel, and a heavy, streamlined sounding weight with fins (or "fish").

To prepare for the test, begin by finding an appropriate stretch of stream. The stretch should be straight, relatively unobstructed, and relatively free of vegetation and tree branches or other debris. If the operator intends to wade and carry a rod-mounted meter (a "wading rod"), the depth, current, and footing of the stream bed should be checked to determine if measurements can be made safely. If the measurements are to be made from a bridge, a portable crane with a cable and reel may be set up on the bridge so that a heavy weight may be used to anchor the gage at the correct measuring point.

Measure the width of the stream, and determine the number of intervals and the locations of the measuring points. Because velocity varies across the width of the stream, finding an average velocity requires making several measurements. To determine the appropriate intervals, measure the total width of the stream and divide it into a number of sections. Using 25 to 30 sections may provide results

with fairly good precision. If obstructions such as bridge piers or abutments cause complex flow conditions, increase the number of sections. Very narrow streams may require fewer sections. Use your best judgment, based on the conditions at the site and the profile of the stream channel. The sections need not be of equal width, especially if flow conditions are complex. Ideally, each section should carry less than 10 percent of the total stream discharge. A section should not be narrower than the length of the current meter propeller or distance from rod to the end of the propeller, because such a narrow section yields no additional helpful information.

Set up the tag line, which will be used to identify the measuring points during the test. A tag line is a cable stretched across the stream perpendicular to flow, and anchored by using stakes or some other secure means (Fig. 3.19). Some tag lines are heavy cable with steel beads at regular intervals; when anchored securely, it may be possible to use this type of tagline to steady a boat while a measurement is being made. Depending on conditions, it may be possible to use a length of sturdy rope or a steel tape as a tag line. Once the width of the measurement intervals is determined, mark the line with tape or surveying flags at the locations where meter readings will be taken.

Measure the depth and velocity of the stream at a few points. Based on these measurements, choose the appropriate meter for the test (see the manufacturer's recommendations). If rotating-element meters are used, such as the "Price type" meters, use the smaller or "Pygmy" model if stream depth is less than 1.5 ft, and the larger model if the stream is deeper (USGS, 1980). Check to be sure the meter is working: Spin the propeller or cups, and watch the display or listen to the headphones to make sure that the display device is accurately indicating the rotation. (Ideally, this test should be performed before going to the field.)

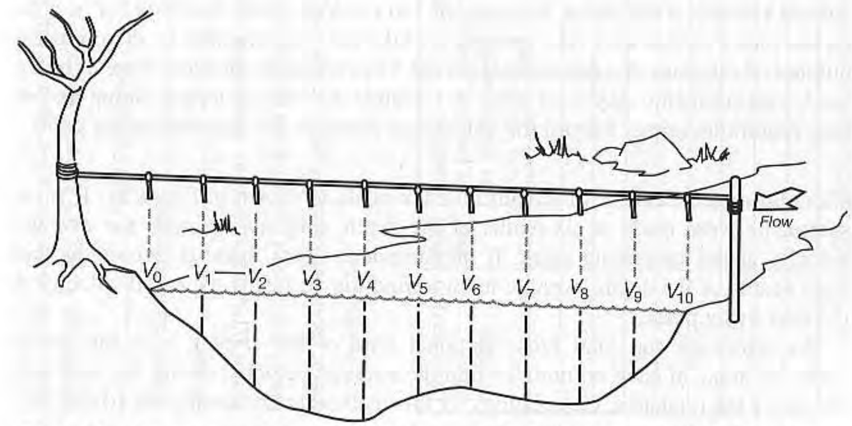


Fig. 3.19 Stretch a tag line across the stream and secure it at both ends. Mark the points at which velocity will be measured. Measure velocity at the edges of each section, not the center.

If vegetation is growing in areas where measurements are to be taken, the area should be raked to remove enough vegetation upstream and downstream of the measuring point to provide unobstructed flow and to keep vegetation from interfering with the rotation of the propeller or cups.

Before starting the measurements, construct a data table. This will facilitate recording the measurements during the test. A sample data table appears in Fig. 3.20.

Running the Test. To make a velocity measurement, go to the first measurement point in the stream, which has been previously identified on the tag line. Record the distance of this point from the bank. Measure and record the depth of the stream at the point.

Next, determine the depth at which velocity will be measured. Stream velocity varies from bottom to top of the stream. When depth is less than 2.5 ft (0.76 m), average velocity at a particular point may be approximated as the velocity at six-tenths of the depth (as measured from the top surface of the stream). Some meters automatically adjust to measure velocity at this depth; others use a system of dual scales to make the setting fairly simple.

When depth is more than 2.5 ft (0.76 m), the USGS suggests another procedure. At these points, a more accurate estimate of average velocity may be obtained by measuring velocity at two-tenths and at eight-tenths of the depth, and averaging these two measurements.

To make a measurement, adjust the height of the meter so that it measures at the appropriate depth. Ensure that vegetation and other debris will not interfere with the reading. Place the meter at the tag line. Stand to the side and slightly downstream of the meter, well away from it; stand sideways, facing the streambank. Hold the meter far enough away from yourself that you will not affect the current velocity at the meter. Keeping the rod vertical, orient the propeller or cups on the meter so that they face upstream. Make the measurement by counting the number of rotations in a certain time period. Depending on the type of meter being used, measurements may need to be of 1-minute duration or longer. Some meters may require less time. Record the value; then move to the next measuring point.

Calculations. A sample of stream measurements is shown in Fig. 3.21. If measurements were made at six-tenths of the depth, they approximate the average velocity at the measuring point. If measurements were made at two-tenths and eight-tenths of the depth, average them to find the vertically-averaged velocity at the measuring point.

To determine the total cross-sectional area of the stream, sum the cross-sectional areas of each section. To find the average velocity, divide the total discharge by the total area. Calculations for this method are summarized in Table 3.2. An example calculation is given in Table 3.3.

These measurements of average velocity also may be used to find average discharge; see the later section "Discharge," for more information.

Data Collection Form for Measuring Average Stream Velocity and Discharge Using a Current Meter

Date ______ **Field Personnel** ______________ **Job No.** ______

Stream name/number ______________________

Location ______________________

Meter type, manufacturer, and model number ______________________

Meter coefficient (velocity per revolution) ______________________

Meter mounted on rod / cable (circle one) ______________________

Comments:

Observation point number	Trial No.	Position on tag line (or distance from edge)	Total depth at observation point	Depth at which measurement is made	Number of revolutions	Elapsed time during trial	Notes

Fig. 3.20 A sample data table for stream-velocity measurements.

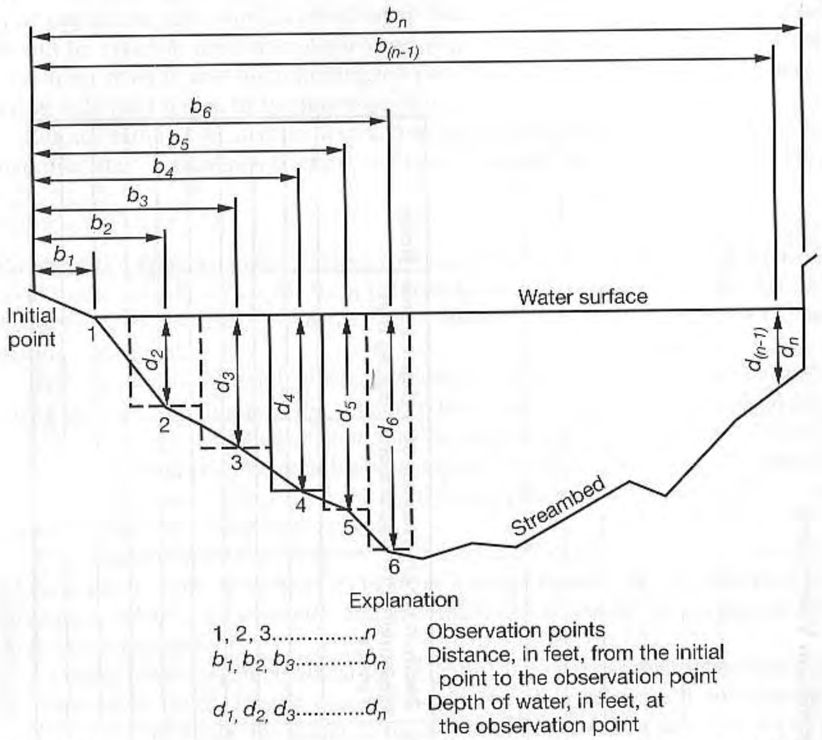


Fig. 3.21 A sample of stream measurements (after Buchanan and Somers, 1969).

Tracers

Tracers may be used to determine "time of travel", which is one method of finding velocity. The method is too complex to describe here, but several good sources (Wilson, 1968; Kilpatrick, 1970; Smart and Laidlaw, 1977; Hubbard and colleagues, 1982; Kilpatrick and Cobb, 1985; Herschy, 1995) describe it in detail. Briefly, the method involves releasing some material (usually a dye or a salt) at a point upstream, and then measuring the concentration of the material downstream. The "plume" of tracer disperses, diffuses, and is diluted as it moves downstream. Time of travel is generally taken to be the length of time it takes the peak concentration of the plume to reach the downstream point divided by the distance the tracer traveled. Critical considerations include the choice of tracer, measuring method, and measuring points. In addition, the appropriate regulatory agencies should be consulted to determine if a permit is needed before adding the tracer to the stream.

Indirect Methods

Some velocity measurements are *indirect,* that is, factors related to velocity are measured in the field, and the velocity is estimated from them. This is particularly

TABLE 3.2

Calculations of Average Stream Velocity and Discharge Using a Current Meter

Column A Observation Point	Column B Distance from Observation Point to Initial Point	Coulmn C Width of Section Encompassing this Observation Point	Column D Depth at Observation Point	Column E Area of Section	Column F Vertically-Averaged Velocity at this Observation Point	Column G Discharge Through this Section
Initial Point (a well-anchored pt. located on stream bank)	0	—	—	—	—	—
1 (edge of stream)	b_1	$\frac{b_2 - b_1}{2}$	d_1	Col. C × Col. D	v_1	Col. E × Col. F
2	b_2	$\frac{b_2 - b_1}{2} + \frac{b_3 - b_2}{2}$	d_2	Col. C × Col. D	v_2	Col. E × Col. F
3	b_3	$\frac{b_3 - b_2}{2} + \frac{b_4 - b_3}{2}$	d_3	Col. C × Col. D	v_3	Col. E × Col. F
4	b_4	$\frac{b_4 - b_3}{2} + \frac{b_5 - b_4}{2}$	d_4	Col. C × Col. D	v_4	Col. E × Col. F
5	b_5	$\frac{b_5 - b_4}{2} + \frac{b_6 - b_5}{2}$	d_5	Col. C × Col. D	v_5	Col. E × Col. F
etc.						
n (edge of stream)	b_n	$\frac{b_n - b_{n-1}}{2}$	d_n	Col. C × Col. D	v_n	Col. E × Col. F

TOTALS: Cross-sectional area = ______ Total discharge = ______

Average velocity = Total discharge/cross-sectional area

TABLE 3.3

Sample Calculation of Average Stream Velocity and Discharge

Column A Observation Point	Column B Distance from Observation Point to Initial Point (ft)	Column C Width of Section Encompassing this Observation Point (ft)	Column D Depth at Observation Point (ft)	Column E Area of Section (ft^2)	Column F Vertically-Averaged Velocity at this Observation Point (ft/sec)	Column G Discharge Through this Section (cfs)
Initial Point	0	—	—	—	—	—
1	2.0	2.5	0.00	0.0	0.00	0.00
2	7.0	5.0	0.91	4.5	0.90	4.05
3	12.0	5.0	0.93	4.5	1.00	4.50
4	17.0	5.0	1.81	9.0	1.09	9.81
5	22.0	3.75	2.67	9.75	1.21	11.80
6	24.5	2.5	2.69	6.5	1.19	7.74
7	27.0	2.5	2.56	6.25	1.24	7.75
8	29.5	2.5	2.54	6.25	1.46	9.13
9	32.0	3.75	2.61	9.75	1.73	16.87
10	37.0	5.0	2.47	12.0	2.67	32.04
11	42.0	5.0	2.47	12.0	2.51	30.12
12	47.0	5.0	2.46	12.0	2.55	30.60
13	52.0	5.0	2.47	12.0	2.43	24.30
14	57.0	4.0	2.59	10.0	2.41	24.10
15	60.0	3.0	2.63	7.8	2.45	19.11
16	63.0	3.0	2.74	8.1	2.52	20.41
17	66.0	3.5	2.68	9.1	2.45	23.11
18	70.0	4.5	2.66	11.7	2.32	27.14
19	75.0	5.0	2.47	12.0	2.49	29.88
20	80.0	5.0	2.48	11.5	2.37	28.44
21	85.0	5.0	2.31	9.5	2.22	25.53
22	90.0	5.0	1.90	9.0	2.05	19.48
23	95.0	5.0	1.81	9.0	1.89	17.04
24	100.0	5.0	1.80	9.0	1.52	13.68
25	105.0	2.5	0.00	0.0	0.00	0.00

TOTALS: Cross-sectional area = 214.2 ft^2 Total discharge = 413.49 cfs

Average velocity = Total discharge/cross-sectional area = 413.49 cfs/214.2 ft^2 = 1.93 ft/sec

useful when the current of the stream is too rapid to allow for safe direct measurement. In some streams, this is particularly relevant when the stream is in flood. Two methods are commonly used: the Manning equation and back-calculation from rating curves.

Manning Equation. The Manning equation uses four factors to estimate velocity: slope, wetted perimeter (WP), cross-sectional area, and a roughness factor (the Manning *n* value). The formula is as follows, when length is measured in meters:

$$V = \frac{R^{2/3}\, S^{1/2}}{n}$$

where V = average velocity, m/sec

S = slope of the water surface, m/m

R = hydraulic radius (R = area/WP), m^2/m

n = roughness coefficient (Manning n) (see Table 3.4)

or where length is measured in feet:

$$V = \frac{1.49R^{2/3}\, S^{1/2}}{n}$$

where V = average velocity, ft/sec

S = slope of the water surface, ft/ft

R = hydraulic radius (R = area/WP), ft^2/ft

n = Manning n (see Table 3.4)

Note that the units indicated must be used with the appropriate formula.

For normal flows, the slope used in the Manning equation is the same as the stream gradient and may be measured as described earlier. The slope of flood flows may be more difficult, or even dangerous, to measure, or the flood may recede before it is possible to measure it. In this case, it may be possible to use high-water marks to measure slope. Alternatively, the slope of the floodplain may be assumed to equal the slope of the water surface during a flood; relying on this assumption may introduce some error, depending on local topography.

The wetted perimeter used in the Manning equation is found as described earlier in this chapter. For flood flows, when it is too dangerous to make a direct reading, or when the flood recedes before the measurement can be made, the best procedure is to construct a cross-sectional profile of the channel and floodplain, up to the highest stage of the flood, and measure the WP from this profile. This should be done before the flood or after it has passed, to avoid injury. If both cross sections are measured and drawn both before and after floods, changes in channel morphology may be evaluated.

TABLE 3.4

Values of Manning's *n* for Channels of Various Types

Type of Channel and Description	Minimum	Normal	Maximum
Minor streams (top width at flood stage <100 ft)			
Streams on plain			
1. Clean, straight, full stage, no riffles or deep pools	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	0.045	0.050
5. Same as above, but lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
1. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070
Floodplains			
Pasture, no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050
Cultivated areas			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
Brush			
1. Scattered brush	0.035	0.050	0.070
2. Light brush and trees, in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
Trees			
1. Dense willows, summer, straight	0.110	0.150	0.200
2. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. Same as above, but with heavy growth of sprouts	0.050	0.060	0.080
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
5. Same as above, but with flood stage reaching branches	0.100	0.120	0.160
Major streams (top width at flood stage >100ft)			
Regular section with no boulders or brush	0.025	—	0.060
Irregular and rough section	0.035	—	0.100

Source: Chow (1959)

Cross-sectional area is determined by constructing a graphical cross section of the channel and measuring area by one of the methods described earlier. For flood flows, be sure the cross section includes the floodplain, up to the highest reach of the flood.

The Manning roughness coefficient, or Manning *n*, is chosen from the table of values. The description best fitting the channel's characteristics is determined, and then a value is read for that description.

The Manning equation gives an approximation, and should be relied on only when other methods cannot be used, such as when flood waters make direct methods unsafe.

Back-Calculation from Rating Curve A rating curve is a graph showing the relationship established between discharge and stage of a stream at a given point (Fig. 3.22). Once the rating curve has been established, if the stage is known, the discharge can be estimated from the graph. Discharge divided by cross-sectional area equals velocity. Cross-sectional area can be determined by constructing a profile of the channel, as described earlier, for a given stream stage, and measuring the area from the profile. Then discharge at that stage is divided by the cross-sectional area at that stage to yield velocity at that stage.

Discharge

Discharge (Q) of a stream is its volumetric flow rate, in units of volume per time. Discharge may be determined by calculations based on velocity and area

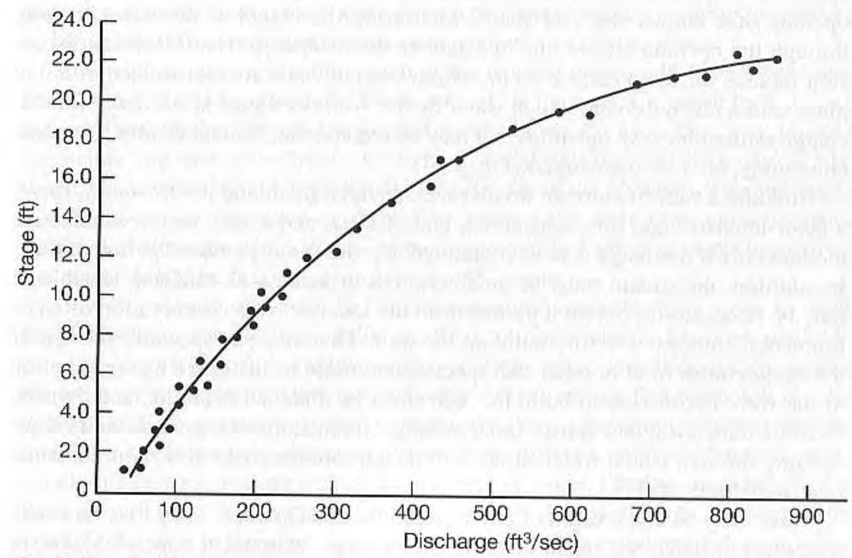


Fig. 3.22 A rating curve.

measurements, measurements with a weir, or estimations from a rating curve and stage data. For more information, see Buchanan and Somers (1969), Dunne and Leopold (1978), USGS (1980) and Herschy (1995).

Calculating Discharge from Velocity

Discharge is velocity of the stream flow multiplied by the cross-sectional area through which the flow occurs. When velocity is measured with the float method or current-velocity meter method, the cross-sectional area is determined as a part of the method. The cross-sectional area of the entire stream multiplied by the average velocity gives the discharge.

It also is possible to find the discharge within each section by multiplying area times average velocity in each section. These discharges may be summed to give the discharge of the entire stream. The result should be the same as that from the method described in the preceding paragraph.

Any discharge measurement is a single data point that represents conditions at a single point in time and space. Discharge varies over time and along the length of the stream. No single measurement should be considered to be representative of the stream discharge, because discharge varies with time and distance.

If velocity was estimated using the Manning equation, then cross-sectional area has already been determined. Multiply the average velocity by the area to get the discharge. Be cautious in using this number; recall that the results of the Manning equation are based on estimation of the *n* value, and this introduces imprecision.

Weirs

Weirs are structures built into the stream that force the water to flow through an opening of a known size and shape. Measuring the height of the water flowing through the opening allows one to calculate the discharge. The following discussion focuses on sharp-crested weirs. Sharp-crested weirs are constructed of a thin plate with a notch through which water flows. Weirs designed specifically for discharge estimation have openings that may be rectangular, V-notched at 90° (or, less commonly, 60°), or trapezoidal (Fig. 3.23).

Building a weir in a stream involves, essentially, damming it. Obviously, this is a labor-intensive and time-consuming undertaking, and it may be a cost-effective method only if discharge is to be monitored at a site for an extended period of time. In addition, the stream must be small enough to make weir-building feasible. It may be necessary to obtain a permit from the local or state conservation or environmental authorities before building the weir. This may be especially relevant if the stream holds trout or other fish species that might be disturbed by construction of the weir. Permission to build the weir must be obtained from the land owners. Existing dams, whether across small or large streams, may be used as weirs if the opening through which water flows is of an appropriate shape (for more information, see USGS, 1977).

Weirs may be constructed of any material that blocks flow. They may be small, temporary installations made of plywood, or large, permanent concrete dams, or anything in between. The important aspects are the following: Water must flow only

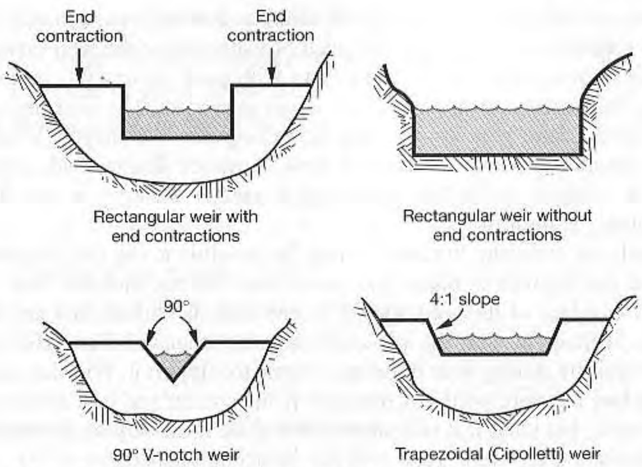


Fig. 3.23 Weirs have openings of varying shapes.

through the notch, the height of flow through the notch must be measurable, and leakage around the sides and bottom of the weir must be eliminated or minimized.

A temporary weir across a small stream can be constructed in a few hours, if the materials are at hand. The project requires several people. Planning must take place before construction begins. Measure the width and depth of the stream. Examine the stream bed. Is it made of sediments? What type? How far is it to bedrock? How high does the water rise when the stream is in flood? Remember that even a small stream, even a dry stream bed, may become a raging torrent in a sudden storm. The weir should withstand even these extreme flows.

How will water height in the notch of the weir be measured? A staff gage may be affixed to it and read from the bank, but only if the weir is accessible. A recording gage may be installed in the pool of water behind the weir. This, too, must be accessible and safe from floods. Of what material will the weir be made? If plywood, sheet metal should be fastened across the lip of the plywood. This will make a smooth surface for water to flow over, protect the weir from current-carried debris, and slow the deterioration of the plywood. To further smooth the surface, the notch should be beveled, typically at a 45° angle.

How big should the notch be? It must accommodate the flow, even in small floods. Estimate the discharge using the float, current meter, or Manning methods; estimate the largest and smallest expected flow rates; and then back-calculate from the weir equations (shown in what follows) to ensure that the notch is sized appropriately. If quantifying small variations in flow is important, do not make the notch too large, because then it will take huge differences in discharge to make small, difficult-to-measure variations in height of water. Finally, consider whether the weir will have "contractions." A contraction is the length from the edge of the notch of the weir to the point where the weir meets the stream bank. A contraction forces the water to flow away from the banks and toward the center of the weir in