

Through the National Nonpoint Source Monitoring Program (NNPSMP), states monitor and evaluate a subset of watershed projects funded by the Clean Water Act Section 319 Nonpoint Source Control Program.

The program has two major objectives:

1. To scientifically evaluate the effectiveness of watershed technologies designed to control nonpoint source pollution
2. To improve our understanding of nonpoint source pollution

NNPSMP Tech Notes is a series of publications that shares this unique research and monitoring effort. It offers guidance on data collection, implementation of pollution control technologies, and monitoring design, as well as case studies that illustrate principles in action.

March 2008

Donald W. Meals and Steven A. Dressing. 2008. Surface water flow measurement for water quality monitoring projects, Tech Notes 3, March 2008. Developed for U.S. Environmental Protection Agency by Tetra Tech, Inc., Fairfax, VA, 16 p. Available online at <https://www.epa.gov/polluted-runoff-nonpoint-source-pollution/nonpoint-source-monitoring-technical-notes>.

Surface Water Flow Measurement for Water Quality Monitoring Projects

Introduction

Measurement of surface water flow is an important component of most water quality monitoring projects. Flooding, stream geomorphology, and aquatic life support are all directly influenced by streamflow, and runoff and streamflow drive the generation, transport, and delivery of many nonpoint source (NPS) pollutants. Calculation of pollutant loads requires knowledge of water flow.

The purpose of this Tech Note is to provide guidance on appropriate ways to estimate or measure surface water flow for purposes associated with NPS watershed projects. The discussion will focus on flow measurement in open channels (natural streams and ditches) or field runoff, but will not address flow in pipes or other structures. This Tech Note will provide a brief overview of surface flow fundamentals and discuss common purposes for flow measurement, fundamental measurements that go into determining flow, some practical methods for making these measurements, and some common applications of flow data in watershed projects. Those who are unfamiliar with flow measurement should seek help from local, state, or federal agencies that routinely measure surface water flows. The U.S. Geological Survey (USGS), for example, is widely recognized as an authority on the science and technology of flow measurement.



Jeff Vanuga, USDA NRCS

Surface Flow Fundamentals

Surface water *flow* is simply the continuous movement of water in runoff or open channels. This flow is often quantified as *discharge*, defined as the rate of flow or the volume of water that passes through a channel cross section in a specific period of time. Discharge can be reported as total volume (e.g., acre-ft or millions of gallons) or as a rate such as cubic feet per second (ft³/s or cfs) or cubic meters per second (m³/s) (USGS, 2007). The terms flow and discharge are often used interchangeably, but they will be used only as defined here. Discharge data are essential for the estimation of loads of sediment or chemical pollutants exported from a river or stream

The depth of flow (m or ft) is most commonly measured as *stage*, the elevation of the water surface relative to an arbitrary fixed point. Stage is important because peak stage may exceed the capacity of stream channels, culverts, or other structures, while both very low and very high stage may stress aquatic life.

Purposes of Flow Measurement

Flow data can be used for a variety of purposes, including problem assessment, watershed project planning, assessment of treatment needs, targeting source areas, design of management measures, and project evaluation. Nonpoint source management projects generally focus on reducing either flow, availability of pollutants, or both. It is often easier and less expensive to document changes in flow than in pollutant levels as a measure of project effectiveness. The selection of appropriate flow variables depends on the specific purpose and situation.

Discharge is the most critical flow-related variable when assessing habitat conditions for fish and benthic organisms in streams with flows of up to 5 cfs, while velocity is more important in streams and rivers with greater flows (Plafkin et al., 1989). Measurement of discharge and stage is important in situations where water management is a priority concern. For example, state legislation in Florida required the South Florida Water Management District (SFWMD) to establish minimum flows and levels for Lake Okeechobee (SFWMD, 2000). A basic step in planning stream and riparian area restoration is to obtain information on the hydrology of the project area (USEPA, 1993). Development of effective urban runoff quantity control depends on good estimates of peak runoff flow rates (Horner, et al., 1994).

The relationship between discharge and pollutant concentrations is often used in both the planning and assessment phases of watershed projects. It may be possible to develop a preliminary understanding of the relative importance of various point and nonpoint sources by observing the relationship between water quality variables and discharge. Discharge and peak flow were used successfully as covariates in evaluating trends in

total suspended sediment and total phosphorus data in the Sycamore Creek, Michigan, watershed (Suppnick, 1999).

When assessing the impacts of forestry activities one should consider the size of peak flows, low-flow discharges, and annual water yield (MacDonald, et al., 1991). Peak flows are important to the stability of the stream channel, the size and quantity of bed material, and sediment transport rates, while low flows are important with regard to stream water temperature and fish habitat. Water yield is important in western states dependent upon hydropower.

The most common use of flow data by watershed projects is pollutant load calculation. Pollutant loads are critical elements of TMDL development and implementation, and reduction in pollutant load is often an important measure of success in nonpoint source watershed projects. For example, a central objective of the Otter Creek (WI) section 319 National Nonpoint Source Monitoring Program project was to reduce the loading of sediment and nutrients to the Sheboygan River and Lake Michigan through the installation of Best Management Practices (BMPs) in the Otter Creek watershed. The project documented success by showing significant decreases in suspended sediment, phosphorus, and nitrogen loads following implementation of BMPs (Corsi et al., 2005). Discharge data are essential for the estimation of loads of sediment or chemical pollutants exported from a river or stream.

There is a broad range of accuracy possible in measurement of flow, from general estimates for planning purposes, to simple measurements that can be done by citizen groups, to detailed scientific measurements conducted by the USGS or other specialists. In many cases, the Quality Assurance Project Plan (QAPP) associated with a particular project will specify the accuracy and precision of flow measurements required to meet project objectives. Numerous examples along this range will be discussed in this Tech Note; first, it is useful to present some fundamental technical information about measuring water flow.

Fundamental Measurements

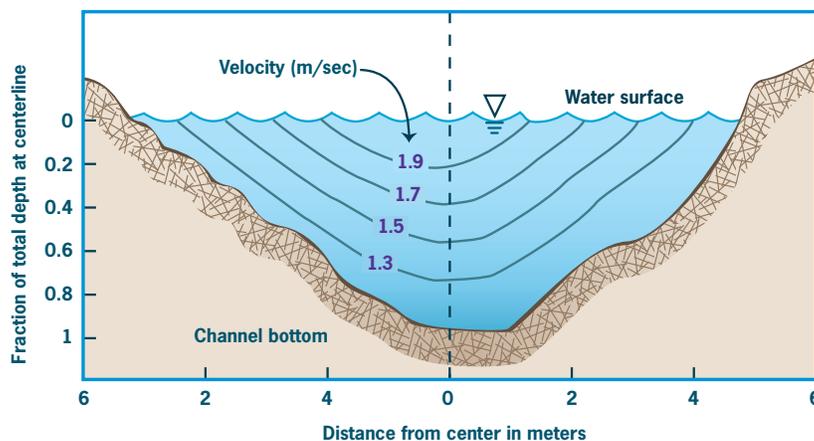
Basic Principles of Discharge Measurement

Discharge is typically calculated as the product of *velocity* and *cross-sectional area*. Surface water *velocity* is the direction and speed with which the water is moving, measured in feet per second (ft/s) or meters per second (m/s). The cross-sectional area of an open channel is the area (ft² or m²) of a slice in the water column made perpendicular to the flow direction.

Determination of discharge (usually symbolized as Q) thus requires two measurements: the velocity of moving water (V , e.g., in m/s) and the cross-sectional area of the water in the channel (A , e.g., in m^2). The product of these two measurements gives discharge in volume per unit time:

$$Q = V \cdot A \quad 1.25 \text{ m/s} \times 36 \text{ m}^2 = 45 \text{ m}^3/\text{s}$$

It is important to recognize that the velocity of moving water varies both across a stream channel and from the surface to the bottom of the stream because of friction and irregularities in cross-section and alignment. Friction caused by the rough channel surfaces slows the water near the bottom and sides of a channel so that the fastest water is usually near the center of the channel and near the surface. On a river bend, the water on the outside of the bend moves faster than the water on the inside of the bend, as it has to cover more distance in the same time. The figure below shows a generalized schematic of the pattern of water velocity in a cross-section of a stream.



Water velocities in a typical stream cross-section

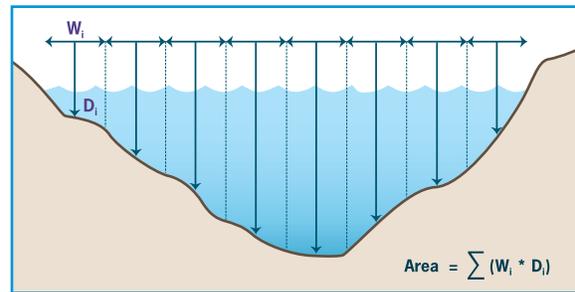
Source: L. L. Sanders. *A Manual of Field Hydrogeology*. Prentice Hall, Upper Saddle River, NJ, 1998. ISBN 0-13-227927-4.

To deal with the variability in stream velocity within any cross-sectional area, studies by USGS support several general rules of thumb:

1. Maximum velocity occurs at 5–25% of the depth, this percentage increases with increasing stream depth.
2. Mean velocity in a vertical profile is approximated by the velocity at 0.6 depth.
3. Mean velocity in a vertical profile is more accurately represented by the mean of the velocities at 0.2 and 0.8 depth.
4. The mean velocity in a vertical profile is 80–95% of the surface velocity, the average of several hundred observations being 85%.

Clearly, more than a single measurement is needed to accurately characterize the velocity of water moving down the stream, particularly when the stream channel is irregular.

Determining the *cross-sectional area* of a flowing stream usually involves measuring water depths at a series of points across the stream and multiplying by the width of the stream within each segment represented by the depth measurement. The areas are summed to determine the entire cross-sectional area, as shown at right.

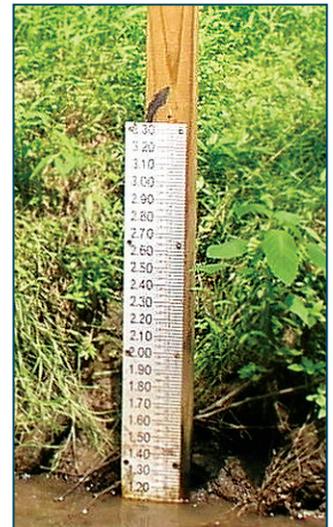


Specific approaches to measuring velocity and cross-section area are discussed in the next section.

Stage Measurement

Stream stage is an important parameter of streamflow measurement. While stage itself may be of interest in some cases, such as flood management or the design of structures, stage can also be a surrogate for stream cross-sectional area if the stream channel has been surveyed and a component of a stage-discharge relationship used to calculate flow.

In a particular location, stage is often measured relative to a fixed point using a staff gage, a rigid metal plate graduated in meters or feet attached to a secure backing and located in a part of the stream where water is present even at low flows. During installation, staff gages are usually related by survey to a fixed reference (e.g., a bridge deck) so that the elevation of the gage can be checked periodically and re-established if it has been disturbed. Stage measurements are taken by simply noting the elevation of the water surface on the graduations of the staff gage; such instantaneous stage data are easily collected by volunteers. Volunteers can, for example, record stage observations each time they collect a sample or make a field measurement in order to place results in context of general flow conditions. In the case of very large rivers, stage can also be read by measurement of the distance from a fixed overhead point to the water surface, e.g., using a weighted wire or tape lowered from a bridge beam.



Stage-Discharge Curves

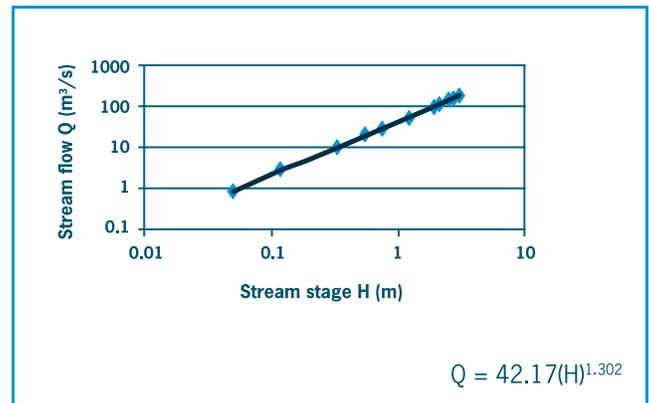
Simple manual stage measurements can give a rough qualitative indication of the magnitude of discharge (caution: the relationship between stage and discharge is not linear). The greatest utility of stage measurements, however, is in the construction of a stage-discharge relationship, also known as a stream rating. A stage-discharge relationship is an equation determined for a specific site that relates discharge to stage,

based on a linear regression of a series of concurrent measurements of stage and discharge. This equation should be based on measurements taken over a full range of streamflow conditions; it is not acceptable to extrapolate the rating equation beyond the range of observations that it is based on, unless measurements are being done in a precisely constructed channel of regular geometry. As shown in the stream rating curve at right, stage–discharge relationships usually take on a log-log form. With a valid stream rating, discharge can be determined simply from a stage observation plugged into the equation or read from a table. For more information on stage–discharge ratings, see:

<http://www.info.usda.gov/CED/ftp/CED/neh630-ch14.pdf>

<http://www.wrcamnl.wr.usgs.gov/sws/SWTraining/RatingsWeb/Index.html>

Note that stream rating curves should be checked periodically, especially after major high-flow events because of possible changes in the stream channel. Rating curves sometimes shift due to changes in streambed slope, channel roughness, and due to filling, scouring, or reshaping of streambanks.



Stream stage-discharge rating curve

Flow Measurement Methods

The preceding material discussed some technical fundamentals underlying good measurement of streamflow variables. The following paragraphs will discuss how to conduct such measurements. Depending on what kind of flow data are needed and the purpose(s) the data will serve, there are several options for flow data ranging from observation of peak stage during an event, estimation of average annual stream discharge, instantaneous flow measurement, and continuous flow measurement using automated equipment. Regardless of the particular method used, it is always essential to document the source and basis of flow measurements to assure acceptable data quality.

Peak Stage Measurement

Knowledge of peak stage—how high the water reached—during a storm event or flood is often crucial information. In urban watershed projects where reduction of peak stormwater flows is a major goal, tracking peak stream stage (and precipitation) during storm events before and after watershed treatment can be a simple and inexpensive surrogate for monitoring actual streamflow. Peak stage may be important to know for stream restoration projects where high flows shape the physical habitat of the stream. Of course,

peak stage is essential to know in flood planning, especially for flood frequency statistics, floodplain management, and design/protection of structures.

Peak stage can be observed by several informal means. Direct observations made during high flow events can record the maximum height of water on buildings or other structures. After flood waters recede, debris lines left on buildings or riparian vegetation can suggest the general height of peak stage. More precise records of peak stage can be obtained using specialized crest gages. A typical crest gage consists of a 2-inch diameter galvanized pipe containing a wood staff held in a fixed position in relation to a reference. The bottom cap has intake holes and contains granulated cork. As the water rises inside the pipe, the cork bits float on the water surface. When the water begins to recede, cork adheres to the staff inside the pipe thereby marking the high point of the flood. The gage height of a peak is obtained by measuring the interval on the staff between the reference point and the floodmark. More information about crest gages is available at <http://pubs.usgs.gov/fs/2005/3136/fs2005-3136-text.htm>.

Estimation of Annual Discharge

Planning for a watershed project may require an estimate of total annual discharge from an ungaged watershed. Such an estimate can be made simply using data from a nearby stream gage with a good historical record, such as one operated by the USGS. Data summaries published by USGS (<http://waterdata.usgs.gov/nwis/rt>) typically contain statistics on annual total discharge, long-term mean discharge, and a statistic on average annual discharge per unit area of watershed, usually expressed as ft^3/mi^2 , or cfs/m. One very simple estimation technique is to multiply the cfs/m for an appropriate nearby USGS station by the area of the study watershed to come up with an estimated average annual discharge. Alternatively, the distribution of annual discharge from a nearby USGS station can be evaluated to predict the mean, median, and range of annual discharge to be expected from the study watershed. Thirdly, if precipitation data are available, the correlation between annual precipitation and annual discharge in a nearby monitored watershed can be used to predict annual discharge from the study watershed.

Selecting a nearby USGS gaging station as a basis for any of these estimation approaches requires careful consideration. It is best if the data come from a site very near the study watershed and that the monitored watershed has similar topography and land cover. This is especially true if direct comparisons of annual discharge values are to be made; be sure that land use and land cover—particularly urbanized areas with much impervious cover—in the gaged watershed are comparable with the study watershed.

Instantaneous Flow Measurement

It is often necessary to estimate or measure discharge at a particular site at a particular time, either to document flow under certain conditions or to develop a data base for a stage-discharge rating. There are numerous ways to come up with an instantaneous discharge number, varying in accuracy and in applicability by the size of the stream.

Manning's Equation. Discharge may be computed based on a slope-area method using the Manning equation:

$$Q = \frac{1.486}{n} A R^{2/3} S^{1/2}$$

Where:

Q = discharge in ft³/s

A = mean area of the channel cross section in ft²

R = mean hydraulic radius of the channel in ft

S = slope of the water surface

n = roughness factor depending on the character of the channel lining

Hydraulic radius is defined as the cross-sectional area divided by the wetted perimeter (the distance around the stream bed cross section that is under water).

Application of the Manning equation requires a straight stream reach between 200 and 1000 ft (61–305 m) in length. Slope of the water surface is determined from accurate measurements of stage at the upstream and downstream ends of the reach referenced to a common fixed point. The n factor depends on the character of the channel, varying between 0.01 for smooth concrete to 0.10 for weedy streams with deep pools. Note that the proper selection of a roughness factor is difficult in many cases and discharge determined by this method is only approximate.

Direct measurement. There are several approaches to direct measurement of discharge; the specific choice depends largely on the size of the stream and the resources or expertise available. In general, for any of these methods, it is important to select a straight stream reach, free of large obstructions and pools, with as regular a cross-section as possible. It is also advisable to avoid areas within or immediately downstream of bridges or culverts because of the changes in hydraulic conditions around these obstructions to flow.

Volumetric measurement. For very small flows, e.g., low-flows in ditches or small streams or discharge from drain outlets, the most accurate method of discharge measurement is to simply measure the time required to fill a container of known

Some typical values for Manning's n

Description	Normal value of n
Natural stream, clean, straight, full stage, no rifts or deep pools	0.030
Mountain stream, gravels, cobbles, and few boulders	0.040
Floodplain, light brush and trees	0.060
Excavated earthen channel	0.018
Corrugated metal culvert, 36 in.	0.019

volume. In some circumstances, it may be necessary to use sandbags to temporarily channel flow to a practical collection point. Volumetric measurements should be repeated several times and an average computed.

Dilution methods. Dilution methods of discharge measurement consist of adding a concentrated tracer solution (salt or dye) of known strength to the stream and by chemical analysis determining its dilution after it has flowed far enough to mix completely with the stream and produce a uniform final concentration in the stream. Discharge is calculated as:

$$Q = q * (C_1 - C_2)/(C_2 - C_o)$$

Where:

Q = stream discharge

q = tracer injection rate

C_1 = tracer concentration in injection

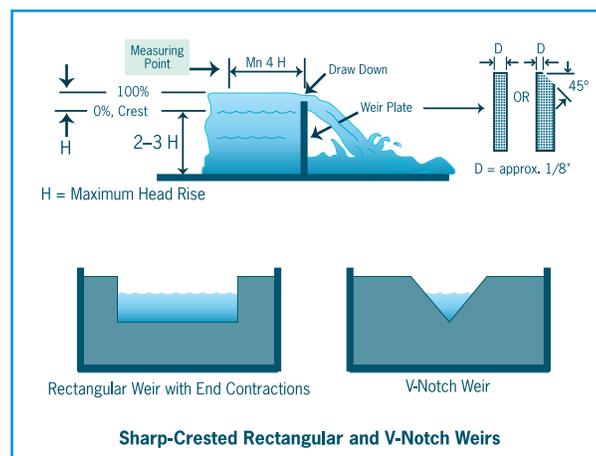
C_2 = final concentration of tracer in the stream

C_o = background tracer concentration in the stream

The particular tracer selected should be conservative, i.e. not taken up by sediments or living organisms in the stream and should be easily measured in the laboratory or in the field. Salt (NaCl) and Rhodamine dye are commonly used tracers; Rhodamine dye can be analyzed in the field by fluorescence. Regardless of the tracer selected, note that a permit or at least notification of the state environmental agency may be required before adding such materials to public waters.

Weirs and flumes. For long-term projects, discharge can be measured using a weir or flume, often referred to as a primary device. A primary device is a structure that water flows through or over that has a known relationship between stage and flow. If a device can be used, discharge measurement can be as simple as observing the stage of water just upstream of the device and consulting a table or using a simple equation to calculate discharge.

There are numerous devices for this purpose, with different applicability. Weirs are essentially dams built across an open channel over which water flows through a specially shaped opening or edge. Weirs are classified according to the shape of their opening—e.g., a 90° V-notch weir has a notch shaped like an inverted right triangle, whereas a rectangular weir has a rectangular notch. Each type of weir has an associated equation for determining the discharge rate, based on the depth (stage) of



water in the pool formed upstream of the weir. In practice, weirs can range from small wood or metal plates temporarily mounted across small ditches or streams to more permanent installations involving concrete walls and other structures. Note that erecting any obstruction in a stream will create a pool upstream and care must be taken to avoid creating the potential for flooding during high flows. In some cases a permit may be required.

Flumes are specially shaped open channel flow sections that restrict the channel area, resulting in increased velocity and a change in water level as water flows through a flume. The discharge through a flume is determined by measuring the stage in the flume at a specific point, depending on the type of flume. In general, flumes are used to measure discharge where weirs are not feasible; flumes are often used to measure field runoff where flows during storm events can be collected and channeled through the device. Flumes are well-suited to measurement of flows containing sediment because the increased velocity through the flume tends to make it self-cleaning. Commonly used flumes include the Parshall and Palmer-Bowlus. The H-flume is a special flume developed for agricultural field research that can measure discharge over a wide range with good accuracy. Flumes come in a wide range of sizes denoting the maximum depth of flow they can accommodate and can be purchased as prefabricated units or built on-site.

Most devices have exacting specifications for installation that may present construction challenges. For more information on weirs and flumes, see http://www.usbr.gov/pmts/hydraulics_lab/winflume/.

Area-velocity technique. The most common method of measuring discharge in open channels is by measuring the cross-sectional area and the mean water velocity, as generally described earlier.

Discharge in a small, wadable stream can be measured by the following process:

- **Select location** – Choose a straight reach, reasonably free of large rocks or obstructions, with a relatively flat streambed, away from the influence of abrupt changes in channel width
- **Establish cross-section** – Determine the width of the stream and string a cable or measuring tape across the stream at a right-angle to the flow. Divide the width



120° V-notch weir

Don Meals, Tetra Tech, Inc.



H Flume

Don Meals, Tetra Tech, Inc.

into 20 to 25 segments (streams less than 10 ft (3 m) wide may not allow as many segments) using tape or string to mark the center of each segment on the cable; typically, the stream is divided into enough segments so that each one has no more than 10 percent of the total streamflow.

- **Measure depth of each segment** – At each mark across the stream, measure the depth from the water surface to the bottom with a graduated rod or stick.
- **Measure water velocity** – At each mark, measure the velocity of the water (see below). Where depth is less than 2.5 ft (0.8 m), a single velocity measurement at 0.6 of the total depth below the water surface gives a reasonable estimate of the average velocity with respect to depth. For depths of 2.5 ft or more, the average of velocity measurements taken at 0.2 and 0.8 of depth is preferred.
- **Calculate discharge for each segment** – For each segment, stream discharge is the product of width of the segment and the measured depth (giving area) multiplied by the velocity measured in that segment.
- **Sum discharges** – Total stream discharge is the sum of all segment discharges.

While wading is the preferred method for accurate discharge measurement, there are obvious safety considerations that limit the flows at which wading can be accomplished. The USGS has a rule of thumb that prohibits wading if the product of depth (in ft) and velocity (in ft/s) exceeds 8 anywhere in the cross-section. Discharge measurement in larger rivers or at high flows follows the same principles of area and velocity, but requires specialized techniques. These include suspension of equipment from bridges, cranes, or cableways, use of weighted sounding lines, and the use of heavy equipment for velocity measurement.

Accurate velocity measurement is a critical component of the area-velocity technique. Several simple methods have been used to obtain rough estimates of velocity. Measuring the time required for a floating object (usually an orange or a tennis ball) to travel a length of stream is a common technique. This approach has the obvious limitation of measuring only velocity at or near the water surface (see discussion of velocity above under “Basic principles of discharge measurement.”) Velocity estimates of this type can be improved by averaging several measurements across the width of a stream, but such estimates still ignore vertical variations. In very small streams, vertical variations in velocity can be accounted for by releasing a floating object (such as a ping-pong ball) from the streambed and measuring the time and distance required for it to pop to the surface. In concept, this technique integrates the vertical velocity profile; in practice it is very difficult to measure both time and horizontal distance with acceptable accuracy.



Low-flow wading measurement

J. Shredd, WA State Dept. of Ecology

In most cases, velocity is best measured using some sort of current meter. Current meters of several different types exist, including rotating cup types like the Price AA or pygmy models, propeller types such as the Ott meter, and electromagnetic sensors. Any of these can be attached to a wading rod that can simultaneously measure depth; larger models can be attached to weighted cables for suspension from bridges or cableways.

Technology for velocity measurement is evolving. For example, acoustic Doppler technology can measure velocity distributions within the flow, eliminating the need for wading or introducing instruments into the water. In tidal areas it may be necessary to use advanced technology to account for backflow.

Accurate measurement of stream discharge is an exacting task and there are many technical details that are beyond the scope of this Tech Note. The information here is given for guidance only; consult more comprehensive information for actual application of individual techniques. The USGS offers standard technical guidance for stream gaging, http://pubs.usgs.gov/twri/twri3-A6/pdf/twri_3-A6_a.pdf, and for discharge measurement at gaging stations, http://pubs.usgs.gov/twri/twri3a8/pdf/TWRI_3-A8.pdf.



Examples of current meters

Continuous Discharge Measurement

A single instantaneous measurement of stream discharge is of limited utility because it provides information about only a single point in time. Where a project seeks to measure pollutant load over time or to assess relationships between stream discharge and pollutant concentrations or aquatic life, it usually becomes necessary to measure discharge continuously.

Continuous discharge measurement in open channels usually requires that the stage-discharge relationship is known, either through development of a stream rating as described above or by the installation of a weir or flume. In either case, continuous discharge measurement then becomes an exercise in continuously measuring stream stage. Depending on the installation, this can be accomplished in a number of ways.

A stilling well is a vertical tube or pipe that is hydraulically connected to the channel such that the level of water in the stilling well matches that in the channel, but the transient variations due to waves or turbulence are damped out. Stilling wells can range from an 8 in. (20 cm) diameter pipe connected to the side of a flume to a 3 ft (0.9 m) diameter pipe placed in the ground and connected by pipes to a stream. Several devices exist to measure and record stage in a stilling well. Traditionally, this was done using a float attached to a

pulley that rose and fell with the water level in the well and moved a pen on a clock-drive chart recorder (e.g., Stevens Type A). There are modern versions that use electric chart drives or digital recording systems.

Other approaches to measuring and recording level, either in stilling wells or directly in the channel include:

- **Bubblers**, where air or an inert gas is forced through a small diameter bubble line submerged in the flow channel; the water level is measured by determining the pressure needed to force air bubbles out of the line;
- **Pressure transducers**, where a probe fixed to the bottom of the channel senses the pressure of the overlying water; and
- **Ultrasonic sensors**, where the sensor is mounted above the flow stream, and transmits a sound pulse that is reflected by the surface of the flow. The elapsed time between sending a pulse and receiving an echo determines the level in the channel.

Output from level recording sensors can either be recorded directly into a basic data logger for later processing or into a specialized flow meter. There are several manufacturers of such meters; the meters often include the facility to calculate and record discharge and summary statistics, record other data such as precipitation, and interact with other devices such as automated water samplers.

Applications of Flow Data

As for all monitoring, the collection of flow data should be designed to provide datasets suitable for data analysis procedures that will allow the project to meet specified objectives. A wide range of objectives are possible, including:

1. Determine basic hydrology of a watershed (e.g., water budget)
2. Characterize water quantity problems in a watershed and evaluate efforts to restore natural flow regimes
3. Identify major sources of pollutant loads in watershed
4. Characterize habitat problems in stream channels
5. Collect habitat data in support of benthic or fish monitoring
6. Quantify discharges from tributaries or major sources
7. Calibrate watershed models
8. Collect design information for water quantity, water quality, or stream restoration practices
9. Quantify pollutant loads in support of TMDL development or other watershed project planning efforts
10. Quantify pollutant loads before and after implementation of practices to determine project effectiveness

The flow variables and the frequency with which they are measured depend on the project objectives and data analysis plans. For example, single measures of instantaneous stream discharge are highly unlikely to satisfy any of the above objectives because they represent only a snapshot in time. If conducted as part of a synoptic survey within a study watershed, however, such data might be useful in comparing the hydrologic behavior of subwatersheds, characterizing the relative magnitudes of loads or flows from subwatersheds, or calibrating a hydrologic model for the study watershed.

Systematic collection of peak stream stage data has wide application for flood management, stormwater projects, nonpoint source projects, and habitat restoration efforts. In urban watersheds where streams are shaped by peak discharges, management of water quantity is often the first objective of watershed projects, for both stream morphology and biological concerns. Peak stage is relatively easy and inexpensive to monitor and a comparison of peak stage before and after a program of stormwater best management practices (BMPs) could be quite useful. Knowledge of changes in peak water levels can also be critical in stream restoration projects for both physical channel work and restoration of biotic communities. It will be necessary in these cases to monitor precipitation and other important explanatory variables to interpret changes in peak stage values.

Continuous stream discharge data are essential to any watershed project that focuses on pollutant loads. Discharge data play an important role in the design of sampling programs for many objectives. Because concentrations of many NPS pollutants are strongly associated with discharge, many sampling programs are stratified by flow conditions—more samples are taken at higher discharges, for example. Flow proportional sampling—a powerful and efficient sampling design for NPS load monitoring—requires good discharge data to drive sampling for water chemistry.

Discharge can be used to diagnose water quantity problems in watersheds and may itself be a variable expected to respond to implementation of BMPs. For example, Baker and Richards (2004) proposed a *Flashiness Index*—a measure of the frequency and rapidity of short-term changes in streamflow, calculated from mean daily stream discharge data. Flashiness is an important component of a stream's hydrologic regime; land use and land management changes may lead to increased or decreased flashiness, often impairing aquatic life. The Index can be used to quantify the hydrologic impacts of watershed change and to evaluate programs aimed at restoration of natural streamflow regimes. Flow data may also be useful in evaluating agricultural programs where BMPs may promote infiltration over runoff or where drainage practices influence surface water flows. The relationship between discharge and pollutant concentration may also change in response to BMP implementation. Suspended sediment concentrations might be lower after implementation of conservation tillage, for example, at comparable flows; good discharge data would be important to document this change.

Even simple calculation of loads based on multiplying a concentration by the total discharge over the period represented by the concentration observation (numeric integration) requires good discharge data. More sophisticated (and accurate) load estimation procedures such as regression of discharge and concentration or ratio estimators require accurate discharge data. Note that when chemical constituents are measured very precisely (e.g., to mg/L), accuracy of discharge measurements becomes the most critical component of load calculations and the largest source of error. In addition to the accuracy of flow measurement, there are numerous considerations for accurate estimation of pollutant load that are beyond the scope of this Tech Note. Consult other sources of information for guidance on proper load estimation techniques (e.g., USDA, 1996; Richards, 1997).

References and Additional Resources

- Baker, D.B., R.P. Richards, T.T. Loftus, and J.W. Kramer. 2004. A new flashiness index: characteristics and applications to midwestern rivers and streams. *J. Amer. Water Resour. Assoc.* 40(2):503–522.
- Corsi, S.R., J.F. Walker, L. Wang, J.S. Horwathich, and R. T. Bannerman. 2005. Effects of Best-Management Practices in Otter Creek in the Sheboygan River Priority Watershed, Wisconsin, 1990–2002. Scientific Investigations Report 2005-5009, US Geological Survey, Reston, VA.
- Horner, R.R., J.J. Skupien, E.H. Livingston, and H.E. Shaver. 1994. *Fundamentals of urban runoff management: technical and institutional issues*, Terrene Institute, Washington, DC.
- MacDonald, L.H., A.W. Smart, and R.C. Wissmar. 1991. *Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska*, EPA/910/9-91-001, Water Division, U.S. Environmental Protection Agency, Region 10, Seattle, WA.
- Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross, and R.M. Hughes. 1989. *Rapid bioassessment protocols for use in streams and rivers: benthic macroinvertebrates and fish*, EPA/444/4-89-001, Office of Water, U.S. Environmental Protection Agency, Washington, DC.
- Richards, R.P. 1997. *Estimation of pollutant loads in rivers and streams: A guidance document for NPS programs*. Draft. Water Quality Laboratory, Heidelberg College, Tiffin, OH.
- SFWMD. 2000. *Minimum flows and levels for Lake Okeechobee, the Everglades, and the Biscayne Aquifer*, South Florida Water Management District, <http://my.sfwmd.gov>, retrieved July 11, 2007.

Suppnick, J. 1999. *Water chemistry trend monitoring in Sycamore Creek and Haines Drain, Ingham County, Michigan 1990–1997*, MI/DEQ/SWQD-99/085, Surface Water Quality Division, Michigan Dept. of Environmental Quality, Lansing, MI.

USDA (U.S. Department of Agriculture). 1996. *National handbook of water quality monitoring, part 600 national water quality handbook*. U.S. Department of Agriculture, Natural Resources Conservation Service, Washington, DC.

USDI Bureau of Land Reclamation. 2001. *Water Measurement Manual*.
http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/

USEPA. 1993. *Guidance specifying management measures for sources of nonpoint pollution in coastal waters*. 840-B-92-002, Office of Water, U.S. Environmental Protection Agency, Washington, DC.

USGS Techniques of Water Resource Investigation
<http://pubs.usgs.gov/twri>

USGS. 2007. *Science in your watershed – general introduction and hydrologic definitions*.
<http://water.usgs.gov/wsc/glossary.html>, retrieved July 10, 2007.

Walkowiak, D.K. (editor) 2006. *ISCO Open Channel Flow Measurement Handbook*.
Teledyne Isco, Lincoln, NE.
<http://www.isco.com/>