ESTIMATING DISCHARGE AND STREAM FLOWS

A GUIDE FOR SAND AND GRAVEL OPERATORS

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WASHINGTON STATE DEPARTMENT OF ECOLOGY

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CONTENTS

PURPOSE AND LIMITATIONS OF THIS GUIDE 1

OVERVIEW OF THE NEW SAND AND GRAVEL GENERAL PERMIT 2

BASIC TERMS AND CONCEPTS 2

MEASUREMENT TECHNIQUES 5

MEASURING SITE DISCHARGE 6
- BUCKET AND STOPWATCH METHOD 6
- FLOAT METHOD 8
- MANNING'S EQUATION METHOD 9

ESTIMATING RECEIVING WATER FLOWS 13
- USING STREAM GAGE DATA 13
- FLOAT METHOD 14
- MEASURING FLOW WITH A METER 16

APPENDIX
- Cross-Sectional Areas
- Manning's Roughness Coefficients
- Area and Hydraulic Radius for Various Flow Depths (for Manning's Equation)

Glossary

Conversions

References

Receiving Water Flow Information Form

PURPOSE AND LIMITATIONS OF THIS GUIDE

In January 2005, The Washington State Department of Ecology (Ecology) reissued the Sand and Gravel General Permit for process water, stormwater, and mine dewatering water discharges associated with sand and gravel operations, rock quarries and similar mining facilities. A new condition has been included in the permit that calls for the estimation of flow. Permit holders are now required to estimate discharge flow from their sites as well as the flow in the stream or river (described as the receiving water in the permit) the discharge flows into. Ecology needs these flow estimates to better understand the potential for impacts to receiving water quality.

The purpose of this guide is to provide permittees with detailed descriptions of a few of the easiest or most common methods for taking flow measurements, if they choose to manually collect the data on their own. The intent is to assist permittees in understanding how to meet the permit requirements in a manner that is simple yet also accurate enough to meet Ecology's needs. Other methods, not described in this guide, such as hydrologic models, in-pipe flow meters, calculations based on pump usage, automated flow devices, and others could also be used. Any flow estimating method that meets the intent of the permit would be accepted by Ecology.

The methods presented may not be useful in every situation. In some cases, permittees may require technical assistance because of time constraints, site complexities or equipment requirements. Skilled professionals could also provide advice on additional techniques not covered in detail here.

It is important to note that the permit requires the estimation of "receiving water" flow. In simplest terms the receiving water is the stream or river your site's stormwater or process wastewater discharge flows into. However, in some cases it can be difficult to distinguish a natural receiving water from a drainage ditch. A definition and some criteria for determining what constitutes an official receiving water is provided in the following section.

Overview of the New Sand and Gravel General Permit

Although the general permit authorizes process water and stormwater discharges to waters of the State of Washington, the permit holders and Ecology each have a responsibility in protecting the quality of the State's waters. Prior permit conditions included monitoring stormwater and wastewater discharges for water quality parameters such as pH, turbidity, and temperature. All monitoring was limited to discharges from the site, and did not reflect conditions in the receiving water. While this data has been useful and is still part of the permit requirements, more information is needed to better assess the potential for impacts to the receiving waters. By monitoring discharge flows and estimating the typical low flows of the receiving water, a more complete picture of receiving water impacts can be formed.

The key flow monitoring requirements of the new general permit include:

Measuring/estimating discharge flow each time turbidity (twice a month) or temperature sampling occurs (weekly during July, August, and September) and

Estimating the typical low flow of the receiving water at the time of critical condition for turbidity and temperature.

There are two separate 'waters' that will be measured: receiving water and discharge water. The methods used to measure discharge flow from a site may be different than the methods used to measure flow in the receiving water. In this guide, the techniques are described in two different sections and focus on methods specific to that 'water'. As the permittee, you will need to choose the methods and develop systems for monitoring that meet the requirements but also are specific to your operations and site conditions.

Basic Terms and Concepts

Before any of the flow measuring techniques can be explained, the basic terms associated with flow should be understood and are defined in this section. It is important to note that the definitions used here and in the permit, may be different from other definitions used by Ecology or other regulating agencies.

Site discharge: In this guide, discharge refers to the water generated by the facility. It may be dewatering water, wash water, stormwater, or any combination of these. This term is comparable to "flow" which is used here in reference to receiving water flow. [Usually site discharge is measured in gallons per minute (gpm).]

Representative discharge: This is the site discharge source that most accurately characterizes the discharge from your site activities. It is often the largest volume of discharge. However, there may be some situations where it is not the largest. For example, stormwater that is not mixed with any kind of process water may be the largest volume discharged from your site but your process water (which could be a smaller volume discharge) may actually better represent the water considered as the representative discharge.

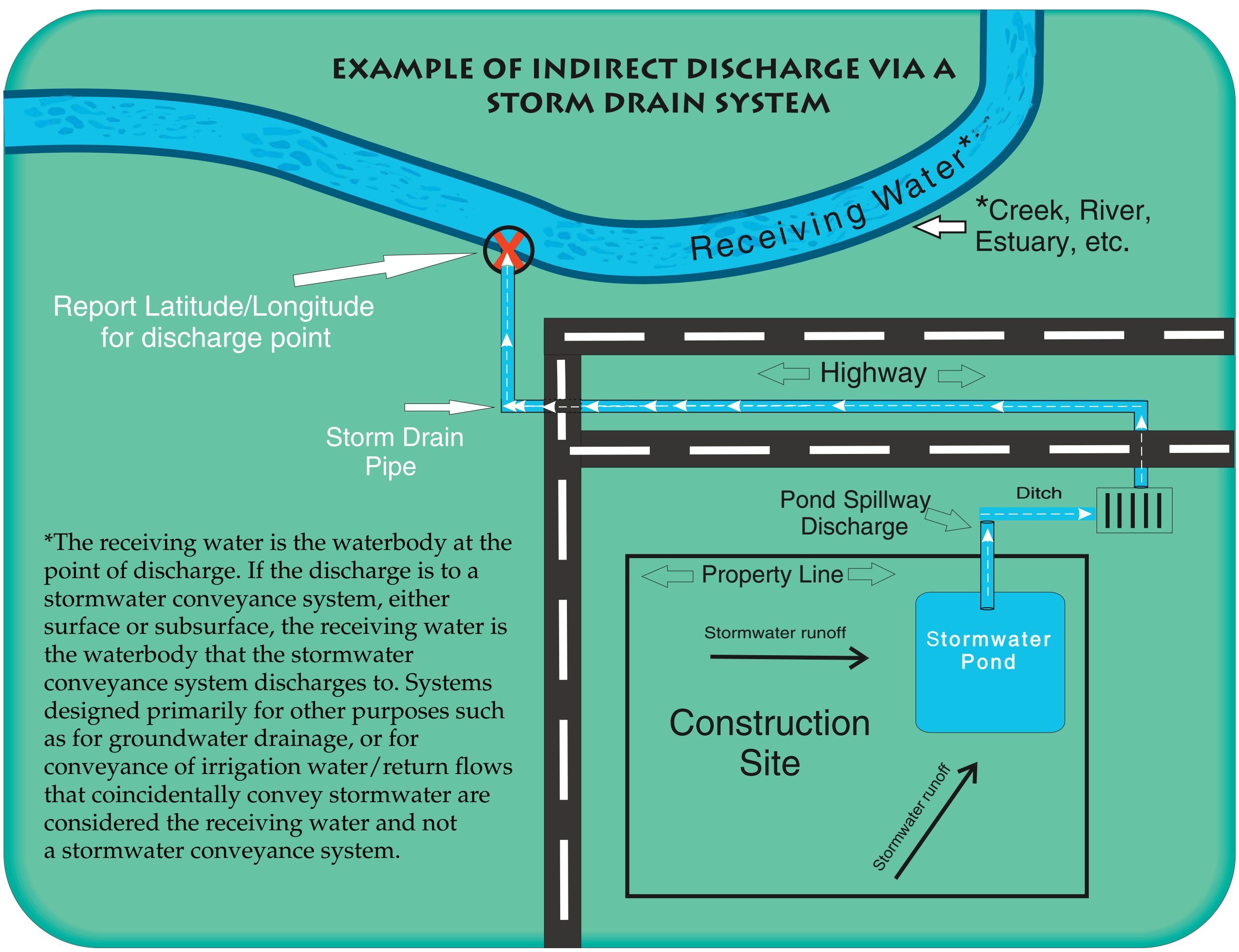
Flow or Flow volume: This takes into account both the rate of flow and the size of the flow. Typically when a "flow measurement" is required, it is the flow volume that is being referred to. To meet permit requirements, the flow volume needs to be estimated for both the discharge and receiving water. [Measured in cubic feet per second (cfs) or gallons per minute (gpm).]

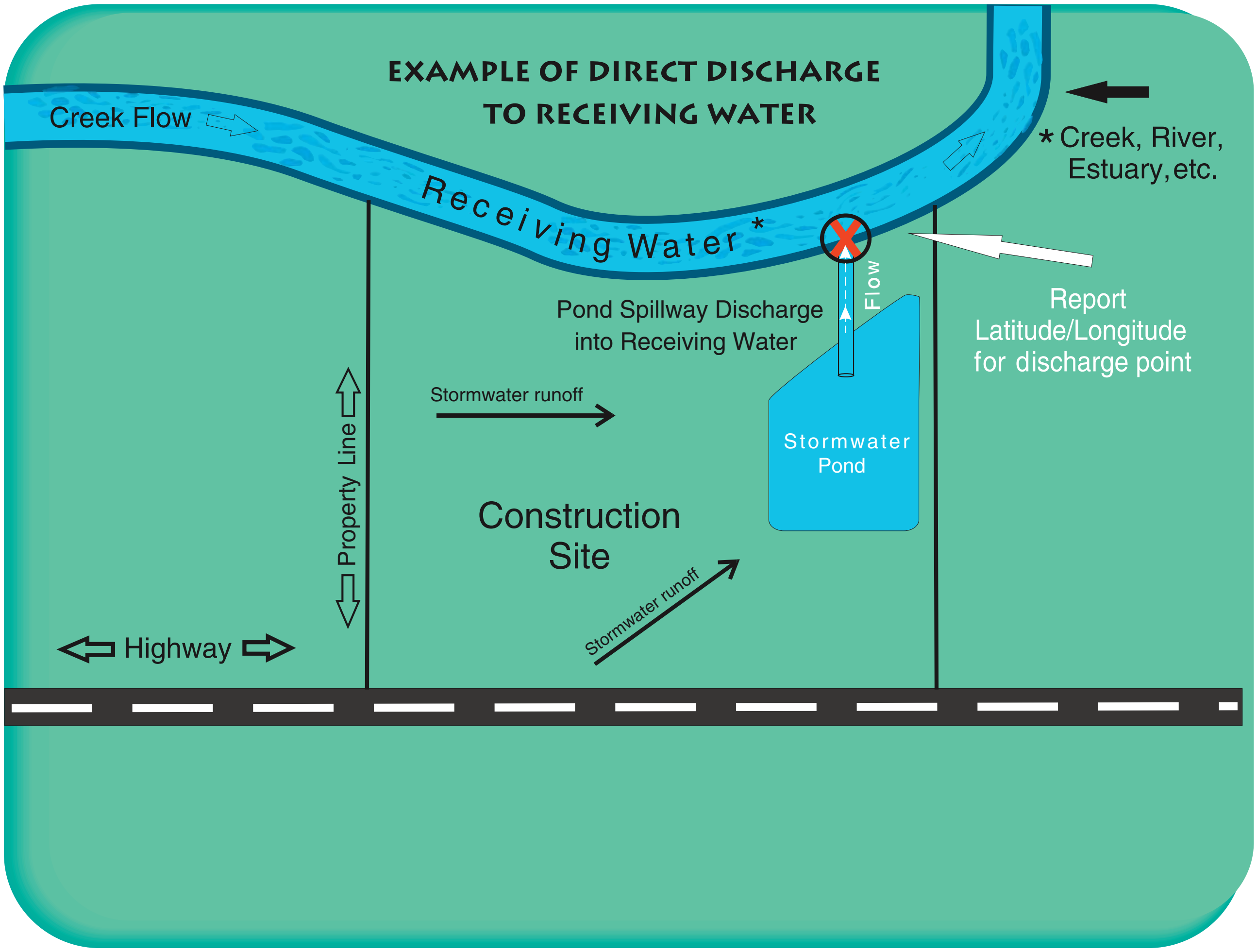
Rate of Flow or Velocity: This refers to how quickly the water is moving. [Measured in feet per second (ft/s).]

Receiving water:

> Note: For the purposes of the data that Ecology is targeting to collect, the term 'receiving water' has been defined slightly differently here than what many are used to.

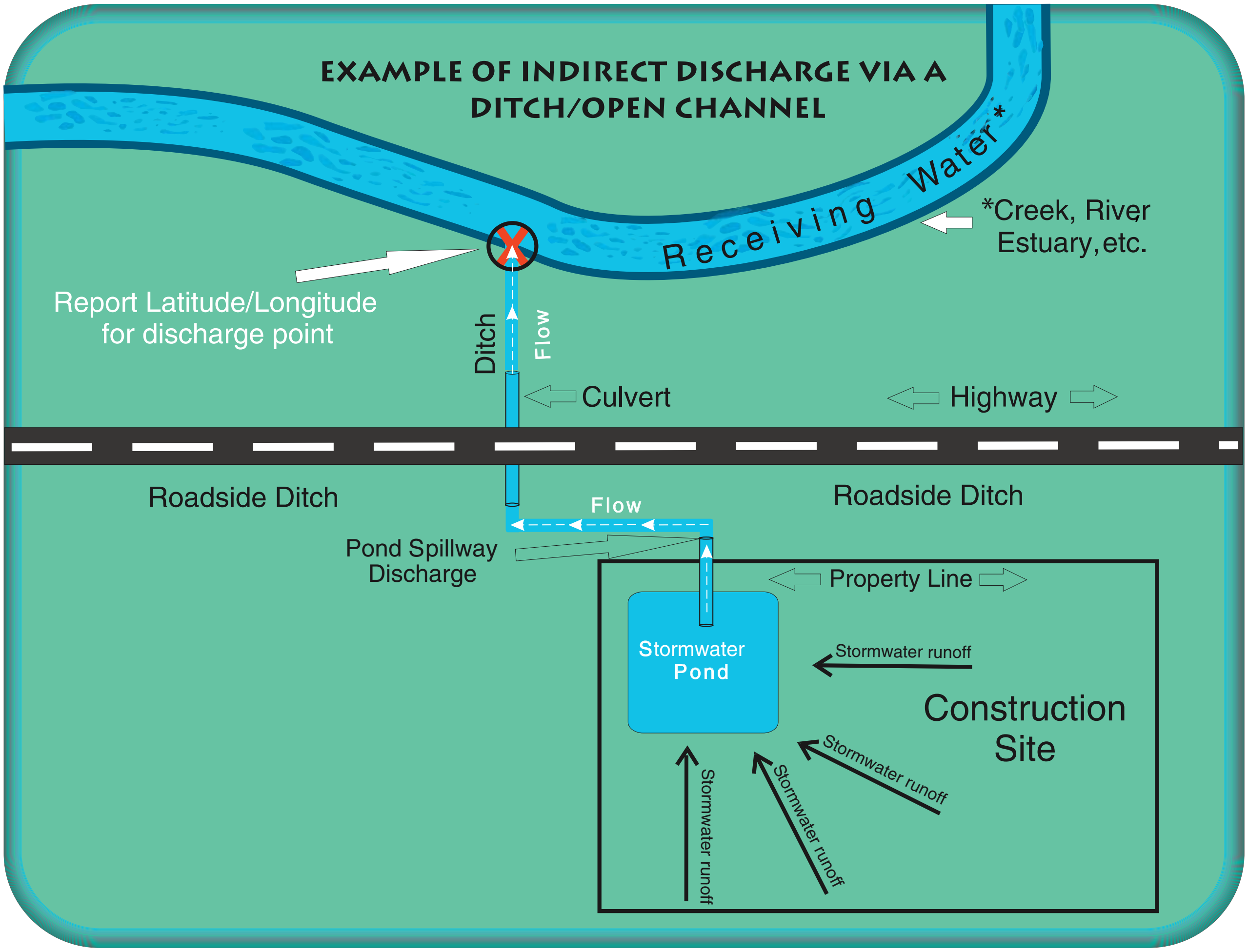
This is the stream or river the site discharge flows into (see illustrations). In most cases this will be easy to determine and it will simply be a named stream or river that is not too far from your site. However, there are some cases where it may be difficult to determine whether something is the actual receiving water or whether it is a conveyance ditch. To determine whether something is a natural receiving water or just a conveyance ditch, there are a number of things to consider. First, consider history; something may look and act like an irrigation ditch, but if historically there was a stream there and it has been channelized for convenience, then it is a receiving water. On the other hand, if the ditch was built to drain land or a wetland, then it is not a receiving water. Second, consider the flow pattern. If the ditch only flows during storm events or during periods of site discharge and/or it was specifically built to convey stormwater or discharge water, then it is not a receiving water. The presence of fish can also be evidence that it is a receiving water, although this is not always the case.





Critical condition:

Defined in the permit as the time "when the physical, chemical, and biological characteristics of the receiving water environment interact with the effluent to produce the greatest potential adverse impact on aquatic biota and existing or characteristic uses." For the purpose of this guide, critical condition has been defined as the August through September period unless there is no discharge from your site during that period. If that is the case, critical condition is the two month period when site discharge begins that is closest to August and September. For example, if there is no discharge from your site until October when the winter rains begin, the critical condition would be the months of October and November.



Measurement Techniques

There are many different methods to estimate flow. Some methods measure flow directly, while others may measure velocities that are used in specific equations to calculate flow. Some methods are better suited for low flows while others can handle a wide range of flows. The method chosen to measure site discharge or stream flow depends on a variety of factors including:

- **Type of flow system**
- **Expected range of flow rates**
- **Configuration of the site**
- **Desired accuracy**
- **Overall cost**

The following section is divided into two parts: Part 1 describes some common flow measurement methods that are most applicable to site discharge measurements. Part 2 describes easy or common methods that could be used for estimating stream (receiving water) flows. Some of the methods described are the same, but different examples are provided due to the slightly different nature of the discharge.

Measuring Site Discharge

This section will provide descriptions and instructions for several methods specific for measuring discharges from the site. It is again important to be aware of site limitations and obtain additional expertise if necessary.

When to measure site discharge:
The permit states that for discharges to surface water, site discharge flow should be estimated each time turbidity or temperature is measured. This would be weekly (along with temperature monitoring in July, August and September) and twice monthly (with turbidity). The site discharge flow estimates should be included with the discharge monitoring report that is submitted quarterly. These estimates should occur at the same time as stream flow estimates. If no discharge occurs from the site during summer months, measurements should be obtained during the first months that discharge does occur. For example, if discharge from the site does not occur until the first rains in October, begin taking measurements in October. The idea is to capture discharge conditions specific to the site, which may be storm events in winter months for some sites.

Where to take site discharge measurements:
Measure discharge flow as close to the point where it enters the river or stream as possible. If there is a pipe that directs discharge into the stream, then measurements would be taken at the end of the pipe. This holds true for channels or culverts, as well. If the site contains multiple locations of discharge into the receiving water, measurements should be obtained from the locations that contribute the representative volume of discharge to the receiving water.

Methods available for measuring site discharge:
As stated previously, multiple methods are available to measure discharge flow. A brief overview will be provided for weirs, flumes and electronic systems but this guide primarily focuses on:

- **Bucket and Stopwatch**
- **Float Method**
- **Manning's Equation**
- **Meter**

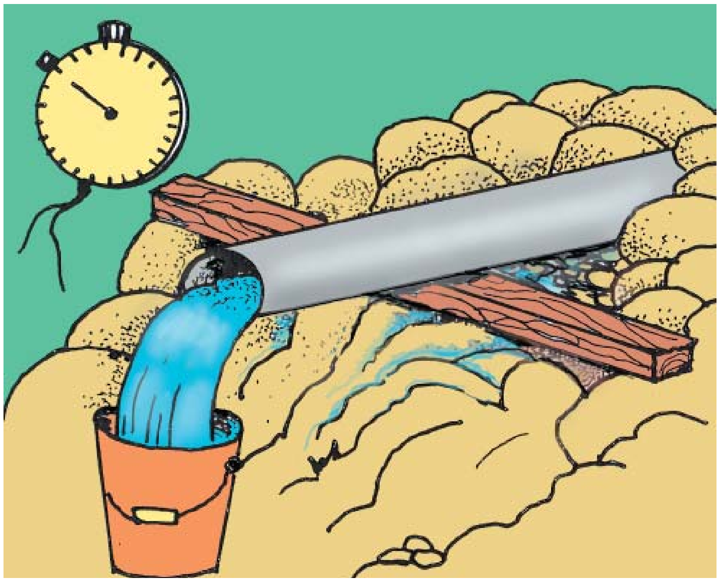
Bucket and Stopwatch Method

Overview
A very easy method to estimate discharge is to simply measure the time it takes to fill a container of a known volume. This method only works for systems with fairly low flow volume. Its main limitation is that the discharge must fall from a pipe or ditch in such a way that the bucket can be placed underneath it to capture all the discharge. Any size bucket can be used as long as it does not fill up too fast to get an accurate measurement.

Equipment Needed

- **Container to fill of known volume (a clean 5-gallon bucket works well)**
- **Timer (stopwatch)**
- **Paper and pencil for record keeping**

Taking the Measurement



1. Locate the site's discharge pipe. If discharge occurs via a channel, then a temporary dam may need to be placed across the channel with the discharge directed through a single outlet pipe.

2. Place the container of a known volume (e.g., a 1 or 5 gallon bucket) directly under pipe. All of the discharge should flow into the container. Note: The 5-gallon line on the bucket may need to be measured and marked ahead of time.

3. Using a stopwatch, time how long it takes to fill the container.

4. Repeat this process three times to obtain an average.

Calculating the Discharge - Example Calculation

A 5 gallon clean paint bucket was placed under the spout of a discharge pipe.
The bucket filled up in 15 seconds, 18 seconds and 14 seconds.

Calculate average time:

Add the three recorded times together and divide by three to obtain the average fill time.

$$\text{Average time} = \frac{15 + 18 + 14}{3} = 15.7 \text{ seconds}$$

Convert average time in seconds to minutes:

Divide average time by 60 seconds per minute to obtain minutes.

$$\text{Average time} = \frac{15.7 \text{ sec}}{60} = 0.26 \text{ minutes}$$

Calculate the site discharge:

Divide the volume of the container (gallons) by the average time needed to fill the container (minutes).

$$\text{Discharge} = \frac{5 \text{ gal}}{0.26 \text{ min}} = 19.2 \text{ gallons per minute (gpm)}$$

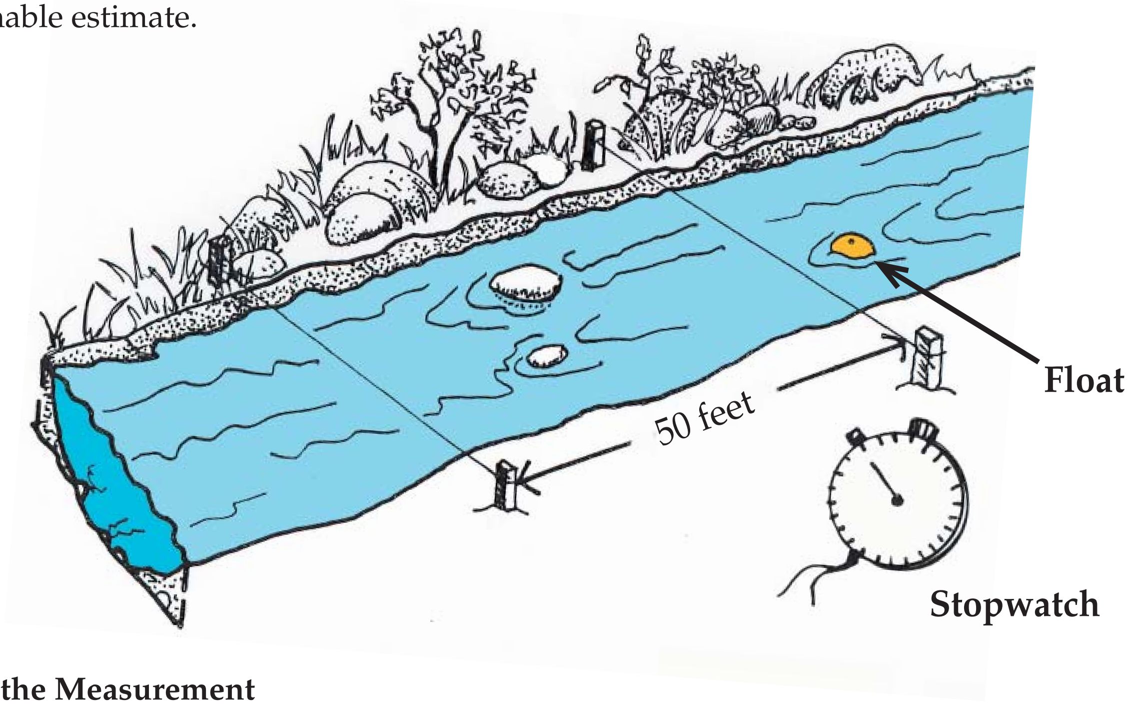
Report discharge to Ecology in gallons per minute.

FLOAT METHOD

Overview
If discharge from the site flows through an open ditch or channel, another fairly simple method to use is the float method. This method requires the measurement and calculation of the cross-sectional area of the channel as well as the time it takes an object to "float" a designated distance. This is the least accurate method of those presented in this guide but does provide a reasonable estimate.

EQUIPMENT NEEDED

- Measuring tape
- Markers (flagging tape, cones, etc.)
- Timer (stopwatch)
- Float (an orange or plastic bottle half filled with water)
- Paper and pencil for record keeping
- Waders or boots



Taking the Measurement

1. Estimate the cross-sectional area of the channel. For a rectangular shaped channel, a simple way to do this is to multiply the bottom width (ft) of the channel by the depth (ft) of the discharge. This is the cross-sectional area (ft^2). Equations and illustrations for calculating the cross-section of other shapes can be found in the appendix (Table A-1).

2. To determine the velocity of the discharge, mark off a 25 to 100 foot long section of the channel that includes the part where you measured the cross-section. The length you choose will be dependent upon the speed of the water. In many channels, 25 feet would be too short a distance because the float would travel too fast to get an accurate time estimate. Gently release the float into the channel slightly upstream from the beginning of the section. Measure the amount of time it takes the "float" to travel the marked section. Repeat this process at least three times and calculate the average time.

3. Compute the velocity (ft/s) by dividing the length of the section (ft) by the time (s) it took the float to move through the section.

Calculating the Discharge - Example Calculation

A rectangular shaped channel is 1 foot wide and average discharge in the channel is measured to be 0.4 feet deep. For a 50 feet long section, an orange traveled from one end to the other in 57 seconds, 48 seconds and 64 seconds.

Calculate cross-sectional area:

Multiply the width of the channel by the depth (in feet).

Cross-sectional area = 1 ft x 0.4 ft = 0.4 ft^2

Calculate average time:

Add the three recorded times together and divide by three to obtain the average fill time.

$$\text{Average time} = \frac{57\text{ s} + 48\text{ s} + 64\text{ s}}{3} = 56.3\text{ s}$$

Calculate velocity:

Divide the distance the float traveled by the average time.

$$\text{Velocity} = \frac{50\text{ ft}}{56.3\text{ s}} = 0.88\text{ fps}$$

Calculate discharge in feet per second:

Multiply the velocity (fps) by the cross-sectional area (ft^2) and by a correction factor (0.8). This correction factor is needed to take into account the different speeds in the water column. Water flows faster closer to the surface (where the orange floated) and slower near the channel bottom.

Discharge = 0.4 ft^2 x 0.88 fps x 0.8 = 0.282 cfs

Convert discharge from feet per second to gallons per minute:

Discharge (gpm) = 0.282 cfs x 448.83

Discharge = 126 gpm

Report discharge to Ecology in gallons per minute.

MANNING'S EQUATION METHOD

Overview

This method can be used for open channels and partially filled pipes when the flow moves by the force of gravity only (not pressurized). The Manning method is widely used for flow measurements because it is easy to use once a few initial measurements have been made. This method provides fairly reliable site discharge estimates.

Official requirements state that the channel should have uniform cross-section, slope, and roughness at least within the vicinity of the measurement. In addition, the pipe (or channel) should be at least 100 feet long and should not have any rapids, falls, or backup flow. For Ecology's purposes a 20 foot long channel or less would probably be sufficient, as long as the water is flowing evenly.

The equation requires obtaining values for the roughness of the channel (determined from standard tables), the cross-sectional area of discharge flow, the hydraulic radius (cross-sectional area divided by the wetted perimeter) and the slope of the gradient. Since the slope and roughness are constants, once they are known, future flow estimates can be calculated by simply measuring the depth of the discharge in the channel or pipe. The appendix contains tables to assist in the discharge calculation.

Though the Manning's equation may seem complicated, it can be relatively simple if the steps are followed.

EQUIPMENT NEEDED:

Measuring tape or ruler

Paper and pencil for record keeping

Waders or boots

Preliminary Determinations (in the office)

1. Calculate the slope (the "S" in the equation) of the channel or pipe. Slope is the rise over the run and can also be calculated by dividing the elevation difference by the length of the section.

2. Determine the roughness coefficient (the "n" in the equation) for the specific channel. Table A-2 in the appendix provides some common coefficients.

Taking the Measurement (For rectangular, triangular or trapezoidal channels)

1. Measure the bottom and top width, and the depth of the discharge. These values will be used to determine the cross-sectional area (A) and the hydraulic radius (R). Table A-1 in the appendix provides the specific equations (depending on channel shape) for calculating A and R as well as corresponding diagrams.

2. Discharge is calculated from the equation:

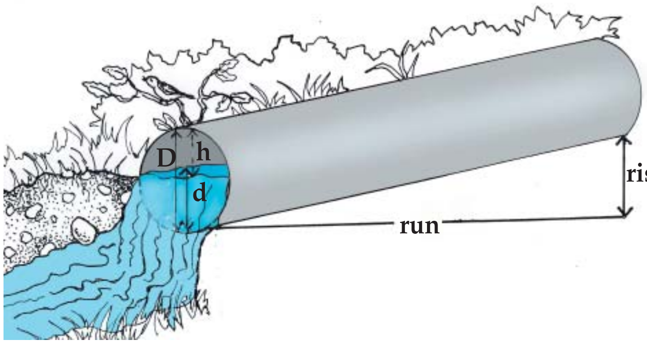
$$Q = \frac{1.29\ A\ R^{2/3} S^{1/2}}{n}$$

A = cross-sectional area
R = hydraulic radius
S = slope
n = Manning's roughness coefficient
Q = discharge

Taking the Measurement (For partially filled round pipes)

1. Measure the diameter of the pipe (D) and depth of the discharge (d). Divide the discharge depth by the pipe diameter (d/D) and use Table A-3 provided in the appendix to calculate A and R.

Note: It is often easier to measure the 'height' from the top of the pipe to the water's surface and then to subtract this 'height' from the pipe diameter to obtain the depth of the discharge. d= D-h



2. Once A, R and S are calculated, the values can be placed into the equation to determine discharge:

$$Q = \frac{1.29\ A\ R^{2/3}\ S^{1/2}}{n}$$

Calculating the Discharge - Example Calculation (For a round pipe)

A 2 foot diameter pipe carries stormwater discharge from a site. The concrete pipe was designed with a slope of 0.8 foot per 100 feet. At the time of measurement, the pipe has 0.8 feet of discharge flowing in it.

Determine roughness coefficient (n) for a concrete pipe from Table A-2 in the appendix:

n = 0.013

Calculate slope (S):

S = rise / run

S = 0.8 ft / 100 ft = 0.008

Divide the discharge depth in the pipe by the diameter of the pipe (d/D):

d/D = 0.8 / 2 = 0.4

Calculate the cross-sectional area (A) of the discharge in the pipe:

In Table A-3 in the appendix, scan the first column for the correct d/D value (0.4 in this example). Read across the row to the second column and obtain the Area Correction Factor (ACF) that corresponds to the water depth and pipe diameter ratio.
(ACF = 0.2934 in this example)

$A = (ACF) \times (D)^2$

$A = (0.2934) \times (2)^2 = 1.18 \text{ ft}^2$

Calculate the hydraulic radius (R):

Continue scanning across Table A-3 in the appendix to the third column that shows the Hydraulic Radius Correction Factor (RCF) that corresponds to the discharge depth and pipe diameter ratio.
(RCF = 0.2142 in this example)

R = (RCF) x D

R = (0.2142) x 2 = 0.428 ft

Calculate discharge by plugging in the values obtained from the tables:

$$Q = \frac{1.29\ A\ R^{2/3}\ S^{1/2}}{n}$$

$$Q = \frac{1.29 \times 1.18 \times (0.428)^{2/3} \times (0.008)^{1/2}}{0.013}$$

Q = 5.95 cfs

A = cross-sectional area
R = hydraulic radius
S = slope
n = Manning's roughness coefficient
Q = discharge

Convert discharge from cubic feet per second (cfs) to gallons per minute (gpm):

Discharge = 5.95 cfs x 448.83

Discharge = 2,670 gpm

Report discharge to Ecology in gallons per minute.

METER METHOD

Overview
This method measures velocity directly in order to calculate stream flow. Both velocity and water depth measurements are taken at the same time and place in multiple locations across the channel, using a flow meter.

Meters are described in detail beginning on page 16. The method outlined in that section can be followed for estimating site discharge. For channels, that tend to be narrower than stream beds, fewer velocity measurements need to be obtained. Generally, taking one measurement in the middle of the channel and one nearer to each side bank, will be sufficient for the permit's requirements to characterize the velocity in a small channel.

OTHER METHODS

There are many other methods that can be used to estimate site discharge flow. Some of these methods require the installation of devices that are used to obtain measurements. In most of these cases, specific equations and tables are then used to determine discharge. These equations are obtained from reference manuals. A few methods are briefly described below and the references listed at the end of this guide can be used to obtain more information.

Weirs
Weirs are structures (i.e. dams) installed across a channel. Water flows either over the dam or through a specially shaped opening or notch in the dam. The water level rises behind the dam and that rise (or 'head') is measured and used to calculate discharge. Weirs are classified by the type or shape of opening that the water flows through (some common examples are the v-notch weir and rectangular weir.). Each type of weir has a specific equation associated with it that is used to calculate the discharge. Once installed, weirs are relatively simple and convenient to use because only one measurement is needed to estimate flow. However, due to the relative complexity of the installation and maintenance requirements, these systems are not described in this guide.

Flumes
Flumes are specially shaped sections that are installed into a channel to restrict the channel cross-sectional area. This restriction results in an increased velocity and a change in the level of discharge flowing through the flume. The head of the flume is measured and used to calculate the flow rate. Like weirs, specific equations are used depending on the type of flume installed.

Flumes are generally used where weirs are not feasible. Flumes can measure higher flow rates than weirs and are better suited for flows that contain sediments. As with the weir, flumes have specific installation requirements and an expert should be consulted if it is to be used for flow measurement.

Pumps
At some sites, pumps may be used to discharge stormwater or process water to the receiving water. If these pumps have flow gages on them, then discharge rates can be easily obtained from the pump.

ESTIMATING RECEIVING WATER FLOWS

Now that site discharge estimates have been determined, stream flow estimates can be calculated. This section provides guidance on when to measure receiving water flow and detailed instructions plus calculations for some simple methods.

Because the primary purpose of this guide is to provide directions for estimating low flow when no stream flow data is available and must be collected by the permittee, this section will focus on three simple methods. However, there is also a brief explanation of how stream gage data can be used, if it is available.

When to measure receiving water flow:
The permit uses the term "typical low flow" and "critical condition" to describe the period when receiving water flow should be monitored. The months of August and September generally represent the period of typical low flow in the vast majority of rivers and streams in Washington State and therefore the period when stream temperatures are highest (i.e. critical condition). For most permittees, this will be the period over which data is collected.

If there is no discharge from the site during summer months, site discharge measurements should be obtained during the first two months that discharge does occur. For example, if discharge from the site does not occur until the first rains in October, then October and November is when the monitoring should occur. The idea is to capture discharge conditions specific to the site, which may be storm events in winter months for some sites. Stream flow measurements should be obtained twice a month, when site discharge is measured.

Methods available for estimating receiving water flows:
Multiple methods are available to measure stream flow. In some cases, a gage may be installed upstream from the site, which could supply required information. Other methods covered in this section include the float method, flow meter and bridge method. The method chosen depends on conditions specific to the stream, such as whether it is wadeable.

USING STREAM GAGE DATA

Larger rivers and streams in Washington may have permanently installed flow monitoring sites (gage sites) that are used to obtain flow information. Stream flow data from a nearby gaging station can be used if it is fairly representative of the flow at the discharge site. Any upstream gage site would work, since in most cases it will provide a conservative (low) estimate of flow near your site. Downstream gage sites may work as well, as long as they are not too far downstream and there are no tributaries, dams or diversions between your discharge site and the gage site. In addition, receiving water flow statistics may have already been calculated and may be available in existing reports and studies. These reported results could also be used, as long as the report is cited as the source of the data.

The permit specifically uses the term "7Q10" as a measure of low flows. This term refers to the lowest 7 day average flow that would occur in a 10 year period. It is a statistic calculated from a long term record of measured stream flows. Stream flow records often include this value. If it is already available, then this measure can be used as an estimate of typical low flows. Other common measures of low flow, such as 90% exceedance flows, are also acceptable.

Stream gage data should be obtained in August and September for most and the months of first discharge for others. River flow data can be accessed from the sources listed below. Others sources include City and County agencies, or watershed groups.

US Geological Survey
http://waterdata.usgs.gov/wa/nwis/rt
http://wa.water.usgs.gov/data/realtime/rt_latest_map.html

Washington State Department of Ecology
https://fortress.wa.gov/ecy/wrx/wrx/flows/regions/state.asp

Seattle District Corps of Engineers
http://www.nwd-wc.usace.army.mil/nws/hh/basins

National Oceanic and Atmospheric Administration
http://www.nwrfc.noaa.gov

FLOAT METHOD

Overview
The float method is an adequate means of estimating flow especially in circumstances where a flow meter is not available or when the water in the stream is not wadeable. This method is simple and inexpensive to perform. The concept is to time how long it takes for a buoyant object to travel a specific distance. Using the time, along with the estimated width and depth of the stream segment, stream flow can be calculated.

(Note: Though this method was described in the previous section, the instructions here focus on streams.)

Selecting a Site
The ideal site is where you can easily and safely access the stream. The stream section should be straight for at least 50 feet, should be at least 6 inches deep and should represent the general flow conditions. In addition, the section should be relatively consistent in width and depth and should not contain any obstructions that may deter the float.

EQUIPMENT NEEDED:

Measuring tape

Timer (stopwatch)

Float (an orange or a plastic bottle filled with water – basically a buoyant object that is heavy enough to sit about an inch below the water line.)

Paper and pencil for record keeping

Waders

Taking the Measurement

1. If the stream is not wadeable, estimate the width and depth at the end of the stream segment and record these measurements. (Note: A bridge often provides an easy spot to measure width and depth from. See bridge method.)

2. If the stream is wadeable, measure the total width of the stream. Also, determine the average depth. To do this, record the depth at 1 or 2 feet increments across the stream. Add all these depth measurements together and divide by the total number of measurements taken. This will be the average depth.

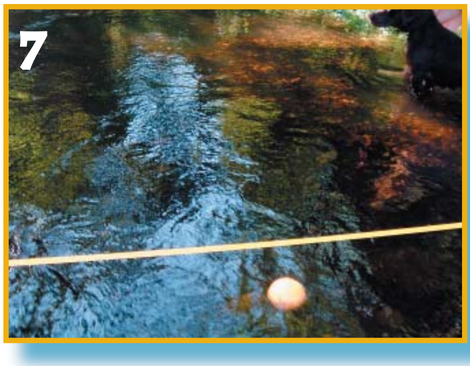
3. Estimate the cross-sectional area of the stream by multiplying the total width by the average depth.

4. Measure off or mark a minimum of 50 feet along the streambank. It may be useful to install a permanent measuring tape or apply marks to the bank so float measurements can be taken at the same location. If the float moves too fast to get an accurate measurement, measure off a longer stretch (such as 75 or 100 feet).

5. Gently release the float slightly before the upstream end of the measured segment. This is done so the float will be moving at the speed of the stream when timing begins. Also, try to release the float towards the portion of the stream, which has the most representative flow.

6. Make sure the float flows freely, without catching on rocks or branches. If the float catches on something, you will need to repeat the process.

7. Begin timing when the float crosses the upstream end of the measured segment and stop when it crosses the downstream end (using a stopwatch or digital watch). Record the time.



8. Retrieve the float and repeat the process at least two more times.

Calculating Stream Flow - Example Calculation

A river is approximately 30 feet wide and approximately 4 feet deep (too deep to wade). A float released upstream traveled 100 feet in 28 seconds, 24 seconds and 30 seconds.

Stream flow = Area x Velocity x Correction factor

Calculate area:

Multiply the width of the stream by the depth.

Area = 30 ft x 4 ft = 120 ft^2

Calculate average float time:

Add up all the individual times and divide by the number of times the float was released (in seconds).

Average float time = $\frac{28 + 24 + 30}{3}$ = 27 sec

Calculate average velocity:

Divide the distance the item floated (i.e. the length of the segment measured in feet) by the average float time.

Velocity = $\frac{100 \text{ feet}}{27 \text{ sec}}$ = 3.7 ft/s

Calculate stream flow:

Multiply the average velocity by the area and by a correction factor (of 0.85). The correction factor takes into account the effects of friction from the stream bed.

Stream flow = 120 ft^2 x 3.7 ft/s x 0.85 = 377 cfs

Report discharge to Ecology in cubic feet per second (cfs).

MEASURING FLOW WITH A METER

Overview
This method involves wading across a stream and taking velocity measurements at multiple places. Both velocity and water depth measurements are taken at the same time and place in multiple locations across the stream.

There are many types of current meters. The most common types are cup, propeller or magnetic. The cup or propeller types determine flow velocity by the number of revolutions of the cups (or propeller) over a given period of time. Magnetic meters measure the difference in water pressure as water flows around a sensor. All provide output in ft/s or m/s. Some meters are more appropriate for small streams, some for larger systems.

FLOW METER METHOD - WADEABLE STREAMS

Selecting a Site
Measurements should be taken just upstream from where discharge from the site enters the stream. The site should be safely accessible and should be in a section of the stream that is free flowing. Other considerations:

Stream should be straight enough to have uniform form.

The flow should not be affected by tributaries or tides.

There should not be any side channels so that all the water flows through the main channel.

Areas where there are large boulders, logs, or thick brush which can create eddies, slack water, turbulence or disturbed flow should be avoided.

EQUIPMENT NEEDED:

Measuring tape

Meter

Top-setting rod (if available) or measuring stick

Paper and pencil for record keeping

Waders

Taking the Measurements

1. Tighten a measuring tape across the stream at right angles to the flow. It should be snug and not sag in the middle.

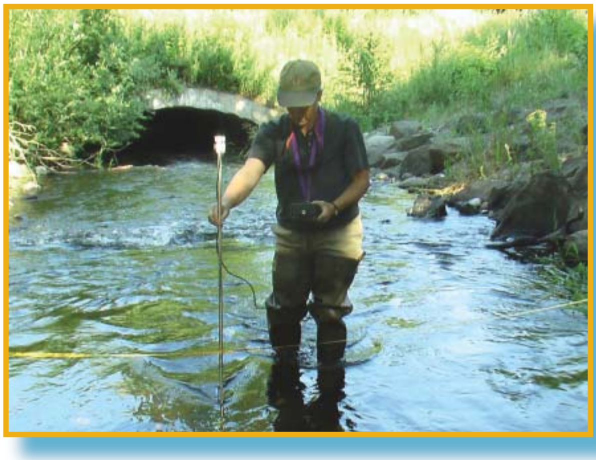
2. Measure the total stream width and record this measurement.

3. Divide the total stream width into equal segments. If the stream is less than 10 feet wide, use ½ foot intervals. For streams greater than 10 feet, use 1 foot or greater intervals. (Note: The standard method is to divide the width by 20, however ½ foot or 1 foot intervals are sufficient for the purposes of this guide.)

4. Step out to the first measuring point and position the rod. Stand downstream from the measuring tape with the rod next to the tape. The rod should be held vertically, the meter should face upstream and you should be standing off to the side or behind the meter.

5. Record the distance to the bank. Measure total stream depth and record this depth. Multiply the total depth by 0.6 and set the propeller at this depth. (Note: 0.6 times the total depth is considered the point of average discharge in a spot that is less than 2 feet deep. If the depth is greater than 2 feet, two different velocity measurements are required one at 0.2 times the depth and one at 0.8 times the depth.) Read and record the velocity at this depth. (Note: If your meter is attached to a "top setting rod" the propeller can be easily set at this 0.6 depth without calculation by you. Directions on using a top setting rod should be provided by the manufacturer.)

6. Move to the next measuring point and repeat the process. (Note: The standard method is to obtain three velocity measurements at each point and average them.) Make sure to record the distance to the bank, the total stream depth and the velocity at the 0.6 depth for each point across the stream. See Table 1 for an example of how to record and calculate the data.



Calculating Stream flow - Example Calculation

A stream is 10 feet wide and measurements were taken at 1 foot intervals. See Table 1.

Calculate area for each cell:
Multiply the width of the cell by the depth of the cell.
(Multiply column 2 by column 3 in Table 1 and create column 4.)

Calculate flow for each cell:
Multiply the area by the velocity obtained from the meter.
(Multiply column 4 by column 5 and create column 6.)

Determine total stream flow:
Add together all the calculated flows for each cell.
(Add all values in column 6.)

Report discharge to Ecology in cubic feet per second (cfs).

Calculating Stream Flow Example

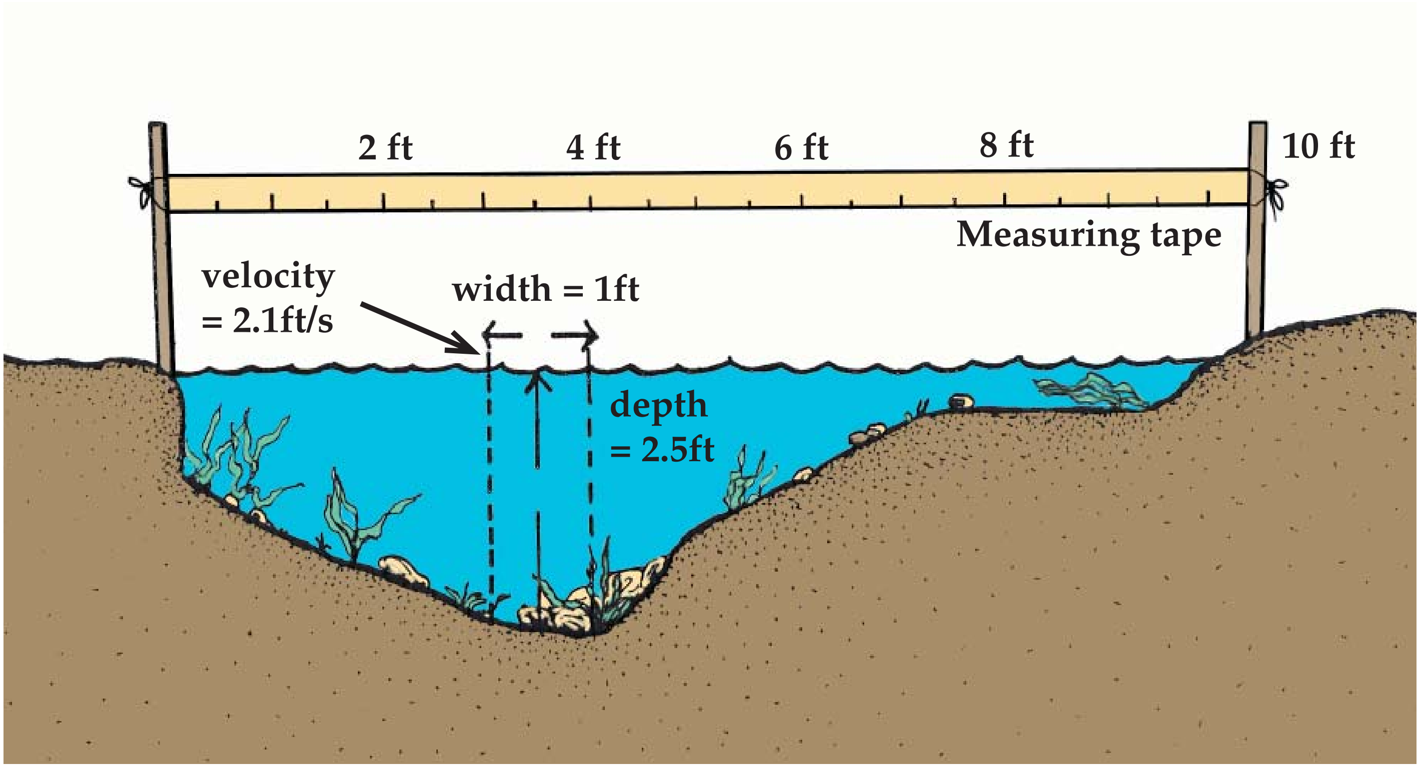


Table 1: Example Calculation – Meter Method Wadeable Streams

Cell	Width of cell (ft)	Depth (ft)	Area (sq ft) (width x depth)	Velocity (from meter) (ft/s)	Stream flow (area x velocity) (cfs)
1	1.0	1.0	1.0	1.5	1.5
2	1.0	1.5	1.5	1.6	2.4
3	1.0	2.0	2.0	1.7	3.4
4	1.0	2.5	2.5	2.1	5.25
5	1.0	2.5	2.5	1.8	4.5
6	1.0	1.5	1.5	1.5	2.25
7	1.0	1.0	1.0	1.6	1.6
8	1.0	0.5	0.5	.7	.35
9	1.0	0.5	0.5	.2	.1
10	1.0	0.5	0.5	.2	.1
		Totals	**13.5**		**21.45**

FLOW METER METHOD - NON-WADEABLE STREAMS WITH A NEARBY BRIDGE

Overview

If a stream is not wadeable, a nearby bridge can be used to obtain measurements. The procedure is similar to that which was outlined above, but with a few modifications.

EQUIPMENT NEEDED

Measuring tape

Weighted, calibrated line for taking total depth measurements

Meter attached to a long, marked line with a weight on the end

Paper and pencil for record keeping

Taking the Measurements

1. Determine the width of the stream by measuring the bridge deck from shore to shore. Record this measurement.

2. Divide the bridge width into equal segments. If the river is less than 10 feet wide, use ½ foot intervals. For rivers greater than 10 feet, use 1 foot or greater intervals.

3. At the first measuring point, lower the weighted line. Record the distance to water surface and the distance to the river bottom.

4. Calculate stream depth by subtracting distance to the river bottom by the distance to the water surface.

5. Multiply the stream depth by 0.6. This will be the point below the water surface where you will want to place the meter.

6. Lower the current meter to this calculated point and obtain a velocity measurement. Record the velocity. (The meter may need to be weighted if the stream is flowing fast.)

7. Move to the next measuring point and repeat the process.

Calculating Stream Flow - Example Calculation

A river is too deep to wade, but a bridge is located just upstream from the site. The width of the river is measured to be 28 feet.

Calculate depth of stream of each cell:

Subtract distance to water surface from distance to river bottom.
(Subtract column 3 from column 4 to create column 5.)

Calculate area for each cell:

Multiply the width of the cell by the depth.
(Multiply column 2 by column 5 to create column 6.)

Calculate flow for each cell:

Multiply area by the velocity obtained from the meter.
(Multiply column 6 by column 7 to create column 8.)

Determine total stream flow:

Add together all the calculated flows for each cell.
(Add all values in column 8.)

Report discharge to Ecology in cubic feet per second (cfs).

Table 2: Example Calculation - Meter Method Non-Wadeable Streams

Cell	Width of cell (ft)	Distance to water surface (1) (ft)	Distance to river bottom (2) (ft)	Depth Dist(1) – Dist (2) (ft)	Area (sq ft) (width x depth)	Velocity (from meter) (ft/s)	Stream Flow (area x velocity) (cfs)
1	**1.0**	**20.0**	**22.0**	**2.0**	**2.0**	**1.5**	**3.0**
2	**1.0**	**20.0**	**22.5**	**2.5**	**2.5**	**1.6**	**4.0**
3	**1.0**	**20.0**	**24.5**	**4.5**	**4.5**	**2.2**	**9.9**
4	**1.0**	**20.0**	**27**	**7.0**	**7.0**	**2.1**	**14.7**
5	**1.0**	**20.0**	**25.5**	**5.5**	**5.5**	**2.0**	**11.0**
6	**1.0**	**20.0**	**26**	**6.0**	**6.0**	**1.9**	**11.4**
7	**1.0**	**20.0**	**27**	**7.0**	**7.0**	**1.9**	**13.3**
8	**1.0**	**20.0**	**24**	**4.0**	**4.0**	**2.0**	**8.0**
9	**1.0**	**20.0**	**21**	**1.0**	**1.0**	**.3**	**.3**
10	**1.0**	**20.0**	**21**	**1.0**	**1.0**	**.3**	**.3**
						Total	**75.9 cfs**

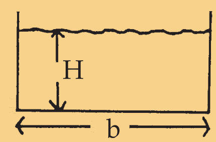
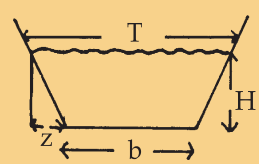
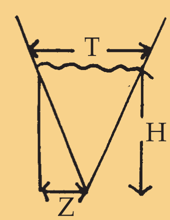
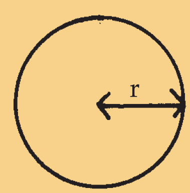
APPENDIX

Cross-Sectional Area Calculations

b = bottom width
H= height
T = top width
Z = (top width – bottom width) / 2 = (T – b) / 2

A = area
WP = wetted perimeter
r = radius
pi = 3.147

Table A – 1 : Areas and Perimeters

Shape	Cross-Sectional Area, A	Wetted Perimeter, WP	Diagrams
Rectangle	$A = b \times H$	$WP = b + (2 \times H)$	
Trapezoid (equal side slopes)	$A = (b + [Z \times H]) \times H$	$WP = b + (2 \times H) \times (1 + Z^2)^{1/2}$	
Triangle	$A = Z \times H^2$	$WP = 2 \times H \times (1 + Z^2)^{1/2}$	
Circle (full pipe)	$A = pi \times r^2$	$WP = 2 \times r \times pi$	

Manning’s Roughness Coefficients (n) for Various Channel Configurations and Conditions

Table A – 2: Manning’s Roughness Coefficients (n)

Channel Description	Manning’s Roughness Coefficient (n)
Steel conduit (lockbar and welded)	0.012
Steel conduit (riveted and spiral)	0.016
Acrylic conduit	0.009
Concrete conduit (straight and free of debris)	0.011
Concrete conduit (with bends and some debris)	0.013
Metal channel (smooth steel surface)	0.012
Cement channel (mortar)	0.013
Concrete channel (finished or unfinished)	0.017
Excavated earthen channel (straight and uniform)	0.022
Excavated earthen channel (winding and sluggish)	0.030
Natural channel (fairly regular section)	0.050
Natural channel (irregular section with pools)	0.070
Mowed grass channel (some weeds)	0.030
High grass channel or dense weeds and plants	0.035

Additional roughness coefficients can be obtained from ISCO. See references

Manning's Equation Area and Hydraulic Radius for Various Flow Depths in partially-filled pipes.

d = actual depth of flow in pipe
D = diameter of pipe

$A = (ACF) \times D^2$
$R = (RCF) \times D$

Table A – 3: Area and Hydraulic Radius for Various Flow Depths

d/D	ACF (A/D²)	RCF (R/D)
0.01	0.0013	0.0066
0.05	0.0147	0.0326
0.10	0.0409	0.0635
0.15	0.0739	0.0929
0.20	0.1118	0.1206
0.25	0.1535	0.1466
0.30	0.1982	0.1709
0.35	0.2450	0.1935
0.40	0.2934	0.2142
0.45	0.3428	0.2331
0.50	0.3927	0.25
0.55	0.4426	0.2649
0.60	0.4920	0.2776
0.65	0.5404	0.2881
0.70	0.5872	0.2962
0.75	0.6318	0.3017
0.80	0.6736	0.3042
0.85	0.7115	0.3033
0.90	0.7445	0.2980
0.95	0.7707	0.2864
1.00	0.7854	0.25

GLOSSARY

cfs	cubic feet per second
Critical condition	defined in this guide as the August and September time period or the two month period when discharge begins
Discharge	defined in this guide as the water generated by the facility
Flow	the volume of water moving past a cross-section of a stream, channel or pipe over a set period of time
gpm	gallons per minute
Manning's coefficient	a value which is dependent on the surface roughness of the pipe or culvert and is used in the Manning's equation. It is not a constant.
Manning's equation	an equation developed in 1890 for determining gravity pipe flow in open channels
Open channel	flow in any channel where the water flows with a free surface (such as a ditch, channel, river)
Receiving water	defined in this guide as the stream or river at the point of discharge
Slope	rise over run of a pipeline or channel
Velocity	the rate of motion of water in relation to time measured in feet per second

CONVERSIONS

1 cubic foot = 7.48 gallons

1 gallon = 0.134 ft^3

1 cubic foot per second = 448.83 gallons perminute

1 gallon per minute = 0.0022 cubic feet per second

1 cubic foot per second = 7.481 gallons per second

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RECEIVING WATER FLOW INFORMATION

NPDES General Permit ID Number:______________________________
Business Name:______________________________
Physical Location:______________________________
Contact Name:____________Contact Phone:____________Contact email:____________
Date of measurement (mm/dd/yr):______________________________
Describe rainfall pattern during the previous few days and the day of measurement:____________

Stream Name:______________________________
Measurement Location (e.g. closest road crossing):______________________________

Latitude/Longitude (optional):______________________________

How was flow estimated?

- ☐ Stream Gage data
  - Data source: ____________________
  - Gage Location: ____________________
- ☐ Float
- ☐ Flow meter
- ☐ Other (Describe)______________________________

Estimated flow rate:________________Units (Circle One): gpm cfs

Average stream width(feet):____________ Average stream depth(feet):____________

Please attach your raw data. (i.e. time, velocity, etc.)

Explain where the stream flow measurement site is located in relation to your site discharge.

Explain how the date these measurements were taken represents the critical condition for your discharge. Is it the August/September period when stream flow is lowest or does it represent the first period of discharge from your site after the late summer low flow period?