# 3. FUNDAMENTALS OF SAMPLING

Because of the variable nature of storm water flows during a rainfall event and different analytical considerations for certain pollutants, the storm water regulations establish specific requirements for sample collection techniques. The quality of storm water discharges and logistical needs for sampling will be different for industrial applicants and municipal applicants. Therefore, specific sampling requirements vary. After a brief review of sampling fundamentals and special sampling requirements for storm water permit applications, the following sections are intended to teach applicants how to sample to meet these requirements.

The applicant should carefully plan his/her sampling strategy prior to the actual sampling event, e.g., walk the site to determine appropriate sampling locations, become familiarized with local rainfall patterns, train sampling staff in procedures and safety, consult with laboratory, and collect supplies.

## 3.1 TYPES AND TECHNIQUES OF SAMPLING

There are three basic aspects of sampling:

- Sample type (i.e., grab versus composite)
- Sample technique (i.e., manual versus automatic)
- Flow measurement methods.

These topics will be discussed in relation to requirements of an NPDES storm water discharge permit application. Once these aspects are addressed, step-by-step instructions on sampling procedures are presented. The sections below define and describe the types of storm water samples that must be collected and methods or techniques for collecting them. In addition, special sampling requirements for certain pollutants are discussed.

### 3.1.1 SAMPLE TYPE VERSUS SAMPLE TECHNIQUE

It is important to understand the difference between sample type and technique. "Sample type" refers to the kind of sample that must be collected -- either a grab or a composite. "Sample technique" refers to the method by which a grab or composite sample is actually collected -- either manually or by automatic sampler. A generalized relationship between sample type and sample technique is presented in Exhibit 3-1.

Sections 3.1.2 and 3.1.3 further explain the significance of these terms as they relate to storm water sampling requirements.

| EXHIBIT 3-1. SAMPLE TYPE vs. SAMPLE TECHNIQUE | |
|---|---|
| **Sample Type** | **Sample Technique** |
| Grab | Manual<br>Automatic sampling system |
| Composite | Manual with manual compositing<br>Automatic system or automatic sampling with manual compositing |

### 3.1.2 SAMPLE TYPE: GRAB AND COMPOSITE SAMPLES

To comply with storm water application requirements, the sample type (grab or composite) must be collected in accordance with 40 CFR 122.21(g)(7) and 40 CFR Part 136. The storm water application requirements clearly specify which pollutants must be analyzed by grab sample, and which by composite sample. Although the requirements in 40 CFR 122.21(g)(7) do not explicitly specify either manual or automatic sampling techniques, the approved analytical methods contained in 40 CFR Part 136 direct that grab samples must be collected manually for certain pollutants. Sections 3.3 and 3.4 clarify which pollutants must be grabbed, which ones must be grabbed manually, and which ones must be flow-weighted composites.

The two types of storm water samples required by the regulations, grab and composite samples, are described below.

<u>Grab Samples</u>

A grab sample is a discrete, individual sample taken within a short period of time (usually less than 15 minutes). Analysis of grab samples characterizes the quality of a storm water discharge at a given time of the discharge.

Composite Samples

A composite sample is a mixed or combined sample that is formed by combining a series of individual and discrete samples of specific volumes at specified intervals. Although these intervals can be time-weighted or flow-weighted, the storm water regulations require the collection of flow-weighted composite samples. This means that discrete aliquots, or samples, are collected and combined in proportion to flow rather than time. Composite samples characterize the quality of a storm water discharge over a longer period of time, such as the duration of a storm event.

Application Requirements

Both types of samples must be collected and analyzed for storm water discharge permit applications. Grab samples must be collected for the following conditions:

- For storm water discharges associated with industrial activity, a grab sample must be obtained during the first 30 minutes of a discharge. This requirement is in addition to the composite sampling requirements. These samples are intended to characterize the maximum concentration of a pollutant that may occur in the discharge and/or may indicate intermingling of non-storm water discharges.

- For storm water discharges from large and medium municipal separate storm sewers, grab samples are required for Part 1 of the application if a discharge is noted during dry weather field screening. Two grab samples must be collected during a 24-hour period with a minimum of 4 hours between samples. These samples are intended to assist in the identification of illicit connections or illegal dumping. In Part 2, grab samples may be required for the analysis of certain pollutants for which municipalities are required to sample.

Flow-weighted composite samples must be collected during the first 3 hours of discharge or the entire discharge (if it is less than 3 hours) for both industrial and municipal applicants.

Pollutant-specific Requirements

The regulations at 40 CFR 122.21(g)(7) identify certain pollutants for which grab sampling is required:

- Monitoring by grab sample must be conducted for pH, temperature, cyanide, total phenols, residual chlorine, oil and grease (O&G), fecal coliform, and fecal streptococcus. Composite samples are not appropriate for these parameters due to their tendency to transform to different substances or change in concentration after a short period of time. Such transformations may be particularly likely in the presence of other reactive pollutants.

Sampling At Retention Ponds

Retention ponds with greater than a 24-hour holding time for a representative storm event may be sampled by grab sample. Composite sampling is not necessary. The rationale for this is that, because the water is held for at least 24 hours, a thorough mixing occurs within the pond. Therefore, a single grab sample of the effluent from the discharge point of the pond accurately represents a composite of the storm water contained in the pond. If the pond does not thoroughly mix the discharge, thereby compositing the sample, then a regular grab and composite sample should be taken at the inflow to the pond. Since each pond may vary in its capability to "composite" a sample, applicants must carefully evaluate whether the pond is thoroughly mixing the discharge. Such factors as pond design and maintenance are important in making this evaluation. Poor pond design, for example, where the outfall and inflow points are too closely situated, may cause short-circuiting and inadequate mixing. In addition, poor maintenance may lead to excessive re-suspension of any deposited silt and sediment during heavy inflows. Because of factors such as these, the applicant should determine the best location to sample the pond (e.g., at the outfall, at the outfall structure, in the pond) to ensure that a representative composite sample is taken. If adequate compositing is not occurring within the pond, the applicant should conduct routine grab and flow-weighted composite sampling.

A grab sample and a flow-weighted sample must be taken for storm water discharges collected in holding ponds with less than a 24-hour retention period. The applicant must sample the discharge in the same manner as for any storm water discharge [as described in 40 CFR 122.21(g)(7)]. In effect, the applicant must take one grab sample within the first 30 minutes of discharge, or as soon as possible. The applicant must also collect a flow-weighted composite sample for at least the first 3 hours of the discharge, or for the event's entire duration (if it is less than 3 hours). The flow-weighted composite sample may be taken using a continuous sampler or as a combination of at least three sample aliquots taken during each hour of the discharge, with a minimum of 15 minutes between each aliquot. If the applicant does not know what retention period the pond is designed for, the design engineer of the pond should be consulted.

### 3.1.3 SAMPLE TECHNIQUE: MANUAL VERSUS AUTOMATIC SAMPLING

As previously discussed, manual and automatic sampling techniques are methods by which both grab and composite samples can be collected. Manual samples are simply samples collected by hand. Automatic samplers are powered devices that collect samples according to preprogrammed criteria. A typical automatic sampler configuration is shown in Exhibit 3-2.

EXHIBIT 3-2. AUTOMATIC SAMPLER

For most pollutants, either manual or automatic sample collection will conform with 40 CFR Part 136. However, one case in which automatic samplers cannot be used is for the collection of volatile organic compound (VOC) samples because VOCs will likely volatilize as a result of agitation during automatic sampler collection. Samples collected for VOC analysis should be filled until a reverse meniscus is found over the top of the collection bottle and capped immediately to leave no air space. Automatic samplers do not perform this function. Special requirements for VOC sampling are discussed in Section 3.5.2.

Although both collection techniques are available, several other pollutants may not be amenable to collection by an automatic sampler, for example fecal streptococcus, fecal coliform and chlorine have very short holding times (i.e., 6 hours), pH and temperature need to be analyzed immediately and oil and grease requires teflon coated equipment to prevent adherence to the sampling equipment.

Other restrictions on sample collection techniques (such as container type and preservation) should be determined by consulting the approved analytical methods listed in 40 CFR Part 136. Section 3.5 and Technical Appendix C provide additional information on sample handling, holding times, and preservation methods. Manual and automatic techniques have advantages and disadvantages that the applicant should consider in relation to the sampling program. The main advantage of manual sampling is that it can be less costly than purchasing or renting automatic samplers. Automatic samplers, however, can be often more convenient. Exhibit 3-3 presents a matrix of advantages and disadvantages associated with each technique. Ultimately, the best technique to use will depend on each applicant's situation.

EXHIBIT 3-3. COMPARISON OF MANUAL AND AUTOMATIC SAMPLING TECHNIQUES

| Sample Method | Advantages | Disadvantages |
|---|---|---|
| Manual Grabs | • Appropriate for all pollutants<br>• Minimum equipment required | • Labor-intensive<br>• Environment possibly dangerous to field personnel<br>• May be difficult to get personnel and equipment to the storm water outfall within the 30 minute requirement<br>• Possible human error |
| Manual Flow-Weighted Composites (multiple grabs) | • Appropriate for all pollutants<br>• Minimum equipment required | • Labor-intensive<br>• Environment possibly dangerous to field personnel<br>• Human error may have significant impact on sample representativeness<br>• Requires flow measurements taken during sampling |
| Automatic Grabs | • Minimizes labor requirements<br>• Low risk of human error<br>• Reduced personnel exposure to unsafe conditions<br>• Sampling may be triggered remotely or initiated according to present conditions | • Samples collected for O&G may not be representative<br>• Automatic samplers cannot properly collect samples for VOCs analysis<br>• Costly if numerous sampling sites require the purchase of equipment<br>• Requires equipment installation and maintenance<br>• Requires operator training<br>• May not be appropriate for pH and temperature<br>• May not be appropriate for parameters with short holding times (e.g., fecal streptococcus, fecal coliform, chlorine)<br>• Cross-contamination of aliquot if tubing/bottles not washed |
| Automatic Flow-Weighted Composites | • Minimizes labor requirements<br>• Low risk of human error<br>• Reduced personnel exposure to unsafe conditions<br>• May eliminate the need for manual compositing of aliquots<br>• Sampling may be triggered remotely or initiated according to on-site conditions | • Not acceptable for VOCs sampling<br>• Costly if numerous sampling sites require the purchase of equipment<br>• Requires equipment installation and maintenance, may malfunction<br>• Requires initial operator training<br>• Requires accurate flow measurement equipment tied to sampler<br>• Cross-contamination of aliquot if tubing/bottles not washed |

## 3.2 OBTAINING FLOW DATA

In addition to collecting samples of storm water discharges, applicants must collect data characterizing the flow rate and flow volume for each storm water discharge sampled. Flow rate is the quantity of storm water discharged from an outfall per unit of time. Total flow is a measure of the total volume of storm water runoff discharged during a rain event. Flow rates and volumes can either be measured specifically or can be estimated (based on rainfall measurements, velocities, and depth of flows). To collect flow-weighted composite samples, flow rate data is necessary to combine proportional volumes of individually collected aliquots. Applicants must also report the mass of pollutants contained in storm water discharges (see Section 3.2.5). To determine mass loadings of pollutants, applicants must measure both discharge flow rate and pollutant concentration. This section presents methods for obtaining flow data.

### 3.2.1 MEASURING FLOW RATES

Flow rates for storm water discharges are most accurately measured using either primary or secondary flow measurement devices. Facilities should use these devices to characterize their discharge as precisely as possible. Where flow measurement devices are not already installed, portable devices should be considered. There are many permanent and portable types of flow measurement devices available. This discussion is limited to the most common flow measurement devices. To purchase flow measurement devices and rain gauges, pertinent engineering journals can be consulted for equipment vendor listings. Proper analysis of site discharge conditions must be conducted prior to purchase and installment of flow measurement devices.

Primary Flow Measurement Devices

A primary flow measurement device is a man-made flow control structure which, when inserted into an open channel, creates a geometric relationship between the depth of the flow and the rate of the flow. The depth of the flow, referred to as the head (H), can then be measured at the respective reference point/area with a ruler or other staff gauge. When substituted into a formula, which mathematically describes the relationship between depth and discharge for the primary devices, the head measurement can be used to calculate a flow rate (Q). The most common primary flow measurement devices are weirs and flumes. Weirs and flumes are flow structures designed to provide a known, repeatable relationship between flow and depth.

*Weirs*

Weirs consist of a crest located across the width of an open channel (at a right angle to the direction of the flow). The flow of water is impeded, causing water to overflow the crest. Diagrams and formulas of some typically found weirs are provided in Exhibit 3-4. Weirs are inexpensive and particularly valuable in measuring flow in natural or man-made swales because they are easily installed in irregularly shaped channels.

## EXHIBIT 3-4. WEIRS

V-Notch

$Q = 2.5\ H^{2.5}$ (90°)
$Q = 1.443\ H^{2.5}$ (60°)
$Q = 1.035\ H^{2.5}$ (45°)
$Q = 0.676\ H^{2.5}$ (30°)
$Q = 0.497\ H^{2.5}$ (22½°)

Q = Flow Rate

H = Depth of flow (Head)

Rectangular (without contractions)

$Q = 3.33\ L\ H^{1.5}$

Rectangular (with contractions)

$Q = 3.33\ (L - 0.2\ H)^{1.5}$

Cipolleti (trapezoidal)

$Q = 3.367\ b\ H^{1\frac{1}{2}}$

Source: Civil Engineering Reference Manual, 5th Edition, by Michael R. Lindeburg, PE, with permission from the publisher, Professional Publications, Inc., Belmont, California, 1989.

**EXHIBIT 3-5. SUPPRESSED FLOW OVER THE WEIR CREST**

(H) Real Head

Nappe

Weir
Crest

Source: Civil Engineering Reference Manual, 5th Edition, by Michael R. Lindeburg, PE, with permission from the publisher, Professional Publications, Inc., Belmont, California, 1989.

Weirs can only provide accurate flow measurements when head measurements are appropriately taken. When flow exceeds the capacity of the weir and water overtops the weir crest, flow depth actually diminishes as the water approaches the weir, as shown in Exhibit 3-5. Therefore, measuring the depth at the weir crest will result in an inaccurate measurement of the actual head. Under these circumstances, the head should be measured upstream, at a point determined by the type of weir and the estimated amount of flow. A staff gauge can be installed at a nonturbulent point upstream of the weir crest to provide accurate and convenient measurements.

*Flumes*

Flumes are structures which force water through a narrow channel. They consist of a converging section, a throat, and a diverging section. Exhibit 3-6

## EXHIBIT 3-6. FLUMES

Parshall Flume

| | |
|---|---|
| $Q = 0.338\ H^{1.55}$ | (1 inch) |
| $Q = 0.676\ H^{1.55}$ | (2 inches) |
| $Q = 0.992\ H^{1.547}$ | (3 inches) |
| $Q = 2.09\ H^{1.58}$ | (6 inches) |
| $Q = 3.07\ H^{1.53}$ | (9 inches) |
| $Q = 4\ W\ H^{1.522}\ W^{0.26}$ | (1-8 feet) |
| $Q = (3.6875\ W + 2.5)H^{1.6}$ | (10-50 feet) |

$Q$ = Flow rate

$H$ = Depth of flow (Head)

Top View

Throat

Converging Section

Diverging Section

Side View

Source: Civil Engineering Reference Manual, 5th Edition, by Michael R. Lindeburg, PE, with permission from the publisher, Professional Publications, Inc., Belmont, California, 1989.

portrays the most common type of flume, the Parshall flume, and also provides formulas for calculating appropriate flow rates.

Parshall flumes have fixed specifications relating to geometric shape. They vary only in throat width. Due to these geometric constraints, Parshall flumes may be expensive to install. They are typically used in permanent flow measurement points and are most commonly placed in concrete-lined channels. However, Parshall flumes can also be used in temporary points. Parshall flumes provide accurate measurements for a relatively wide range of flow rates. The flow rate through the Parshall flume (see Exhibit 3-6) is calculated from the depth ($H_a$) of flow measured in the converging

EXHIBIT 3-7. PALMER-BOWLUS FLUME

Source: Wastewater Engineering: Treatment, Disposal, Reuse, 2nd Edition, Metcalf & Eddy, Inc., with permission from the publisher, McGraw-Hill Book Co., New York, 1979.

section of the flume. The exact location of the depth measurement depends on the specific design of the Parshall flume. Exhibit 3-6 indicates the equations used to calculate flow rate through a typical Parshall flume. These equations are accurate only when the submergence ratio ($H_b/H_a$) is greater than 0.7. The manufacturers' information should be consulted for the flow rate equation and measuring points for a specific Parshall flume.

Palmer-Bowlus flumes, shown in Exhibit 3-7, are also used at some facilities. Palmer-Bowlus flumes are designed to be installed in an existing circular channel (such as a manhole channel) and are available as portable measurement devices. While Palmer-Bowlus flumes are inexpensive, self cleaning, and easy to install, they can only measure flow rates accurately over a narrow range of flow.

The flow from a Palmer-Bowlus flume is calculated using the height between the floor of the flume portion and the water level, not the total head of the water level. Head measurements are taken at a distance from the throat equal to one half the width of the flume. The dimensions of a Palmer-Bowlus flume have been standardized in a generic sense, but the flume shape may vary. Therefore, there are no formulas that can be applied to all Palmer-Bowlus flumes. Device-specific head-flow relationships for each device should be obtained from the manufacturer.

There are a number of other, less common, flow measurement devices available which will not be discussed (see Appendix D for additional references).

Secondary Flow Measurement Devices

Secondary flow measurement devices are automated forms of flow rate and volume measurement. Typically, a secondary device is used in conjunction with a primary device to automatically measure the flow depth or head. This value is then processed, using established mathematical relationships to relate the depth measurement to a corresponding flow rate. The device also may have the capacity to convert this flow rate to a volume. Secondary flow measurement devices include floats, ultrasonic transducers, pressure transducers, and bubblers. The output of the secondary device is transmitted to a display, recorder, and/or totalizer to provide flow rate and volume information. The user manuals for these devices should be consulted for proper usage.

Evaluation of Flow Measurement Devices

To ensure accurate results, facilities should evaluate, via visual observation and routine checks, the design, installation, and operation of flow measurement devices. When evaluating design, select a device which:

- Is accurate over the entire range of expected flow rates
- Can be installed in the channel to be monitored
- Is appropriate to the sampling location (i.e., power setup, submersible, etc.).

When evaluating the installation of flow measurement devices, ensure that:

- There are no leaks and/or bypasses of flow around the measuring device
- The primary device is level and squarely installed
- The secondary device is calibrated.

When evaluating the operation of flow measurement devices, look for:

- Excessive flows which submerge the measuring device
- Flows outside the accuracy range of the device
- Leaks and/or bypasses around the measuring device
- Turbulent flow through the measuring device
- Corrosion, scaling, or solids accumulation within the measuring device
- Obstructions to the measuring device
- Use of the correct factor or formula to convert head readings to actual flow rate.

Other than ensuring appropriate design and installation, accuracy checks are difficult to accomplish for primary flow measurement devices. Secondary flow measurement devices, on the other hand, may require evaluation of design, installation, and calibration. Applicants should examine the secondary recording devices and their readouts after installation to ensure that they are operating properly. Unusual fluctuations or breaks in flow indicate operational or design flaws.

### 3.2.2 ESTIMATING FLOW RATES

There are a variety of techniques for estimating flow rates. These methods are not as accurate as the methods described in Section 3.2.1 above, but are suitable for those discharges where primary or secondary devices are not practical or economically feasible. Each of the following methods is suitable for certain types of flow situations, as indicated. For each, the procedure for collecting flow rate data will be given along with a sample calculation.

Float Methods

Float methods can be used for any discharge where the flow is exposed and/or easily accessible. It is particularly useful for overland flows, gutter flows, and open drain or channel flows. The flow rate is calculated in each of the float methods by estimating the velocity of the flow and the cross-sectional area of the discharge and using the standard flow rate equation:

$$Flow\ Rate\ (cfm) = Velocity\ (ft/min) \times Area\ (ft^2)$$

The velocity is estimated by measuring the time it takes a float to travel between two points (point A and point B) along the flow path. For most accurate results, the two points should be at least 5 feet apart. The cross-sectional area is estimated by measuring the depth of the water and the width of the flow, and multiplying the depth by the width. This assumes a uniform cross-section in the flow path and a geometric cross-section shape. The float method can also be used for any accessible pipe or ditch where the movement of the float can be traced downstream for at least 5 feet. Subsurface storm water flows can be measured with the float method where there are two accessible manholes.

If the flow is overland, the water will need to be directed into a narrow channel or ditch so that the measurements can be taken. The initial preparation for this method requires that a shallow channel or ditch be dug that is 6 feet long or longer and 4 to 12 inches wide. The channel or ditch should be shallow enough to easily obtain flow depths but should be deep enough to carry the flow that will be diverted to it. Boards or other barriers should be placed on the ground above the channel (so that the flow is diverted into the channel) and along the edges of the channel or ditch (flush with the ground surface so that flow does not seep under them).

## EXHIBIT 3-8. EXAMPLE CALCULATION OF FLOAT METHOD FOR UNIMPEDED OPEN CHANNEL FLOW

**Step 1:** When each sample or aliquot is taken, record the data for the time the sample was taken and the length between points A and B (at least 5 feet apart). See columns A, B, and C.

EXAMPLE DATA:

| A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|
| **Sample Number** | **Time in Minutes** | **Distance Between Points A & B (feet)** | **Time of Travel (A to B) (min)** | **Depth of Water at Point B (feet)** | **Width of Flow at Point B (feet)** | **Calculated Flow Rate (cfm)** |
| 1 | 0 | 5.0 | 0.17 | 0.12 | 0.5 | 1.8 |
| 2 | 20 | 5.0 | 0.18 | 0.25 | 0.5 | 3.5 |
| 3 | 40 | 5.0 | 0.20 | 0.29 | 0.5 | 3.6 |
| 4 | 60 | 5.0 | 0.21 | 0.33 | 0.5 | 3.9 |
| 5 | 80 | 5.0 | 0.18 | 0.29 | 0.5 | 4.0 |
| 6 | 100 | 5.0 | 0.17 | 0.25 | 0.5 | 3.7 |
| 7 | 120 | 5.0 | 0.17 | 0.12 | 0.5 | 1.8 |
| 8 | 140 | 5.0 | 0.16 | 0.12 | 0.5 | 1.9 |
| 9 | 160 | 5.0 | 0.18 | 0.12 | 0.5 | 1.7 |

**Step 2:** Place a float in the water flow at point A and time it as it moves from point A to point B. Record the time in minutes. See column D.

**Step 3:** Measure the depth of the water and the width of the flow at point B. See columns E and F.

**Step 4:** Calculate the flow rate for each sample time using the common flow rate formula. See column G.

Formulas:

$$\text{Velocity (V)} = \frac{\text{Length from A to B}}{\text{Time of Travel}}$$

$$\text{Area (A)} = \text{Water Depth} \times \text{Width of Flow}$$

$$\text{Flow Rate (Q)} = (V) \times (A)$$

Example: For Sample 1

$$V = \frac{5.0\ ft}{0.17\ min} = 29.4\ ft/min$$

$$A = 0.12\ ft \times 0.5\ ft = 0.06\ ft^2$$

$$Q = 29.4\ ft/min \times 0.06\ ft^2 = 1.8\ cfm$$

The procedure for measuring the flow rate by the float method involves measuring the length of the channel between chosen points A and B (which must be 5 feet apart or more). The depth of the water at point B, in the middle of the channel, must be determined, and the width of the water flow must be measured at point B. A float is then placed in the water and timed as it moves from point A to point B. Exhibit 3-8 provides an example of estimating the flow rate using the float method.

## EXHIBIT 3-9. EXAMPLE CALCULATION OF FLOAT METHOD FOR ESTIMATING DRAIN FLOW RATES

**Step 1:** When each sample or aliquot is taken, record the data for the time the sample was taken. Measure the outer perimeter or edge of the drain where the water flows in. See columns B and C.

**Step 2:** Designate three evenly spaced points surrounding the drain approximately 3 to 5 feet from the drain. These points will be referred to as points A, B, and C. Record the distance from each point to the edge of the drain. See column D.

EXAMPLE DATA: Assume the drain dimensions are 1 ft x 1 ft square, and flow surrounds drain.

| A | B | C | D | | | E | | | F | | | G |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample Number | Sample Time (min) | Drainage Perimeter (feet) | Distance of Point to Drain (feet) | | | Time of Travel to Drain (min) | | | Depth of Water (feet) | | | Calculated Flow Rate (cfm) |
| | | | Pt. A | Pt. B | Pt. C | Pt. A | Pt. B | Pt. C | Pt. A | Pt. B | Pt. C | |
| 1 | 0 | 4 | 3 | 4 | 5 | 0.2 | 0.3 | 0.5 | 0.08 | 0.08 | 0.08 | 4 cfm |
| 2 | 20 | 4 | 3 | 4 | 5 | 0.3 | 0.4 | 0.5 | 0.11 | 0.12 | 0.14 | 5 cfm |
| 3 | 40 | 4 | 3 | 4 | 5 | 0.3 | 0.4 | 0.5 | 0.11 | 0.12 | 0.14 | 5 cfm |
| 4 | 60 | 4 | 3 | 4 | 5 | 0.4 | 0.5 | 0.6 | 0.16 | 0.17 | 0.20 | 6 cfm |
| 5 | 80 | 4 | 3 | 4 | 5 | 0.3 | 0.4 | 0.5 | 0.11 | 0.12 | 0.14 | 5 cfm |
| 6 | 100 | 4 | 3 | 4 | 5 | 0.3 | 0.4 | 0.5 | 0.11 | 0.12 | 0.14 | 5 cfm |
| 7 | 120 | 4 | 3 | 4 | 5 | 0.3 | 0.4 | 0.5 | 0.11 | 0.12 | 0.14 | 5 cfm |
| 8 | 140 | 4 | 3 | 4 | 5 | 0.3 | 0.4 | 0.5 | 0.11 | 0.12 | 0.14 | 5 cfm |
| 9 | 160 | 4 | 3 | 4 | 5 | 0.2 | 0.3 | 0.5 | 0.08 | 0.08 | 0.08 | 4 cfm |

**Step 3:** Place a float at each of the three points and measure the time it takes to reach the drain. Record the times in minutes. See column E.

**Step 4:** Determine the depth of flow at each place where the float enters the drain from points A, B, and C. Record the depth in feet. See column F.

**Step 5:** Calculate the flow rate by adding the individual flow rates for points A, B, and C. Record the data in column G.

Formulas:

$$\textit{Velocity } (V) = \frac{\textit{Distance of Point from Drain}}{\textit{Time of Travel}}$$

$$\textit{Area } (A) = \textit{Water Depth} \times \textit{Drainage Perimeter}$$

$$\textit{Flow Rate } (Q) = 1/n \sum A_n V_n, \textit{ where n equals points A, B, and C}$$

Example: For Sample 1

$$V_A = \frac{3 \text{ Feet}}{0.2 \text{ Min}} = 15 \text{ ft/min}$$

$$A_A = 0.08 \text{ ft} \times 4 \text{ ft} = 0.32 \text{ ft}^2$$

For runoff flows from many directions into a drain in a low or flat area where ponding is evident, the float method can also be used. The total flow rate is calculated by measuring flow rates for several points into the drain and adding these values together. Exhibit 3-9 provides an example of estimating the flow rate using the float method in this situation.

**EXHIBIT 3-9. EXAMPLE CALCULATION OF FLOAT METHOD FOR ESTIMATING DRAIN FLOW RATES (Continued)**

$$Q_{(TOTAL)} = \frac{1}{3}(V_A A_A + V_B A_B + V_C A_C)$$

$$= \frac{1}{3}[(15\ ft/min)(0.32\ ft^2) + (13\ ft/min)(0.32\ ft^2) + (10\ ft/min)(0.32\ ft^2)]$$

$$= 4\ cfm$$

Bucket and Stopwatch Method

The bucket and stopwatch method of estimating flow rate is the easiest of all the flow rate estimation procedures. However, it can only be used under certain conditions. The flow or discharge to be measured must be flowing from a small pipe or ditch, and it must be free-flowing. In other words, the pipe or ditch must be raised above the ground. Also, the flow must be small enough to be captured by a bucket or other suitable container without overflowing. If these conditions are not present, another method must be used. The procedure involves recording the time that each sample is taken, the time it takes for the container to be filled, and the volume of discharge collected. The flow rate is then calculated in gallons per minute (gpm) or in cubic feet per minute (cfm). The basis for the bucket and stopwatch method is the collection of a measured amount of flow over a measured amount of time to determine flow per unit of time (or flow rate) as per the formula below.Exhibit 3-10

$$Flow\ Rate\ Q\ (gpm) = \frac{Volume\ of\ Bucket\ (gal)}{Time\ to\ Fill\ (sec)} \times \frac{60\ sec}{1\ min}$$

## EXHIBIT 3-10. EXAMPLE CALCULATION OF BUCKET AND STOPWATCH METHOD FOR ESTIMATING FLOWS

**Step 1:** When each sample or aliquot is taken, record the data for the time the sample was taken. See column B.

EXAMPLE DATA:

| A | B | C | D | E | F |
|---|---|---|---|---|---|
| **Sample Number** | **Time (minutes)** | **Time to Fill Bucket (seconds)** | **Volume of Bucket (gallons)** | **Calculated Flow Rate (gpm)** | **Calculated Flow Rate in (cfm)** |
| 1 | 0 | 40.0 | 2.0 | 3.0 | 0.4 |
| 2 | 20 | 26.0 | 2.0 | 4.6 | 0.6 |
| 3 | 40 | 24.0 | 2.0 | 5.0 | 0.7 |
| 4 | 60 | 32.0 | 2.0 | 3.7 | 0.5 |
| 5 | 80 | 45.0 | 2.0 | 2.7 | 0.4 |
| 6 | 100 | 31.0 | 2.0 | 3.9 | 0.5 |
| 7 | 120 | 50.0 | 2.0 | 2.4 | 0.3 |
| 8 | 140 | 21.0 | 2.0 | 5.7 | 0.8 |
| 9 | 160 | 28.0 | 2.0 | 4.3 | 0.6 |

**Step 2:** Put a bucket beneath the flow, while measuring with a stopwatch the time it takes to fill the bucket to a certain level. If the water spills over the sides, the process must be redone. Record the time it took to fill the volume of water. See columns C and D.

**Step 3:** Calculate the flow rate in gpm and cfm.

Formulas:

$$\textit{Flow Rate, } Q(gpm) = \frac{\text{Volume of bucket (gal)}}{\text{Time to fill (sec)}} \times \frac{60 \text{ sec}}{1 \text{ min}}$$

$$Q(cfm) = Q(gpm) \times 0.1337\ ft^3/gal$$

Example: For Sample 1

$$Q\ (gpm) = \frac{2 \text{ gal}}{40.0 \text{ sec}} \times \frac{60 \text{ sec}}{1 \text{ min}} = 3.0 \text{ gpm}$$

$$Q\ (cfm) = 3.0\ gpm \times 0.1337\ ft^3/gal = 0.4\ cfm$$

provides an example of estimating flow rates with the bucket and stopwatch method.

Slope and Depth Method

The slope and depth method is also a relatively easy method for estimating flow rates in pipes and ditches. This procedure requires that the slope of the pipe or ditch be known. A survey or engineering design data such as sewer or grading plans may provide the slope or grade of the pipe or ditch. In addition, the flow or effluent to be measured should not fully fill the pipe or ditch from which it is flowing. To measure the depth of the flow at the center of the pipe or ditch at the outfall, the outfall should be accessible. If these conditions are not present, another method should be used. The procedure involves recording the time that each sample is taken and measuring the depth of the flow in the middle of the pipe or ditch. If the flow is coming from a pipe, the inside diameter of the pipe should be recorded. If the effluent is coming from a ditch, the width of the flow in the ditch should be measured. Also, the modified slope of the ditch should be calculated.

## EXHIBIT 3-11. EXAMPLE CALCULATION OF SLOPE AND DEPTH METHOD FOR ESTIMATING FLOW RATES

**Step 1:** Obtain the pipe or ditch channel percent slope from engineering data. Determine the inside diameter if the flow is from a pipe.

EXAMPLE DATA: For purposes of this example, a ditch with a 2 percent slope is assumed.

**Step 2:** When each sample or aliquot is taken, record the data for the time the sample was taken. See column B.

EXAMPLE DATA:

| A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|
| **Sample Number** | **Time (minutes)** | **Depth of Water (in)** | **Width of Flow (ditch only) (feet)** | **"M" Modified Slope (ditch only)** | **Calculated Flow Rate (cfm Pipe only)** | **Calculated Flow Rate (cfm ditch only)** |
| 1 | 0 | 3.6 | 2.2 | 3.7 | - | 246.1 |
| 2 | 20 | 6.0 | 3.2 | 3.2 | - | 713.6 |
| 3 | 40 | 7.2 | 4.0 | 3.3 | - | 1,237.3 |
| 4 | 60 | 8.4 | 4.2 | 3.0 | - | 1,532.9 |
| 5 | 80 | 7.2 | 4.0 | 3.3 | - | 1,237.3 |
| 6 | 100 | 6.0 | 3.2 | 3.2 | - | 713.6 |
| 7 | 120 | 6.0 | 3.0 | 3.0 | - | 624.2 |
| 8 | 140 | 6.0 | 2.9 | 2.9 | - | 581.8 |
| 9 | 160 | 4.6 | 2.5 | 3.3 | - | 374.1 |

**Step 3:** Measure the depth of the water in the center of the pipe or ditch. Record the data in feet. See column C.

**Step 4:** Measure the width of the flow only if the flow is in a ditch. Record the data in feet. See column D.

**Step 5:** Calculate the modified side slope only if the flow is in a ditch (leave column E blank if the flow is in a pipe).

Formula:

$$\text{Modified slope } (M) = \frac{12.0\ \text{in/ft} \times \text{flow width (ft)}}{2.0 \times \text{water depth (in)}}$$

Example: Sample 1:

$$M = \frac{12.0\ \text{in/ft} \times 2.2\ \text{ft}}{2.0 \times 3.6\ \text{in}} = 3.7$$

**Step 6:** For pipes, calculate the flow rate and record the data in column F.

$$\text{Flow Rate } (Q) = 0.004 \times (I.D.)^{1.67} \times D \times \sqrt{S}$$

***where Q = flow rate in pipe (cfm), I.D. = inside diameter of pipe (in), D = water depth (in), S = pipe slope (%)***

**Step 7:** For ditches or channels, calculate the flow rate in cfm. Record the flow rate in column G.

Formula:

$$\text{Flow Rate } (Q) = \frac{0.42M \times (M)^{1.67} \times (D)^{2.67} \times \sqrt{S}}{(M^2 + 1)^{0.33}}$$

***where Q = flow rate in ditch (cfm), M = modified slope, D = water depth (in), S = ditch slope (%)***

Example: For Sample 1:

$$Q_1 = \frac{0.42\ (3.7) \times (3.7)^{1.67} \times (3.6)^{2.67} \times \sqrt{2}}{[(3.7)^2+1]^{0.33}}$$

$$Q = 246.1\ \text{cfm}$$

The flow rate is calculated in cfm using the same formulas for both pipes and ditches. Exhibit 3-11 provides an example of estimating the flow rate with the slope and depth method.

Runoff Coefficient Methods

Runoff coefficient methods are the least accurate of all the flow rate estimation methods. These methods should only be used for composite flow-weighted samples if all of the other methods are inappropriate for the site. Although the least accurate, runoff coefficients are the simplest method of estimating runoff rates.

Runoff coefficients represent the fraction of total rainfall that will be transmitted as runoff from the drainage area that flows into the facility outfall. Runoff coefficients consider the ground surface or cover material and determine the amount of storm water flow which may infiltrate or runoff as a discharge. A simple estimate of runoff volume assumes that paved areas and other impervious structures such as roofs have a runoff coefficient of 0.90 (i.e., 90 percent of the rainfall leaves the area as runoff). For unpaved surfaces, a runoff coefficient of 0.50 is normally assumed. A more accurate estimate can be made by using more specific runoff coefficients for different areas of the facility, based on the specific type of ground cover. Commonly used runoff coefficients are listed in Exhibit 3-12.

EXHIBIT 3-12. TYPICAL "c" COEFFICIENTS FOR 5- TO 10-YEAR FREQUENCY DESIGN STORMS

| Description of Area | Runoff Coefficients |
|---|---|
| Business | |
| • Downtown areas | 0.70-0.95 |
| • Neighborhood areas | 0.50-0.70 |
| Residential | |
| • Single-family areas | 0.30-0.50 |
| • Multiunits (detached) | 0.40-0.60 |
| • Multiunits (attached) | 0.60-0.75 |
| Residential (suburban) | 0.25-0.40 |
| Apartment dwelling areas | 0.50-0.70 |
| Industrial | |
| • Light areas | 0.50-0.80 |
| • Heavy areas | 0.60-0.90 |
| Parks and cemeteries | 0.10-0.25 |
| Playgrounds | 0.20-0.35 |
| Railroad yard areas | 0.20-0.40 |
| Unimproved areas | 0.10-0.30 |
| Streets | |
| • Asphalt | 0.70-0.95 |
| • Concrete | 0.80-0.95 |
| • Brick | 0.70-0.85 |
| Drives and walks | 0.75-0.85 |
| Roofs | 0.75-0.95 |
| Lawns - course textured soil (greater than 85 percent sand) | |
| • Slope: Flat (2 percent) | 0.05-0.10 |
| Average (2-7 percent) | 0.10-0.15 |
| Steep (7 percent) | 0.15-0.20 |
| Lawns - fine textured soil (greater than 40 percent clay) | |
| • Slope: Flat (2 percent) | 0.13-0.17 |
| Average (2-7 percent) | 0.18-0.22 |
| Steep (7 percent) | 0.25-0.35 |

Source: *Design and Construction of Sanitary and Storm Sewers*, with permission from the publisher, American Society of Civil Engineers, *Manual of Practice*, page 37, New York, 1960.

The average runoff coefficient can be estimated for drainage areas that have both paved and unpaved areas by weighting the coefficients based on their proportion of the total area. An equation for this would be:

$$Estimated\ Average\ Runoff\ Coef. = \frac{(Area\ A)(Runoff\ Coef.\ A) + (Area\ B)(Runoff\ Coef.\ B)}{Area\ A + Area\ B}$$

The area of the drainage basin can generally be obtained from land surveys conducted at the time of facility purchase or site surveys taken from design documents developed as part of construction planning. If these are not available, the applicant may estimate the drainage areas from a topographic map of the area. The areas used in this calculation should include only those areas drained by the sampled outfall. When determining the basin area that drains through the outfall, some special considerations should be noted: (1) storm water from sources outside an industrial facility's property boundary may contribute to the discharge; and (2) storm water not associated with industrial activity may contribute to the flow volume. Where these conditions occur, the facility should accurately quantify and appropriately address these contributions.

There are two specific methods to estimate flow rate using runoff coefficients. The first method uses depth of flow in a pipe or ditch and an average runoff rate to estimate each of the sample flow rates where the slope/pitch of the pipe or ditch is unknown. Exhibit 3-13

## EXHIBIT 3-13. EXAMPLE CALCULATION OF RUNOFF COEFFICIENT/FLOW DEPTH METHOD FOR ESTIMATING FLOW RATES

**Step 1:** Estimate the runoff coefficient for the drainage area that contributes flow to the sampled outfall (see Section 3.2.2).

EXAMPLE: Assume the drainage area to the outfall is 3 acres. Two of those acres are paved with a runoff coefficient of .90, and 1 is unpaved with a runoff coefficient of .50. Using the equation for estimated runoff coefficient from the text in Section 2.2.2.2:

$$\textit{Est. Run. Coef.} = \frac{(2\,Ac)(0.90) + (1\,Ac)(0.50)}{2\,Ac + 1\,Ac} = 0.77$$

The runoff coefficient for the entire drainage area is 0.77.

**Step 2:** Measure the rainfall depth. Record the total rainfall of the storm or the rainfall that occurred in the first 3 hours (if it lasted more than 3 hours). Also record the duration of the rain event.

EXAMPLE: Assume the rainfall depth to be 1.0 inches in 3 hours.

**Step 3:** Calculate an average runoff rate.

Formula:

$$\textit{Average Runoff Rate} = \frac{\textit{Drainage Area} \times \textit{Runoff Coef.} \times \textit{Rainfall Depth}}{\textit{Rainfall Duration}}$$

Example:

$$\textit{Average Runoff Rate} = \frac{3\,Ac \times .77 \times 1\,in}{3\,hrs} \times \frac{43{,}560\,ft^2}{Ac} \times \frac{ft}{12\,in} \times \frac{hr}{60\,min} = 47\,cfm$$

When each sample or aliquot is taken, record the data for the time the samples were taken and the depth of the water in the center of the ditch or pipe. Record the data in columns B and C.

EXAMPLE DATA:

| A | B | C | D | E |
|---|---|---|---|---|
| **Sample Numbers** | **Time (minutes)** | **Channel or Ditch Water Depth (feet)** | **Calculated Depth-Weighted Flow Factor** | **Flow Rate (cfm)** |
| 1 | 0 | 1.0 | 0.82 | 39 |
| 2 | 20 | 1.1 | 0.90 | 42 |
| 3 | 40 | 1.2 | 0.98 | 46 |
| 4 | 60 | 1.25 | 1.02 | 48 |
| 5 | 80 | 1.3 | 1.06 | 50 |
| 6 | 100 | 1.25 | 1.02 | 48 |
| 7 | 120 | 1.2 | 0.98 | 46 |
| 8 | 140 | 1.7 | 1.39 | 65 |
| 9 | 160 | 1.0 | 0.82 | 39 |

**Step 4:** Sum up all the water depths for each sample taken as indicated above in column C.

**Sum = 11.0 feet**

**EXHIBIT 3-13. EXAMPLE CALCULATION OF RUNOFF COEFFICIENT/FLOW DEPTH METHOD FOR ESTIMATING FLOW RATES (Continued)**

**Step 5:** Calculate a depth-weight flow factor and record the data in column D.

Formula:

$$\textit{Factor} = \frac{\textit{Measured Water Depth} \times \textit{Number of Flow Measurements}}{\textit{Sum of all Water Depths}}$$

Example: For Sample 1

$$\textit{Factor} = \frac{(1\ ft) \times 9}{11.0} = 0.82$$

**Step 6:** Calculate the flow rate. Record the data in column E.

Formula:

$$\textit{Flow Rate, Q (cfm)} = \textit{Average Runoff Rate} \times \textit{Depth Factor}$$

Example: For Sample 1

$$Q = 47\ cfm \times 0.82 = 39\ cfm$$

provides an example calculation of estimating flow rates based on depth and runoff coefficients. The second method uses only rainfall accumulation and runoff coefficients to estimate a flow associated with the time the sample was taken. No actual flows or flow depths are measured. Exhibit 3-14

## EXHIBIT 3-14. EXAMPLE CALCULATION OF RUNOFF COEFFICIENT RAINFALL DEPTH METHOD FOR ESTIMATING FLOW RATES

**Step 1:** Estimate the runoff coefficient for the drainage area that contributes flows to the sampled outfall.

EXAMPLE: See Step 1 in Exhibit 3-14. The site for this example will be similar so a coefficient of .77 will be used for the same 3-acre drainage area.

**Step 2:** When each sample or aliquot is taken, record the data for the time the sample was taken. Record the data in column B.

EXAMPLE DATA:

| A | B | C | D | E | F |
|---|---|---|---|---|---|
| **Sample Number** | **Time (minutes)** | **Total Rainfall Depth (inches)** | **Time Since Last Sample** | **Incremental Rainfall (inches) per 20 minutes** | **Calculated Flow Rate (cfm)** |
| 1 | 0 | 0.0 | 0 | 0.0 | -- |
| 2 | 20 | 0.2 | 20 | 0.2 | 84 |
| 3 | 40 | 0.3 | 20 | 0.1 | 42 |
| 4 | 60 | 0.5 | 20 | 0.2 | 84 |
| 5 | 80 | 0.6 | 20 | 0.1 | 42 |
| 6 | 100 | 0.8 | 20 | 0.2 | 84 |
| 7 | 120 | 0.9 | 20 | 0.1 | 42 |
| 8 | 140 | 1.0 | 20 | 0.1 | 42 |
| 9 | 160 | 1.1 | 20 | 0.1 | 42 |

**Step 3:** Using a rainfall gauge, measure the total rainfall depth (in inches) and record the data in column C.

EXAMPLE: See sample data above.

**Step 4:** Calculate the incremental time since the last flow measurement and record the data in column D.

EXAMPLE: Samples were taken 20 minutes apart so this increment will be 20 minutes for every sample.

**Step 5:** Calculate the additional or incremental rainfall that has occurred since the last measurement. Record the data in column E.

Formula:

***Incremental Rainfall = Total Rainfall Sample 2 - Total Rainfall Sample 1***

Example: For Sample 2

***Incremental Rainfall = .2 - 0 = .2 inches***

**Step 6:** Calculate the flow rate. Record the data in column F.

Formula:

$$\textit{Flow Rate (cfm)} = \frac{\textit{(Drainage area)(Runoff coefficient)(Incremental rainfall)}}{\textit{(Incremental time)}}$$

Example:

$$\textit{Flow Rate} = \frac{(3\ Ac)(0.77)(0.2\ in)}{20\ min} \times \frac{(43{,}560\ ft^2)}{Ac} \times \frac{1\ ft}{12\ in} = 84\ cfm$$

provides an example of estimating the flow rate based on rainfall depth and runoff coefficients.

### 3.2.3 MEASURING TOTAL FLOW VOLUMES FOR THE SAMPLED RAIN EVENT

Similar to measuring flow rates, flow volumes may be measured using automatic flowmeters or primary/secondary devices as discussed in Section 3.2.1. Measurement of flow volume with these devices provides a reasonably accurate determination of the total flow volume for the entire storm water discharge. In many cases, however, primary or secondary devices have not been installed for storm water flow measurement. Portable flow measurement devices are often expensive. Many of the automatic samplers that are currently on the market can measure flow volumes as well as perform sampling. Where available and when economically feasible, measuring devices should be used to generate data for calculating flow.

### 3.2.4 ESTIMATING TOTAL FLOW VOLUMES FOR THE SAMPLED RAIN EVENT

Since accurate measurement of total flow volumes is often impracticable due to lack of equipment, total flow volumes are more commonly estimated. The two methods provided in this section require only simple estimated measurements. The first method is based on rainfall depths and runoff coefficients and the second is based on flow rates that can be either measured or estimated.

Runoff Coefficients Methods

Discharge volumes are most easily estimated using the area of the drainage basin contributing to the outfall, the rainfall accumulation, and a runoff coefficient. The total volume of discharge can be estimated using a simple equation that relates the amount of rainfall to the volume of discharge that will leave the site as runoff. The equation is as follows:

$$V_t = R_t \times [(A_{paved} \times C_{runoff}) + (A_{unpaved} \times C_{runoff})]$$

where: $V_t$ = the total runoff volume in cubic feet
$R_t$ = the total rainfall measured in feet

$A_{paved}$ = the area (sq ft) within the drainage basin that is paved or roofed
$A_{unpaved}$ = the area (sq ft) within the drainage basin that is unpaved
$C_{runoff}$ = a specific runoff coefficient (no units) for the drainage area ground cover

## EXHIBIT 3-15. EXAMPLE CALCULATION OF TOTAL RUNOFF VOLUME FROM RAINFALL DATA

**Step 1:** Determine the area of drainage contributing to the runoff volume at the outfall and convert it to square feet.

Example: Using a land survey, a facility has determined its site encompasses 0.3 acres (13,068 square feet). The entire site is used for industrial activities, and therefore, any storm water discharges from the site will be associated with industrial activity. A berm surrounds the entire site limiting the drainage area to the site itself and preventing any dilution or contamination from other discharges. (Note: To convert acres to square feet, multiply the number of acres by 43,560, which is the conversion factor).

**Step 2:** Determine the rainfall depth during the event that was sampled to the nearest one-hundredth of an inch and convert it to feet.

Example: From the rain gauge, the rainfall accumulation is measured at 0.6 inches or 0.05 feet (ft). (Note: To convert inches to feet, divide the inches by 12, which is the conversion factor).

**Step 3:** Determine the runoff coefficients for each area.

Example: The facility has estimated that ⅓ of the site, or 4,356 square feet, is covered by impervious surfaces (i.e., roofs or paved roadways) and ⅔ of the site, or 8,712 square feet, is unpaved.

**Step 4:** Calculate the volume of flow using the following formula and convert the volume to liters.

Formula: ***Total runoff volume in cubic feet (cu ft) = total rainfall (ft) x [facility paved area (sq ft) x 0.90 + facility unpaved area (sq ft) x 0.50]***

Example: ***Total runoff volume (cu ft) = 0.05 x [4,356 x 0.90 + 8,712 x 0.50]***

***Total runoff volume = 413.8 cu ft or 11,720 liters***

(Note: To convert cubic feet to liters, multiply cubic feet by 28.32, which is the conversion factor).

Exhibit 3-15 provides an example calculation of total runoff volume from rainfall data.

Discharge Volumes Estimated Based on Measured Flow Rates

Another method of estimating the total volume of a discharge uses a series of measured or estimated flow rates. The total volume of discharge can be estimated by first multiplying each of the flow rates by the time interval in between flow measurements. This time period represents the portion of the total storm duration that can be associated with the flow rate measurement. Adding all such partial volumes results in a total flow volume. A procedure for calculating the total runoff volume from a set of discrete measurements of flow depth and velocity in a ditch during a storm runoff event is presented in Exhibit 3-16.

## EXHIBIT 3-16. EXAMPLE CALCULATION OF TOTAL RUNOFF VOLUME FROM FLOW RATE DATA

**Step 1:** Measure and tabulate flow depths and velocities every 20 minutes (at the same time that the sample is collected) during at least the first 3 hours of the runoff event.

EXAMPLE DATA:

| A | B | C | D | E | F |
|---|---|---|---|---|---|
| **Sample Number** | **Time (minutes)** | **Flow Velocity (feet per minute)** | **Flow Depth (feet)** | **Width (feet)** | **Calculated Flow Rate (cfm)** |
| 1 | 0 | - | - | - | - |
| 2 | 20 | 4 | 0.2 | 5 | 4 |
| 3 | 40 | 8 | 0.4 | 5 | 16 |
| 4 | 60 | 12 | 0.4 | 5 | 24 |
| 5 | 80 | 8 | 0.4 | 5 | 16 |
| 6 | 100 | 4 | 0.2 | 5 | 4 |
| 7 | 120 | 8 | 0.2 | 5 | 8 |
| 8 | 140 | 4 | 0.2 | 5 | 4 |
| 9 | 160 | 4 | 0.2 | 5 | 4 |

## EXHIBIT 3-16. EXAMPLE CALCULATION OF TOTAL RUNOFF VOLUME FROM FLOW RATE DATA (Continued)

**Step 2:** Calculate and tabulate the cross-sectional area of flow for each of the flow depths measured. Calculate the flow rate for each discrete set of measurements.

Formula: ***Flow Rate Q (cfm) = Velocity (ft/min) × Area (sq ft)***
***Area = Depth × Width***

Example: For Sample 1

***Area = 0.2 ft × 5 ft = 1 sq ft***
***Flow Rate = 4 ft/min × 1 sq ft = 4 cfm***

**Step 3:** Plot the flow rate, Q, versus time. Also, assume that flow drops uniformly from the last calculated flow rate ($Q_9$) to zero at the time when $Q_{10}$ would have been taken.

Example: The flow rates calculated in Step 3 are plotted against the time between samples.

EXHIBIT 3-16. EXAMPLE CALCULATION OF TOTAL RUNOFF VOLUME FROM FLOW RATE DATA (Continued)

**Step 4:** The total flow volume ($V_t$) can be calculated by geometrically determining the area under the curve. The summation of the individual volumes per increment of time ($V_1$ through $V_9$) is the total flow volume of the event.

Example:

**Step 5:** Compute the flow volume associated with each observation ($V_1$, $V_2$, ..., $V_9$) by multiplying the measured flow rate by the duration (in this case, 20 minutes). Be sure the units are consistent. For example, if durations are in minutes and flow velocities are in cubic feet per second (cfs), convert the durations to seconds or the velocities to feet per minute.

**EXHIBIT 3-16. EXAMPLE CALCULATION OF TOTAL RUNOFF VOLUME FROM FLOW RATE DATA (Continued)**

Formula: ***Volume (V) = Flow Rate (cfm) x Duration (minutes)***

Example:

$$V_1 = \frac{1}{2}(Q_1 - Q_o)(t_1 - t_0) = \frac{1}{2}(4-0)(20-0) = 40 \ ft^3$$

$$V_2 = \frac{1}{2}(Q_2 - Q_1)(t_2 - t_1) + Q_1(t_2 - t_1)$$

$$= \frac{1}{2}(16-4)(40-20) + 4(20)$$

$$= 120 + 80 = 200 \ ft^3$$

$V_1 = 40$ ft$^3$

$V_2 = 200$ ft$^3$

$V_3 = 400$ ft$^3$

$V_4 = 400$ ft$^3$

$V_5 = 200$ ft$^3$

$V_6 = 120$ ft$^3$

$V_7 = 120$ ft$^3$

$V_8 = 80$ ft$^3$

$V_9 = 40$ ft$^3$

**Step 6:** Total the individual volumes calculated in Step 5 to obtain the total runoff volume.

Example:

***Total Storm Runoff = 1,600 ft$^3$***

### 3.2.5 REPORTING STORM WATER DISCHARGE FLOW RATES AND VOLUMES

Form 2F requires applicants to provide quantitative data (reported both as concentration and as total mass) based on flow-weighted samples collected during storm events. In addition, applicants are required to provide flow estimates or flow measurements, as well as an estimate of the total volume of the discharge. The method of flow estimation or measurement must be described in the application. Although EPA only requires flow estimates in Form 2F, accurate flow measurement is necessary for collecting representative flow-weighted composite samples and reporting pollutant mass loadings.

### 3.2.6 MEASURING RAINFALL

Many types of instruments have been developed to measure the amount and intensity of precipitation. All forms of precipitation are measured on the basis of the depth of the water that would accumulate on a level surface if precipitation remained where it fell. There are two types of rain gauges -- standard and recording gauges. A standard rain gauge collects the rainfall so that the amount of rain can be easily measured. The standard gauge for the NWS has a collector which is 8 inches in diameter. Rain flows from the collector into a cylindrical measuring tube inside the overflow can. The measuring tube has a cross-sectional area one tenth the size of the collector so that 0.1 inch of rainfall will fill 1 inch of the measuring tube. While this standard gauge is both accurate and easy to use, any open receptacle with vertical sides can be an effective rain gauge. Standard rain gauges are simple and inexpensive; however, with a standard gauge, there is no way to record changes in the intensity of the rainfall without making frequent observations of the gauge during the storm.

The second type of gauge is the recording rain gauge, which provides a permanent record of the amount of rainfall which accumulates over time. Three common types of recording gauges are:

- Tipping Bucket Gauge - Water caught in a collector is funneled into a two-compartment bucket; a known quantity of rain fills one compartment, overbalancing the bucket and emptying it into a reservoir. This moves the second bucket into place beneath the funnel. The tipping of the bucket engages an electric circuit, which records the event.

- Weighing Type Gauge - Water is weighed when it falls into a bucket placed on the platform of a spring or lever balance. The weight of the contents is recorded on a chart, showing the accumulation of precipitation.

- Float Recording Gauge - Water is measured by the rise of a float that is placed in the receiver. These gauges may be self-siphoning, or may need to be emptied periodically by hand.

Recording rain gauges provide a permanent record of rainfall, and they can be used to determine variations in rainfall intensity over time without making frequent observations during the storm. But recording gauges are more complicated mechanically than standard gauges, making them more costly, less durable, and more difficult to operate.

Although all gauges are subject to error, most errors can be minimized. To minimize errors, the gauge should be placed on a level surface that is not windswept and is away from trees or buildings that might interfere with the path of rainfall. When taking measurements, other factors contributing to error should also be considered: mistakes in reading the scale, dents in the collector rim (which changes the receiving area), measuring sticks that may retain some of the water, and water lost to evaporation. In the case of tipping bucket gauges, water may not be collected while the bucket is still tipping. The most common source of inaccuracy is changes in data that are attributable to wind. It is possible to assess wind errors by comparing measurements of gauges that are protected from the wind with those that are not.