SECTION 5
SELECTION OF MONITORING METHODS AND EQUIPMENT

This section discusses the various methods and equipment that may be used for sample collection and flow measurement. In addition, appropriate methods of data management are discussed.

Water quality in stormwater runoff may vary both laterally and vertically throughout the cross section of flow, and with time. For instance, floatable materials (oil, grease, light particles and debris, scum) may be present in significant amounts near the water surface, while heavier sediments are often concentrated near the bottom of the conveyance. Also, concentrations of some constituents may be higher in the first hour or two of runoff; this is often referred to as a "first flush" effect. During the course of a storm, rainfall intensity also may increase, raising runoff flow rates to the point where sediments are mobilized and scour occurs, resulting in temporarily higher concentrations of sediment-bound constituents.

The stormwater monitoring program should be designed to ensure that collected samples are representative of runoff quality throughout a given storm event. Ideally, this means collection of flow-proportioned composite samples throughout the runoff hydrograph. See ***Appendix C*** for a discussion of flow-proportional compositing.

This section is organized under the following subsections:

KEY TOPICS

- **Sample Collection Methods**
- **Sample Collection Equipment**
- **Flow Measurement Methods and Equipment**
- **Precipitation Measurement**
- **System Integration**
- **System Command/Control**
- **Remote Communication**
- **Data Management**

➤ SAMPLE COLLECTION METHODS

Stormwater samples can be collected to represent a point in time (i.e., "grab" sample) or a period of time (i.e., "composite" sample). A grab sample is essentially a one-time collection of a sample volume adequate to perform the intended water quality analysis. A composite sample is comprised of some number of individual sample aliquots mixed

together. For stormwater monitoring, this usually refers to samples collected sequentially over time during a stormwater runoff event.

Stormwater samples can be collected using either manual or automated means. Districts should select the combination of sample types and techniques most suitable to the monitoring program objectives and available resources. In most cases, automated composite sampling is the recommended sample collection method, with manual grab sampling as required for certain constituents (as discussed below and in ***Section 10***).

Composite Sampling

Automated sampling generally is the most cost effective method of composite sample collection, and is particularly appropriate for large-scale programs (e.g., where a large number of sampling sites are monitored, or numerous sampling events are conducted over multiple years). Automatic samplers can be configured to collect flow-proportioned (flow-weighted)[1] composite samples, which provide the most accurate means for estimating EMCs[2] and pollutant loads. Pollutant loads can be calculated using the EMC and runoff volume (see ***Appendix C***).

Automated monitoring systems are comprised of electromechanical devices that can be operated automatically (i.e., an on-site operator is not needed). Automated monitoring is recommended for the following reasons:

- Personnel are not required to be on-site; therefore, worker safety is not threatened by hazardous conditions (e.g., traffic, inadequate oxygen, toxic or explosive gases) and after hours labor requirements are reduced.
- Automatic samplers can be programmed so that sampling operations are initiated when pre-determined conditions are met, such as a specific flow rate, flow depth, or rainfall amount. This reduces the possibility of missing the early stages of runoff.
- Automated equipment can be programmed in conjunction with a flow meter to collect flow-weighted composite samples, using a constant volume proportional flow method (***Appendix C***). This permits collection of representative samples throughout the storm event.

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[1]Discussion of flow measurement methods is presented later in this section. Flow-proportioned (flow-weighted) composite sampling is discussed in more detail in Sections 9 and 10.

[2]The event mean concentration (EMC) is a statistical parameter that describes the average concentration of a given constituent at a specific location during a storm event. The EMC should be representative of the complete runoff hydrograph, and can be defined as the total constituent mass transported in the runoff, divided by the total runoff volume. The EMC is normally derived by analytical measurement of the constituent concentration in one or more representative composite samples. Flow-proportioned composite sampling for the purpose of determining EMCs is further discussed in ***Appendix C***.

The key elements of an automated monitoring system that are required to collect flow-proportioned composite samples include:

Sample Collection:

- An automatic sampler,
- Sample intake tubing and strainer, and
- Sample bottle(s).

Flow Measurement:

- A flow measurement device,
- Flow sensor and cable, and
- Optional rain gauge.

Data Recording/Retrieval:

- A data storage device,
- System software,
- Optional remote communications capabilities, and
- Optional secondary/back-up power source.

These components are discussed individually later in this section.

Composite samples also may be collected using manual methods. This approach may be warranted when the sampling program is to be of limited scope or duration, or where the installation of automated sampling equipment is economically or logistically infeasible. Although manual composite sample collection is more labor-intensive during a storm event, it will reduce required station setup and maintenance prior to each storm event. See ***Section 10*** for a description of manual compositing techniques.

Grab Sample Collection

A grab sample is an individual sample collected at one specific site at one point in time. Analysis of a grab sample provides a "snapshot" of stormwater quality. Grab samples are required for monitoring parameters that transform rapidly, require special preservation, or adhere to bottles. For example, samples to be analyzed for oil and grease, petroleum hydrocarbons, ammonia, volatile organics, and bacteria are required to be collected as grab samples only.

Grab samples are most often collected using manual methods and equipment. Some grab samples may be collected using intermediate containers and some (oil and grease, petroleum hydrocarbons) may not. When use of an intermediate container is appropriate

(e.g., for ammonia, volatile organics), grab samples should be collected by holding an appropriate container (bucket, bailer, sample bottle, etc.) under the outfall of a discharge pipe, at the lip of an inlet grate, or by dipping a container downstream of a discharge with the container opening facing upstream, depending on monitoring site configuration. The sample is then poured immediately into the appropriate grab sample bottle. Samples for bacteriological analysis must be collected in sterile bottles. Sterile Teflon bailers are available for this purpose; otherwise, the sample must be collected directly into the sterile "bacti" bottle. Clean techniques must be used when collecting bacteriological samples (see ***Section 10***).

When collecting samples for oil and grease or petroleum hydrocarbon analysis, the sample must be collected directly into the bottle that will be used in the laboratory, because petroleum-derived compounds may adhere to the sample container (the laboratory analyzes samples for these constituents by extracting the entire contents of the sample bottle). Because oil and grease and other petroleum hydrocarbons tend to float, these grab samples should be collected at the air/water interface.

➤ SAMPLE COLLECTION EQUIPMENT

For all collection efforts, sampling devices must be made of chemical resistant materials that will not affect the quality of the stormwater sample. In general, suitable sampling devices should be constructed of one of three materials: Teflon, glass, or polyethylene. These materials are known to be the most inert in terms of adsorption or desorption of organic and inorganic compounds, although both glass and plastic are subject to certain use limitations, depending upon the type of constituent being measured, as discussed below.

All sampling equipment used for trace metals determinations must be nonmetallic and free from any material that may contain metals. Acceptable materials include Teflon, polyethylene, and borosilicate glass (e.g., Pyrex). All sampling equipment used for trace organics determination must be glass or Teflon. All sampling equipment used for bacteriological determination must be sterile. Polyethylene or glass sampling equipment and bottles should be used for collection of nutrients. Borosilicate glass is generally adequate for composite sample collection when analysis is to be performed for a mixture of organic and inorganic constituents. See ***Section 12*** for specifications of acceptable bottle materials for each analytical constituent.

It is important to evaluate each component of the sampling device (e.g., bottle lids, connections, tubing) for possible sources of sample contamination. For example, latex and neoprene rubber tubings should be avoided because latex is organic and neoprene rubber may contain trace metals. Butyl rubber seals may also contaminate samples for organic analysis.

Equipment that is constructed of stainless steel, such as dippers or sample intake strainers, may be Teflon-coated to make them suitable for use in a stormwater monitoring program.

Automated Sampling Equipment

Key components required for automated sample collection include an automatic sampler, tubing with strainer, and sample bottle(s).

Automatic Sampler

Automatic samplers are comprised of a peristaltic pump, pump control electronics, a sample distribution system, a power supply, and a housing that contains the composite bottle(s). A peristaltic pump creates suction by compressing a flexible tube with a rotating roller, drawing a sample that is then pushed out of the pump. The pump operates best when placed close to the source; this reduces the suction head or lift (experience has shown that the reliability of peristaltic pumps drawing a consistent sample volume is greatly reduced as the static suction head increases). According to manufacturer's specifications, vertical lift must be no greater than 26 feet. When sampling with an automated sampler, static head height refers to the vertical distance from the surface of the flow stream to the automatic sampler pump inlet.

Automatic samplers may be configured for single or multiple bottle composite collection (see Figures 5-1 and 5-2 for examples of single and multi-bottle configurations). Samplers configured to fill multiple sample bottles have a sample distribution mechanism. Tubing from the discharge port of the intake pump is connected to a rotating distributor arm that dispenses the samples into several sample bottles.

If flow-weighted sampling is planned, the automatic sampler must be capable of accepting a signal from a flow meter that is used to trigger collection of a sample aliquot. Cables can be purchased that connect each type of flow meter to an automated sampler.

Automatic samplers are equipped with internal memory circuits, and typically a small LCD data screen. The memory holds the user-programmed values for the sample aliquot volume, sample bottle configuration, and number of samples per bottle. The memory also retains information describing the status of the sampling program and the time at which each triggering signal was received from the flow meter. Messages can be displayed on the data screen for the user regarding any sample collection failures.

Samplers are powered by 12 volt DC batteries, AC power, or solar-powered batteries. Two types of 12V DC batteries are available: nickel-cadmium and lead-acid. Most automated sampler manufacturers offer AC power packs for use where line power is available. Use of AC power decreases routine maintenance requirements, as battery changes are not necessary. The preferred configuration includes AC power with an in-

line battery backup. However, back-up batteries typically will not provide adequate power for refrigerated units.

Figure 5-1. Single Bottle Configuration for Automatic Composite Sample Collection

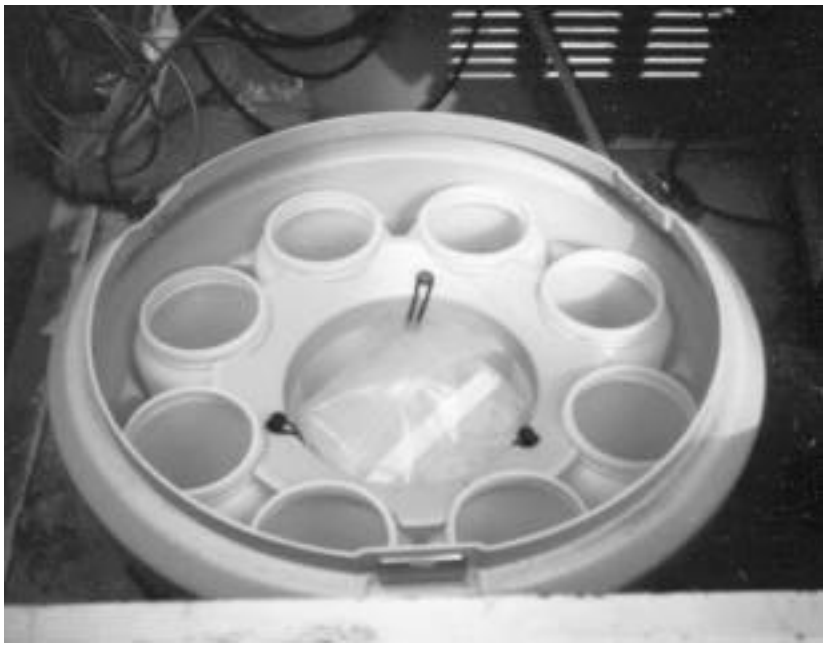


Figure 5-2. Multiple Bottle Configuration for Automatic Composite Sample Collection

Sampler Intake Strainer, Intake Tubing and Flexible Pump Tubing

The intake strainer is attached to the intake tubing and mounted to the bottom of a pipe or channel. Intake strainers prevent rocks and debris from clogging or damaging the intake tubing or pump. Sizes vary, but smaller intake strainers are generally better for use under low flow conditions. Sample intake strainers is typically made of stainless steel, or a combination of stainless steel and Teflon. For trace metals analyses, all intake strainer parts must be Teflon, or coated with Teflon or Teflon-like material. See ***Section 7*** for guidance on intake strainer placement.

Specific intake and pump tubing requirements are listed below:

Intake tubing:

- ✔ Teflon
- ✔ Maximum vertical lift = 26 feet
- ✔ Maximum length = 99 feet

Pump tubing:

- ✔ Silicon or other medical grade flexible tubing
- ✔ Limit to length needed to feed through peristaltic pump, connect to Teflon intake tubing and sample bottle

Teflon tubing is used for the sample intake tubing because of its inert properties. This tubing is connected from the intake strainer to the pump tubing, and may range from 3 to 99 feet in length. EPA protocols permit the use of the minimum amount of flexible pump tubing needed to carry the sample water through a peristaltic pump (illustrated in Figure 5-3). Silicone tubing is normally used for this purpose.

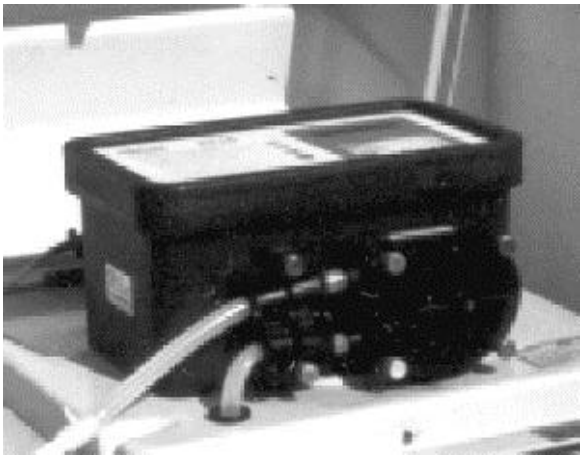


Figure 5-3. Peristaltic Pump

Sample Bottle(s)

Automatic samplers may be configured to have a variety of sample bottles, from one to a dozen or more sample bottles. If a sampler holds a single bottle, all of the sample aliquots are pumped into this bottle, resulting in one large composite sample. Use of a single composite bottle has the advantage of providing for the estimation of the event mean concentrations (EMCs) directly from analysis of the constituents in the one bottle. However, it does not allow for isolation of specific samples or groups of samples from specific periods of the runoff hydrograph, and provides less visual indication of sampler malfunction (if this should occur). A multiple bottle configuration, however, provides these latter capabilities.

It is important to keep extra bottles (for either the single or multiple bottle configuration) available in case bottles are contaminated or damaged, or in the event that bottles need to be changed to accommodate a larger-than-expected storm. If a storm delivers more precipitation than expected, sample bottles will fill prior to the end of the storm, prompting sample bottle replacement.

In-situ Analytical Measurement Equipment

Electronic equipment is available for certain field-measured analytical parameters (e.g., turbidity, conductivity, pH). Electronic sensors and data loggers may allow for near-continuous measurements of indicator parameters at reasonable cost. This equipment also makes it feasible to monitor every storm that occurs over a period of time, including short-duration events that would otherwise be impractical to monitor. In addition, data reduction and evaluation are simplified because the water quality results are simply downloaded from the data logger onto a laptop computer or a personal computer with a modem. However, it is important to realize the limitations associated with the use of sensors and data loggers:

- ✔ Sensors are only available to measure a limited number of parameters.
- ✔ The ion-specific sensors now available may not provide low enough detection limits to meet monitoring project DQOs.
- ✔ It may be difficult to assure the quality (i.e., precision & accuracy) and reliability of the results.
- ✔ Laboratory analysis is required in conjunction with the results to allow correlations to be made between the indicator readings and concentrations of specific constituents of concern.
- ✔ It may not be possible to reliably correlate a sensor-measured "indicator" parameter with a given constituent of concern.
- ✔ Sensors are subject to fouling or clogging from debris, algae, oil & grease, etc.
- ✔ Some sensors (e.g., turbidity) may require substantial flow for accurate readings.

- ✔ Some sensors (e.g., pH, conductivity) cannot be allowed to dry out; this is problematic in many drainage conveyances.

Manual Sampling Equipment

Manual sampling is required for the collection of certain samples, including samples to be analyzed for bacteriological analysis, oil and grease, petroleum hydrocarbons, and others (see ***Section 10***). Manual equipment can include hand-operated items such as bailers, grab poles or other items designed to lower an appropriate sample container into the runoff flow. This equipment is relatively inexpensive and easy to maintain. All grab sampling equipment which directly contacts the sample during or after collection must be compatible with the specific constituents to be analyzed, as discussed previously.

➤ FLOW MEASUREMENT METHODS AND EQUIPMENT

Flow measurements are required for accurate sample compositing. Flow rate may be measured manually or with automated equipment. Manual measurements can be made using the volume-based bucket and stop watch method, the velocity-based float method, or various depth-based methods (which are also appropriate for automated sampling). Automated flow measurements can be made with electronic depth measurement or area/velocity measurement devices. Making accurate flow measurements is typically a difficult task. For additional reading regarding flow measurement see *Isco Open Channel Flow Measurement Handbook* (Isco, 1997), Douglas M. Grant & Brian D. Dawson (fifth edition).

The flow measurement method selected will depend upon the conditions at a given site; no one approach is suited to all conditions. The following are some factors to consider before selecting the flow measurement method to be used at a particular site:

- ✔ Applicability of the method to site conditions,
- ✔ Accuracy of the method,
- ✔ Ease of measurement during a sampling event, and
- ✔ Ease and cost of installation of the measurement device.

This section contains information on several manual flow measurement methods, including the bucket and stopwatch method, the float method, and various depth-based methods, including the use of flumes and weirs. This section also discusses automated methods of flow measurement that are applicable to monitoring stations designed for flow-proportioned, composite sampling.

Manual Flow Measurement Methods

Listed below is information on several manual flow measurement methods, including the bucket and stopwatch method, the float method, and depth-based methods.

Bucket and Stopwatch Method

The basis for the "bucket and stopwatch method" is the collection of a measured amount of flow over a measured amount of time to directly determine flow per unit of time (flow rate) using the following equation:

$$Flowrate\,(cms) = \frac{Volume_{bucket}\,(gal.) * 3.785\left(liters/gal.\right)}{time\,(\text{sec}) * 1000\left(liters/m^3\right)}$$

As a general rule, the bucket should be large enough (or the flow small enough) so that it takes at least five seconds to fill. If the bucket fills in less than 5 seconds, it will be difficult to accurately estimate the flow rate.

Float Method

Using the float method, the flow rate is calculated from the measured velocity of the flow and the cross-sectional area of the discharge using the following equation:

Flow rate (cms) = Velocity (meter/sec) * Area (sq. meter)

Current velocity is measured as the time it takes a float to travel between two points separated by at least 5 feet (approx. 1.5 meters). Examples of good floats are oranges, lemons, and limes, articles which have a specific density similar to water and tend to float totally submerged. These floats truly reflect current velocity, are not affected by wind or bottom snags, and are easily observed. In addition, these floats do not persist in the environment if they are not recovered after flow measurements are taken.

Depth of flow is also measured in the vicinity of the velocity measurement. The cross-sectional area of flow is calculated from the measured depth, based on the known geometry of the pipe or channel.

The product of velocity and cross-sectional area is then calculated to produce the flow rate.

Depth-Based Methods

A depth-based flow measurement method estimates flow rate directly from the measurement of flow depth, using a predetermined relationship of flow depth and discharge rate. The depth-based method can incorporate the use of a flume or weir, but can also be used under uniform flow conditions within a pipe or channel of known geometry to determine the depth-discharge relationship. Depth can be measured manually (i.e., with a hand-held ruler or via an electronic depth measurement device).

Flumes

A flume is a specially built reach of channel (sometimes a prefabricated insert) that has a converging entrance, a throat section, and a diverging exit section (see Figure 5-4). The throat area or slope (or both) of the flume is designed to differ from that of the channel, inducing a depth of flow which is proportional to flow rate. For each type of flume there is a functional relationship (described by a mathematical equation) between depth and flow rate.

To estimate flow rate, use a yardstick to measure depth (for manual monitoring) or a continuous depth meter attached to a data logger or computer that converts data from depth-of-flow measurements to estimates of the corresponding flow rate, based upon the flume's dimensions. If using the latter, use the empirical equation provided by the manufacturer. If depth is measured manually, prepare a stage-discharge table using the equation for the specific flume (i.e., calculate the estimated flow rate for each depth of flow using the appropriate equation).

Weirs

A weir is a vertical obstruction built or placed across an open channel (or within a pipe if it flows under open channel conditions) so that water flows over the weir's top edge (or through a well-defined opening in the plate). A weir can be used to regulate flow in a natural channel with irregular geometry, a situation where Manning's equation, for example, cannot provide reliable estimates. However, a weir is intended to back up water by creating a partial dam. During large storm events, the ponded water could overflow the weir structure, invalidating the weir equation. In addition, sediments and/or debris which accumulate behind a weir can alter the hydraulic conditions, changing the empirical relationship between depth of flow and discharge rate. Therefore, weirs should be regularly inspected and accumulated sediment or debris removed. If excessive sedimentation deposition and accumulation occurs, use of a flume may be more appropriate as they avoid these problems.

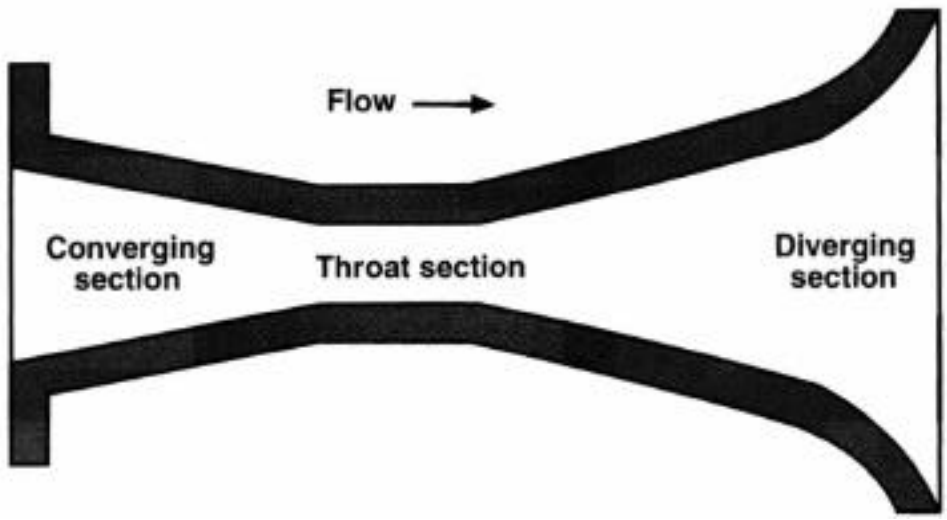


Figure 5-4. General Flume Configuration
Source: ISCO Open Channel Flow Measurement Handbook (5th ed.),1997.

Pipe or Channel

Flow rate can also be estimated with the depth-based method without the use of a flume or weir, in any pipe or channel of known geometry, material, and gradient. Depth measurement is used together with Manning's equation (see Figure 5-6) and the known pipe characteristics to calculate flow, based on an assumed relationship of depth to flow rate, given the specific characteristics of the conveyance.

This method may be applied in areas where the flow is uniform, non-turbulent, and not affected by changes in direction or grade. It is also essential that the flow remain free-flowing, and not affected by downstream backwater or surcharge conditions.

Electronic Depth Measurement Devices

Electronic depth measurement devices are typically used for automatic flow measurement by providing a means to electronically measure flow depth and automatically convert depth to flow rate, using the known geometry of the conveyance and the appropriate depth/discharge equation. The following types of depth-measuring devices, which convert level measurements to flow rates with accuracy of ±15%, are available from manufacturers such as ISCO and American Sigma:

Bubbler: The depth of the flow is determined by measuring the pressure needed to force bubbles out of a line submerged in the flow stream.

Pressure Transducer: The pressure of the liquid above a pressure sensor is measured to determine the depth of the flow stream.

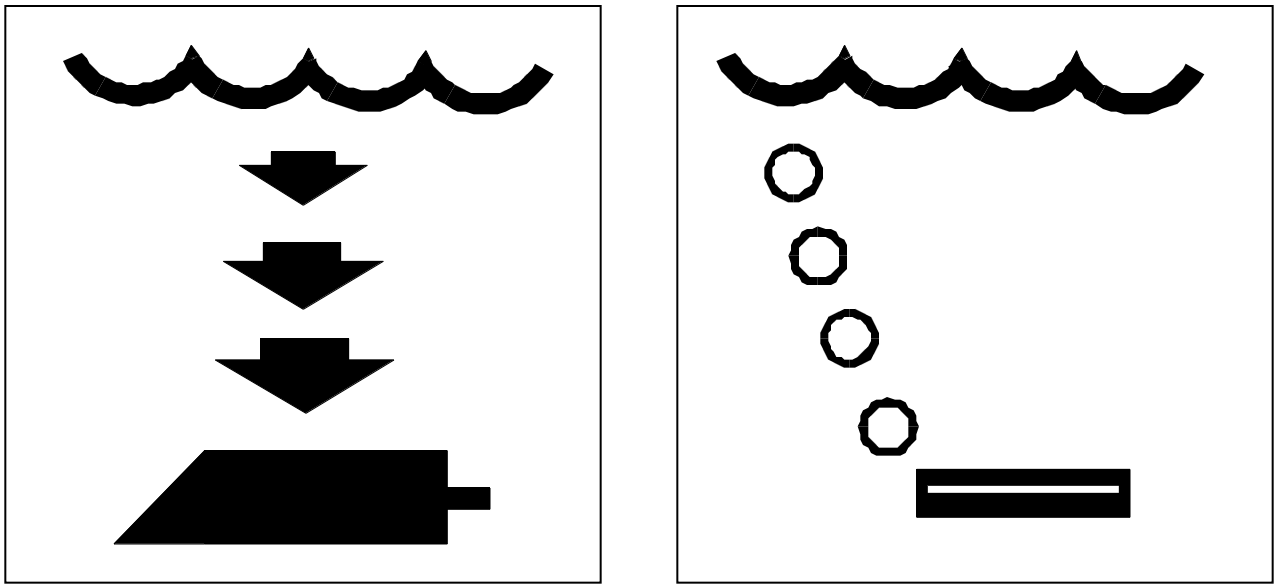
Ultrasonic: Depth is measured by transmitting an ultra sound pulse from the sensor mounted above the stream, and measuring the time for the echo to return from the flow stream surface. This measuring device must be placed in a secure location, where it will not be affected by wind, temperature flux, etc.

Each of these options is illustrated in Figure 5-5 .

These devices use internal circuitry to calculate flow rate from the measured depth, typically by use of the Manning equation (Figure 5-6), with user-input pipe or channel characteristics. The measured depth is first used to calculate the cross-sectional area of flow, based on the known geometry of the pipe or channel. The cross-sectional flow area is the input into Manning's equation to compute instantaneous flow rate.

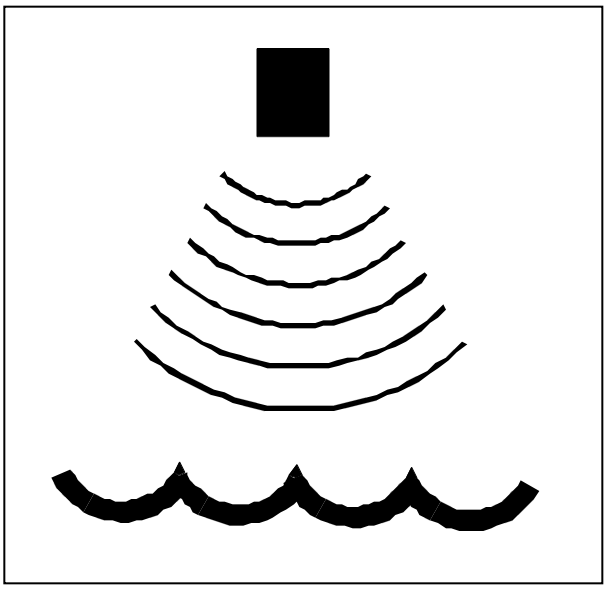
Because the Manning equation assumes essentially unrestricted gravity flow (subject only to the friction provided by the pipe or channel surface), anything that alters the flow path or otherwise restricts free flow will cause deviations from the value calculated by the Manning equation. Examples include: imprecisely known or non-uniform slope of the conveyance; physical deterioration of the pipe or channel surface; the presence of standing water or downstream "backwater" conditions; and the presence of substances in the water that would alter its normal fluid characteristics. The presence of extraneous flow inputs or outputs, including infiltration and exfiltration, also may cause the Manning equation to overestimate or underestimate flow.
Manning's equation was developed for uniform slopes of less than 0.1ft/ft. Therefore, other flow measuring techniques should be explored for monitoring sites that do not meet this criterion.

See Table 5-1 for typical examples of Manning roughness coefficient "n" for various channel configurations. For additional Manning "n" values, refer to Table 851.2 of the *Caltrans Highway Design Manual, 5th Edition "Manning n-values for alternate pipe materials*" (Caltrans, 1999d).



Pressure Transducer

Bubbler



Ultrasonic Sensor

Figure 5-5. Depth Measurement Devices

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

where:

Q = flow rate, ft^3/sec

n = Manning's roughness coefficient, dimensionless (when used with the English units specified for the other input variables)

A = cross sectional area of flow, ft^2

R = hydraulic radius, ft (R=A/WP, WP = wetted perimeter in ft.)

S = slope of the energy grade line (slope of the conduit), ft/ft

Figure 5-6. Manning's Equation

Table 5-1. Examples of Typical Manning Roughness Coefficient "n"

	Min.	***Norm.***	***Max.***
Closed Conduit – partly full			
Corrugated storm drain	0.021	0.024	0.030
Brick lined with cement	0.012	0.015	0.017
Concrete culvert, straight	0.010	0.011	0.013
Concrete culvert with bends, connections & some debris	0.011	0.013	0.014
Concrete sewer with manholes, inlet, etc., straight	0.013	0.015	0.017
Unfinished concrete, steel form	0.012	0.013	0.014
Unfinished concrete, smooth wood form	0.012	0.014	0.016
Unfinished concrete, rough wood form	0.015	0.017	0.020
Rubble masonry, cemented	0.018	0.025	0.030
Lined or Built-up Channels			
Corrugated metal	0.021	0.025	0.030
Mortar finish cement	0.011	0.013	0.015
Trowel finish concrete	0.011	0.013	0.015
Float finish concrete	0.013	0.015	0.016
Unfinished concrete	0.014	0.017	0.020
Cemented rubble masonry	0.017	0.025	0.030
Smooth asphalt	0.013	0.013	-
Rough asphalt	0.016	0.016	-
Excavated or Dredged			
Earth, straight and uniform	0.016	0.022	0.035
Earth, winding and sluggish	0.023	0.030	0.040
Unmaintained channels	0.040	0.070	0.140
Natural Channels			
Fairly regular section	0.030	0.050	0.070
Irregular section with pools	0.040	0.070	0.100

Source: ISCO Open Channel Flow Measurement Handbook (5th ed.),1997.

Area/Velocity Measurement Devices

Flow rate may be measured automatically with an area-velocity flow meter. This technology combines use of an electronic velocity sensor with a depth-measurement device. The velocity sensor typically uses Doppler technology or electromagnetics to measure average velocity throughout the flow stream. The depth measurement is converted to cross-sectional area of flow, using user-input channel or pipe geometry. The flow is then calculated automatically from the cross-sectional flow area and the velocity.

This technology is more accurate than the use of depth measurement and Manning's equation done under the full range of flow conditions. This capability is particularly important when downstream conditions cause backwater or otherwise impede flow at the point of measurement. In such cases, depth measurement alone would overestimate the actual flow rate from Manning's equation.

This technology is not ideal for extreme low flow conditions. Typically, the velocity sensor has to be completely submerged before accurate readings can be made. Flow below the sensor can account for a significant part of the hydrograph in smaller drainages.

Automated flow meters are designed to take frequent or continuous measurements of depth of flow and/or velocity, and convert the depth and/or velocity into a flow rate as described above. The standard hydraulic equation (Manning's equation) or an empirically-derived relationship is used to automatically convert the measurements to a flow rate. It is important to select the appropriate flow measurement technology for a specific application. A flow measurement technology selection guide is presented as Table 5-2.

Table 5-2. Flow Measurement Technology Selection Guide

	Ultrasonic Sensor	*Pressure Transducer*	*Bubbler*	*Area Velocity*
Suitability for Different Applications				
Weirs and flumes	Excellent[1]	Excellent	Excellent	Excellent
Channels less than 6”	Not recom.	Excellent	Excellent	Not recom.
Small round pipes 6-8”	Good[2]	Excellent	Excellent	Good
Medium round pipes 10-15”	Good[2]	Excellent	Excellent	Excellent
Large round pipes 15-96”	Excellent[2]	Good	Excellent	Excellent
Irrigation channels & small streams	Excellent[2]	Good	Excellent	Good
Rivers & large streams	Excellent[2]	Good	Excellent	Good
Performance Under Adverse Conditions				
Strong wind	Not recom.	Excellent	Excellent	Excellent
Air temperature fluctuations	Very good[3]	Excellent	Very good[3]	Excellent
Foam on liquid	Not recom.	Excellent	Excellent	Excellent
Flow stream turbulence	Not recom.	Excellent	Excellent	Excellent
Floating debris	Not recom.	Excellent	Excellent	Excellent
Floating oil or grease	Not recom.	Excellent	Excellent	Excellent
Suspended solids	Excellent	Very good	Good	Very good
Suspended grease	Excellent	Very good	Good	Very good
Silting in	Excellent	Very good	Good	Very good
Liquid temperature fluctuations	Very good[4]	Good[4]	Excellent	Good[4]
Submerged flow	Not recom.	Not recom.	Not recom.	Very good
Full pipe flow	Not recom.	Not recom.	Not recom.	Very good
Surcharged flow	Not recom.	Not recom.	Not recom.	Very good
Reverse flow	Not recom.	Not recom.	Not recom.	Very good
Maintenance Requirements Caused by Adverse Conditions				
Silting in	Occasional	Occasional	Occasional	Occasional
Suspended solids	None	Occasional	Occasional	Occasional
High grease concentration	None	Occasional	Occasional	Occasional

Source: Introducing ISCO 4200 Series Flow Meters, Accurate Flow Measurement That's Versatile and Easy to Use, Brochure 60-3213-298, 1994.

1. Use with caution in small flumes
2. There must be adequate space above for mounting sensor
3. Large air temperature fluctuations will affect accuracy
4. Large water temperature fluctuations will affect accuracy

➤ PRECIPITATION MEASUREMENT

Precipitation can be measured using either a portable “direct-reading” rain gauge (graduated collector that is read manually) or an electronic “tipping bucket” rain gauge.

Rain gauges serve two major purposes in a stormwater monitoring program. Firstly, collection of rainfall data, when compared with flow data, can provide useful information regarding site hydrology. Secondly, electronic rain gauges can be used to initiate sample collection when used in conjunction with automated sampling equipment. To do this, the electronic rain gauge is connected to a datalogger and a specified rainfall amount is programmed using system software, such that when the target minimum rainfall amount is reached the automated sampler is switched into sample collection mode.

Use of an electronic "tipping bucket" rain gauge is recommended whenever possible, due to the improved accuracy and electronic recordability of the data. This type of rain gauge collects rainfall in increments, usually 0.01 to 0.05 inch, and automatically tips and is emptied after each increment. The rain gauge is normally connected to a datalogger, which counts the number of tips. Total rainfall is recorded automatically by the datalogger.

Use of a portable, direct-reading rain gauge is recommended when automated sampling stations are not available, when the monitoring is being performed at a temporary site, and when field personnel will be present on site to take periodic readings.

➤ SYSTEM INTEGRATION

For the various elements of an automated monitoring system to function effectively, an automated sampling program must include system integration to permit communication among the components and allow downloading of stored data. Manufacturers of automated monitoring equipment, such as ISCO and American Sigma, offer system software that allows integration of automated monitoring equipment such as a flow meter, automated sampler, rain gauge, and other sensors such as a pH, temperature, turbidity, and dissolved oxygen meters. This software also has data logging/retrieval and remote communication capabilities, and the flow meter or sampler can be purchased with a built-in data logger. Other manufacturers can provide custom designed system integrating/data logging software and hardware that allows integration of additional monitoring devices, and provides more advanced command and control options.

➤ SYSTEM COMMAND/CONTROL

Custom-designed system command/control software should, at a minimum, provide the following options:

- ✔ System counters for precipitation, runoff volume, sample count, etc., which can be easily reset prior to each anticipated monitoring event.
- ✔ Monitoring and non-monitoring modes. Typically when the software is set in "monitoring mode", data collection frequency is increased, and the system is capable of sample collection.
- ✔ Monitoring "triggers" or thresholds (e.g., minimum precipitation amount, flow depth, or flow volume). When met, these parameters allow the system to enter "monitoring mode" and initiate sample collection.
- ✔ Flow volume per sample (i.e., the flow volume that passes between each composite aliquot collected), for sites that require the collection of flow-proportional samples. See ***Section 9*** for guidance on the calculation of flow volume per sample.

- ✔ "Start sampling" and "stop sampling" commands that can be selected, as appropriate, at the beginning of a storm, during bottle changing, and at the end of a storm.
- ✔ System data retrieval capabilities.

➤ REMOTE COMMUNICATION

One of the advantages of automated equipment is that it can be controlled remotely. Monitoring stations are controlled and monitored from off-site locations by use of line of sight (LOS) radio, cellular telephone telemetry, or hard-wired telephone, and a computer with a modem and specially designed software. Remote communication is recommended because it facilitates preparation of monitoring stations for stormwater monitoring, and reduces the number of field visits by monitoring personnel. Remote communications also makes it possible to determine more accurately when composite bottles may need to be replaced during a monitoring event.

➤ DATA MANAGEMENT

Efficient data storage, retrieval, and transfer methods should be established prior to initiation of monitoring activities. The following suggestions are provided to guide Caltrans Districts in the development of a reliable and useful data management system:

- Establish a central file for hard copy information; create a system that will ensure that superseded information is not confused with current information.
- Select a database system that can accommodate digital information such as laboratory analyses and recorded data logger measurements.
- Choose a database program that allows for efficient data input, back-up, and retrieval of selected information in response to queries.
- To perform useful queries, include the following categories in the *same* database: sampling event description, catchment area characteristics, sample identification information, sample collection and runoff data, analytical results, analytical methods, and data qualifiers.
- Coordinate electronic data transfer with the analytical laboratory (i.e., the laboratory should provide analytical results in an electronic format that can be directly input into the program's existing database). This can save time and minimize data entry errors.

All storm water monitoring data will be incorporated into the Caltrans Statewide Stormwater Database. See *Caltrans Storm Water Management Program 1999-2000 Data-Reporting Protocols, October 1999* (or latest version), for specific data reporting protocols (Caltrans, 1999c; see also ***Section 14*** and ***Appendix H***).