Future Monitoring Strategies with Lessons Learned on Collecting Representative Samples

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Future Monitoring Strategies with Lessons Learned on Collecting Representative Samples

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Introduction

Regulatory framework such as National Pollutant Discharge Elimination System (NPDES) Permits, Total Maximum Daily Loads (TMDLs), and the California Toxics Rule (CTR) have stressed the importance of properly characterizing discharges. Meeting these stringent regulations has shown to be challenging from a practical standpoint. Most of the current regulations require that storm water monitoring be done by trained personnel and high-tech equipment. With the onset of automated sampling stations, some of the practical challenge has been minimized, but additional monitoring challenges have been created. For instance, sample representativeness is an area that has not been fully standardized or uniformly practiced by monitoring groups on a national basis. The issue of sample representativeness was evaluated by careful review of over 50 monitoring stations with complete histories of site drainage characteristics, hydrograph data, and hyetograph data. During the past several years, the California Department of Transportation (Caltrans) has reviewed this information and has taken a proactive approach in establishing criteria for representative samples through their Stormwater Monitoring Protocols Guidance Manual (Guidance Manual). Caltrans periodically updates their Guidance Manual to reflect lessons learned from previous years to improve their sample collection techniques and other aspects of their monitoring program. This paper is an overview of some of those lessons learned in collecting representative samples. Examples include proper sampler intake location and installation, use of primary and secondary flow measurement devices, and insight into properly programming monitoring equipment to collect flow-weighted composite samples. A case study is also presented and demonstrates variability of Event Mean Concentrations (EMCs) from samples collected at the same site using different monitoring techniques.

Sample Representativeness

Sampling is performed when it is simply not feasible to take a census due to time and resource constraints. If a sample is selected properly from the study population, and high quality measurements of indicators are taken (i.e., measures that are precise, accurate, reliable, and valid), then accurate conclusions, also known as inferences, can be drawn about the study population. Sample representativeness is the degree to which the characteristics of a sample approximate the same characteristics in the population from which the sample was drawn. However, samples seldomly represent the population perfectly. The degree to which the characteristics of a sample differ from the same characteristics in the population from which the sample was drawn is defined as sampling error.

Water quality sampling is performed to satisfy various purposes and requirements such as characterization of discharges, enforcement of water quality standards and objectives, and planning, design, and operation of treatment Best Management Practices (BMPs). Before sample collection begins, steps must be taken to ensure that samples will be representative of the aqueous system being investigated. A representative water sample is a sample that typifies (i.e., represents) that part of the
aqueous system to be studied and is delineated by the study objectives and scope. Confidence in the data can be no better than how well the sample represents the aqueous system.

Depending on the program need, agencies and organizations define representation in many different ways. For example, the USGS data-collection efforts often take a whole-system approach, meaning that data-collection methods ensure representation of an entire stream reach or aquifer volume. The California State Water Resources Control Board defines a representative sample (for compliance with the NPDES General Permit for Discharges Associated with Industrial Activities) as a grab sample collected within the first hour of discharge. Regardless of the program type, when designing a water quality sampling program, consideration must be given to:

- General characteristics of the aqueous system;
- Flow modes (e.g., intermittent, highly variable, base and peak flows, hydrology and hydraulics); and
- Variability of pollutant concentrations
  - Time (e.g., first-flush, whole event)
  - Cross-section (e.g., turbulent/laminar flow, velocity, density, lateral dispersion, stratification).

**Sample Collection Types and Techniques**

Understanding the difference between sample type and technique is fundamental when planning monitoring programs. "Sample type" refers to the kind of sample (grab, composite, isokinetic, and nonisokinetic). "Sample technique" refers to the method by which a grab or composite sample is collected (manually or by automatic sampler). Regulations often establish specific requirements for sample collection types and techniques. For example, because of the variable nature of storm water discharges during rainfall events, storm water regulations require the collection of composite samples from large and medium municipal separate storm sewer systems (MS4s), whereas grab samples must be collected from discharges associated with industrial activities.

**Sample Type**

Following are definitions of sample types.

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

**Composite Sample:** Sample comprised of a series of individual aliquots that have been combined to reflect mean analyte concentrations of the discharge during the sampling period. A composite sample can be developed based on time or flow rate. The four different types of composite samples are graphically shown in Figures 1 through 4 and are described as follows:

- Constant Time - Constant Volume ($T_c V_{cv}$)
- Constant Time - Volume Proportional to Flow Rate ($T_c V_{vq}$)
- Constant Time - Volume Proportional to Flow Increment ($T_c V_{vv}$)
- Constant Volume - Time Proportional to Flow Volume Increment ($V_c T_{vv}$)
An evaluation of the four composite sampling schemes was performed by the United States Environmental Protection Agency (EPA, 1975). During the study four flow scenarios were considered: $q = c$, $q = t$, $q = 1-t$, and $q = \sin\pi t$; and five concentration scenarios were considered: $k = 1-t$, $k = 1-t/2$, $k = \cos(\pi t/2)$, $k = e^t$, and $k = \sin(\pi t)$. For each flow/concentration combination, the average concentration of the flow was computed; and then the ratio between the composite sample concentration and the actual concentration was calculated (refer to Table 1). The results showed that the best overall composite for the scenarios tested were the $T_c V_{vq}$; followed by $T_c V_{vv}$, which was very similar; then by $V_c T_{vv}$, and then $T_c V_{cv}$. However, the differences were not large for any scenario.

Additionally, grab samples and composite samples can be either isokinetic or nonisokinetic:

**Isokinetic, Depth-Integrated Sample:** Depth-integrating method designed to produce a discharge-weighted (velocity-weighted) sample along the stream cross-section; that is, each unit of stream discharge is equally represented in the sample. When using an isokinetic sampler there should be no change in velocity (speed and direction) as the sample enters the intake. The analyte concentrations determined in a discharge-weighted sample are multiplied by the stream discharge to obtain the discharge of the analyte. Collection of an isokinetic, depth-integrated, discharge-weighted sample is standard procedure for the USGS. However, site characteristics, sampling-equipment limitations, or study objectives constrain how a sample can be collected and could necessitate use of other methods.

**Nonisokinetic Sample:** Methods such as use of an automated sampler with fixed intake location. Typically does not result in a discharge-weighted (velocity-weighted) sample unless the stream is completely mixed laterally and vertically. Thus, the accuracy of the analytical results directly affects the accuracy of the analyte discharges.

Generally, due to rapidly changing flow velocities and volumes, shallow flow depths, small conveyance cross-sections, and access constraints, grab samples and composite samples of storm water discharge are collected nonisokinetically.
Table 1

Ratio of Composite Sample Collection Concentration to Actual Concentration

| Source: An Assessment of Automatic Sewer Flow Samplers, USEPA 600/2-75-065, 1975 |
**Sampling Technique**

Manual and automatic sampling techniques are methods by which both grab and composite samples can be collected. Manual samples are samples collected by hand; automatic samplers are powered devices that collect samples according to pre-programmed criteria. Manual and automatic techniques have advantages and disadvantages that should be considered (e.g., cost and accuracy). Ultimately, the best technique to use will depend on the situation.

For most pollutants, either manual or automatic sample collection will conform with 40 CFR Part 136. However, automatic samplers should not be used to collect volatile organic compound (VOC) samples because VOCs will likely volatilize as a result of agitation during automatic sampler collection; they should not be used to collect bacterial samples because they must be collected directly into sterile bottles; and automatic samplers should not be used to collect oil and grease samples because oil and grease tends to adhere to the sampling equipment.

**Monitoring Evolution**

The need for sample collection and use of the collected data has evolved over the years. Accordingly, monitoring has evolved from conventional to state-of-the-art methodologies. A review of conventional monitoring techniques briefly precedes the discussion of state-of-the-art techniques.

**Conventional Monitoring Techniques**

Conventional flow measurement and sample collection techniques have accuracy limitations, but are easy and inexpensive to use. Samples collected conventionally are taken manually by collecting discharge into individual bottles. Sometimes the discharge is collected directly into bottles and other times an intermediate device is needed to collect the sample before placement into bottles (e.g., sampling sheet flow may require use of a scoop). Samples collected in this manner are considered grab samples, which represent the characteristics of a single slug of discharge at one point in time. Grab samples are not suitable for estimating event mean concentrations or mass loading.

A variety of conventional flow measurement techniques are available: float method, bucket-and-stopwatch, runoff coefficient method, and Manning’s n. Refer to EPA’s *NPDES Storm Water Sampling Guidance* (EPA, June 1992) for more information.

**State-of-the-Art Monitoring Techniques**

Sample collection today is generally automated through the use of an automated sampler, which consists of a pump, sampler intake tubing, strainer, and a chamber where sample bottles are placed. Automated sampling is preferred because personnel are not required to be on-site (increasing worker safety) and the equipment can easily be programmed (with a flow meter) to collect flow-weighted samples. Nevertheless, sometimes manual collection of samples is required due to analytical requirements (e.g., coliform samples must be collected in sterile bottles) or physical reasons (e.g., petroleum hydrocarbons tend to be present predominantly at the air/water interface).

Samples today are generally flow-weighted to provide an event mean concentration (EMC) or mass loading of a storm event. Although not all NPDES permits require composite sampling, it is often necessary to accurately plan and execute the load reductions required by TMDLs.
Several methods exist for reliable flow measurement, and they are generally divided into two categories: primary and secondary. Primary flow measurement devices depend on the measurement of one variable, such as head over a weir or flume. Secondary flow measurement devices are used for two purposes: 1) to measure the liquid level through a primary device, and 2) to convert this liquid level to the known liquid level-flow rate relationship of the primary device.

The following primary flow measurement devices are used in conjunction with secondary devices to calculate flow:

**Weirs:** Weirs have the advantages of being relatively inexpensive and easy to install but have the disadvantages of causing significant head loss and require periodic cleaning to prevent accumulation of sediment. Common types include triangular, rectangular, and Cippoletti weirs.

**Flumes:** Flumes are generally self-cleaning and do not cause significant head loss, but are more expensive and difficult to install. Common configurations include H-type, Palmer-Bowlus, and Parshall flumes.

Secondary flow measurement devices include:

**Pressure Transducer:** This type of level measurement device uses a pressure sensor to estimate depth. These units are reliable but can be affected by temperature of the flow stream and by debris.

**Ultrasonic Probe:** Flow depth is measured by determining the time it takes sound waves to travel from the probe to the surface of water and be reflected back to the probe. Ultrasonic probes can measure a wide range of flow depths but are sensitive to air temperature changes and wind velocities, and should not be used when depth changes abruptly.

**Bubbler:** A tube discharges a constant bubble rate and the pressure necessary to sustain the constant bubble rate is measured. This pressure is proportional to fluid depth. Bubblers are simple to use and maintain but care must be taken to ensure the bubbler tube does not get constricted or blocked by sediment or debris.

**Velocity Meters:** Electromagnetism or Doppler technology is used to measure velocity. An associated pressure transducer, ultrasonic probe, or bubbler measures depth and converts it to a cross-sectional area. The velocity multiplied by the cross-sectional area calculates the flow rate.

**Key Factors and Challenges of Collecting Representative Samples**

The next three sections describe key factors influencing the collection of representative samples including monitoring site selection, automated sample collection, and flow measurement.

**Monitoring Site Selection**

One of the first steps in designing a water quality sampling program is identifying sites representative of a specific type of aqueous system; these may include point(s) or transect(s). Selecting sites for water quality monitoring depends primarily on the program objectives, permit requirements, and analytes of
interest. For most water bodies, a single sampling site or point is not adequate to describe the sampling area’s physical properties and the distribution and quantity of chemical constituents or biological communities. Location, distribution, and number of sampling sites can affect data quality. Following are generic guidelines used by the USGS when selecting flowing-water sites such as streams (fast or slow, intermittent, ephemeral, or perennial), canals, ditches, and flumes or any other surface feature in which water moves in one direction:

- Located at or near a stream-gauging station to obtain concurrent discharge data;
- Located in straight reaches with uniform flow, with a uniform and stable bottom contour, and where constituents are mixed along the cross-section;
- Away from poorly mixed or non-unidirectional flows such as a confluence or point source of contamination;
- In reaches upstream of bridges or other structures to avoid potential contamination;
- In unidirectional flow that does not eddy;
- At or near a transect in a reach where other data has been collected; and
- At a cross-section where samples can be collected safely at any stage throughout the study period.

As another example, when Caltrans selects highway discharge characterization sites, several considerations are made including permit requirements, traffic volume, grade, hydrology, geographic setting, and location relative to other land uses. Once these criteria have been used to establish the number and type(s) of monitoring sites, then the following site attributes are considered to help ensure selection of the most appropriate monitoring locations:

- Representativeness;
- Personnel Safety;
- Site Access;
- Equipment Security;
- Flow Measurement Capability;
- Electrical Power and Telephone;
- Non-Caltrans Sources; and
- BMP Effectiveness.

**Automated Sample Collection**

As described above, use of automated samplers has been the preferred technique for collecting flow-weighted composite samples because they can be unattended during sampling. However, their use requires intensive planning and quality assurance, including careful monitoring point selection, equipment selection (e.g., tubing and sample bottle type), a review of historical hydrologic information, and collection of an adequate number and types of quality control samples. Homogeneity of the physical, chemical, and biological characteristics of the discharge must also be considered.

Although much advancement has been made with automated samplers, many problems can be encountered when employing them. These include faulty electronic and physical components, inlet blockage and line plugging, limited suction lift, and improper installation and programming. More importantly, collection of representative samples can be compromised because of the sampler intake position, limited or constrained sample intake and transport velocities, and sample volume deviations. An ideal sampler intake would be designed and installed with the following factors in mind:
Discharge Spatial Variation: In most cases, discharges are not homogenous in nature with respect to physical, chemical, and biological characteristics. For example, separate considerations must be made when sampling floatables such as oil and grease or courser bottom solids. To enhance sample representativeness, the intake should be located far enough downstream from a confluence to allow mixing; positioned in a straight length of conveyance; and at a point of maximum turbulence.

Intake/Transport Velocity: Variability in specific gravity of suspended solids results in different momentum characteristics, which is a function of velocity. These varied momentum characteristics require that samples be drawn at the same velocity as the discharge being sampled. Automatic samplers generally are not used to collect isokinetic samples because of the difficulty in controlling the sample velocity through the sampler intake relative to the flow rate and direction of suspended particulates in the stream. Ideally, sampler intake velocity should equal the velocity of the stream being sampled; a range of 0.6 to 3 m/s (2.0 to 10 ft/s) is desirable.

Orifice Size: Sampler intakes and tubing should be large enough to minimize clogging, large enough to draw in the largest expected particle size, and small enough to assure adequate transport velocity. Sizes are typically ⅜” and ½” diameter.

Orientation: Intakes can be secured to the conveyance in a number of orientations. The preferred orientation is up to 20 degrees to either side of head-on into the flow (EPA, 1975).

Flow Depth: Discharges, especially storm water runoff, have rapidly fluctuating depths of flow and are often shallow in depth. Intakes should be designed such that samples can be drawn under shallow conditions.

Obstructions: An incomprehensible quantity and type of debris are conveyed during discharges. Accordingly, intakes should be designed to minimize plugging and clogging; their cross-section exposure should be minimized to limit obstruction within the conveyance; and they should be positioned such that they are protected from physical damage.

Vertical Lift: Most automated samplers use peristaltic pumps to draw samples. These pumps are limited in drawing a sample vertically to approximately 9 m (30 ft) due to atmospheric pressure; most samplers are capable of drawing a sample approximately 6 m (20 ft) vertically. Accordingly, the vertical distance between the sampler pump and sample intake should be minimized.

Distance: Many samplers have the capability of drawing a sample from as far away as 30 m (100 ft). However, samplers should be placed as close as possible to the sampling point. This will minimize battery usage, tubing wear, and the duration to draw the sample.

Aliquot Volume: Sample aliquot volumes should be consistent and not vary with lift, water level, etc. Typically, samplers allow calibration of aliquot volume.
Programming: Monitoring equipment has evolved to be very complex to suit a variety of situations. However, this complexity often results in improper programming. It is essential that automated sampling equipment be properly programmed to reflect site conditions as well as the forthcoming monitoring event. Also, in many cases they need to be programmed to meet regulatory requirements. Some examples of improper programming include:

- Insufficient number of sample aliquots due to over forecasted storm event;
- Insufficient percent storm capture; and
- Under predicting flows resulting in the sampler not being able to keep up with the programmed pacing.

Flow Measurement Accuracy

Obtaining accurate flow measurements at monitoring stations is necessary to ensure representativeness of flow-weighted composite samples, to determine constituent mass loadings, and to assess the relationship between rainfall and runoff to support mathematical modeling.

Accuracy is the degree of conformance of a measurement to a true value. Accurate application of flow measuring devices generally depends upon careful selection of devices, care of fabrication and installation, good calibration data and analyses, and proper operation with adequate inspection and maintenance procedures.

The target or desired accuracy of the measurement system is an important consideration in measurement method selection. Accuracy is usually reported for the primary measurement device. Most flow measurement devices can produce an accuracy of ±5 percent under ideal conditions (e.g., under a laboratory setting); however, accuracy of ±10 percent is typically obtained in the field when properly constructed, calibrated, and maintained. Additionally, many methods rely on a secondary measurement, which typically adds error to the overall measurement. To ensure accurate results, the design, installation, and operation of flow measurement devices should be evaluated. When evaluating design, select a device that:

- Is accurate over the entire range of expected flow rates;
- Can be installed in the channel to be monitored; and
- 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; and
- 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; and
• Use of the correct factor or formula to convert head readings to actual flow rate.

Selecting the proper flow measurement device for a particular site or situation can be a challenge. Many site-specific factors and variables must be considered and weighed. Additionally, each system has unique operational requirements and constraints. Reliable estimates on future demands of the proposed system and knowledge of the immediate measurement needs are essential. The main factors that influence the selection of a measuring device, as defined by the U.S. Department of the Interior Bureau of Reclamation (BR, 1997) include:

• Accuracy requirements;
• Cost;
• Legal constraints;
• Range of flow rates;
• Head loss;
• Adaptability to site conditions;
• Adaptability to variable operating conditions;
• Type of measurements and records needed;
• Operating requirements;
• Ability to pass sediment and debris;
• Longevity of device for given environment;
• Maintenance requirements;
• Construction and installation requirements;
• Device standardization and calibration;
• Field verification, troubleshooting, and repair;
• User acceptance of new methods;
• Vandalism potential; and
• Impact on environment.

Case Study: The Representation of Storm Water Samples Collected by an Automatic Sampler as Compared to a Manual Grab Sampling Program

Data collected during the February 19, 2001 storm event at Site 8-23C in Los Angeles, California for the Caltrans First Flush Characterization Study (FFCS) was used to evaluate the representation of discharges. Samples were collected automatically using a Constant Volume – Time Proportional to Flow Volume Increment (VcTv) compositing scheme and manually using a modified Constant Time – Volume Proportional to Flow Volume Increment (modified TcVv) compositing scheme (refer to Figure 5). The manual grab samples were collected at specified time intervals during the first hour (i.e., the “first flush”) of the storm event and up to eight hours thereafter. Specifically, four grab samples were collected during the first hour of the storm event (one every 15 minutes), two during the second hour (one every 30 minutes), and one sample each hour for up to a total of eight hours. Analytical results of all manually collected grab samples (All Grabs) were then mathematically weighted based on the flow volume increment to estimate constituent EMCs. A second calculation using only the first four grab samples (First Flush Grabs) was also performed in the same manner as the All Grabs to estimate the First Flush mean concentration.
Results of the First Flush Grabs, All Grabs, and Auto Sampler Composite are shown in Table 2. Additionally, relative percent differences of each compositing scheme are shown in Table 2. As expected, First Flush Grab results were greater than All Grab and Auto Sampler Composite results, with the exception of a few constituents. Another interesting trend is that the majority of Auto Sampler Composite results were greater than the All Grab results. Based on review of Figure 5, it is hypothesized that Auto Sampler Composite results are greater than All Grab results because the auto sampler collected several aliquots during peak flows (flows that may have higher constituent concentrations) as compared to the fewer grab samples collected during the same flows. As can be seen from the data, differing results can be yielded by each sampling method, even when the guidance described in previous sections is followed and variables such as site selection and flow measurement are eliminated.

![Figure 5](image_url)

**Figure 5**
Rainfall Intensity and Flow Rate vs. Time Site 8-23C
February 19, 2001 Storm Event
## Table 2

EMCs and Relative Percent Difference of Various Sampling Schemes at Site 8-23C
February 19, 2001 Storm Event

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Units</th>
<th>First Flush Grabs</th>
<th>All Grabs</th>
<th>Auto Sampler Composite</th>
<th>Relative Percent Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>First Flush vs. All Grabs</td>
</tr>
<tr>
<td><strong>Conventionals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Suspended Solids</td>
<td>mg/L</td>
<td>360.7</td>
<td>143.56</td>
<td>166</td>
<td>86%</td>
</tr>
<tr>
<td>Total Dissolved Solids</td>
<td>mg/L</td>
<td>173.76</td>
<td>111.8</td>
<td>100</td>
<td>43%</td>
</tr>
<tr>
<td>Total Organic Carbon</td>
<td>mg/L</td>
<td>19.58</td>
<td>11.08</td>
<td>10.9</td>
<td>55%</td>
</tr>
<tr>
<td>Dissolved Organic Carbon</td>
<td>mg/L</td>
<td>18.48</td>
<td>10.53</td>
<td>11.1</td>
<td>55%</td>
</tr>
<tr>
<td>Chemical Oxygen Demand</td>
<td>mg/L</td>
<td>436.96</td>
<td>235.07</td>
<td>234</td>
<td>60%</td>
</tr>
<tr>
<td><strong>Hydrocarbons</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil &amp; Grease</td>
<td>mg/L</td>
<td>16.35</td>
<td>10.76</td>
<td>9</td>
<td>41%</td>
</tr>
<tr>
<td><strong>Total Metals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arsenic</td>
<td>µg/L</td>
<td>2.62</td>
<td>1.02</td>
<td>1.16</td>
<td>88%</td>
</tr>
<tr>
<td>Cadmium</td>
<td>µg/L</td>
<td>2.65</td>
<td>1.19</td>
<td>1.32</td>
<td>76%</td>
</tr>
<tr>
<td>Chromium</td>
<td>µg/L</td>
<td>28.13</td>
<td>11.99</td>
<td>10.5</td>
<td>80%</td>
</tr>
<tr>
<td>Copper</td>
<td>µg/L</td>
<td>104.81</td>
<td>57.74</td>
<td>68.9</td>
<td>58%</td>
</tr>
<tr>
<td>Nickel</td>
<td>µg/L</td>
<td>24.6</td>
<td>11.09</td>
<td>10.4</td>
<td>76%</td>
</tr>
<tr>
<td>Lead</td>
<td>µg/L</td>
<td>349.46</td>
<td>168.55</td>
<td>200</td>
<td>70%</td>
</tr>
<tr>
<td>Zinc</td>
<td>µg/L</td>
<td>431.47</td>
<td>202.62</td>
<td>251</td>
<td>72%</td>
</tr>
<tr>
<td><strong>Dissolved Metals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arsenic</td>
<td>µg/L</td>
<td>0.83</td>
<td>0.5</td>
<td>0.76</td>
<td>50%</td>
</tr>
<tr>
<td>Cadmium</td>
<td>µg/L</td>
<td>0.16</td>
<td>0.11</td>
<td>0.32</td>
<td>37%</td>
</tr>
<tr>
<td>Chromium</td>
<td>µg/L</td>
<td>2.19</td>
<td>1.27</td>
<td>1.98</td>
<td>53%</td>
</tr>
<tr>
<td>Copper</td>
<td>µg/L</td>
<td>26.38</td>
<td>16.98</td>
<td>24.5</td>
<td>43%</td>
</tr>
<tr>
<td>Nickel</td>
<td>µg/L</td>
<td>4.27</td>
<td>2.35</td>
<td>3.09</td>
<td>58%</td>
</tr>
<tr>
<td>Lead</td>
<td>µg/L</td>
<td>16.33</td>
<td>9.6</td>
<td>16</td>
<td>52%</td>
</tr>
<tr>
<td>Zinc</td>
<td>µg/L</td>
<td>33.09</td>
<td>20.95</td>
<td>34.3</td>
<td>45%</td>
</tr>
<tr>
<td><strong>Nutrients</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrate as Nitrogen</td>
<td>mg/L</td>
<td>1.3</td>
<td>0.93</td>
<td>0.95</td>
<td>33%</td>
</tr>
<tr>
<td>Ammonia</td>
<td>mg/L</td>
<td>1.12</td>
<td>0.51</td>
<td>0.3</td>
<td>75%</td>
</tr>
<tr>
<td>Total Kjeldahl Nitrogen</td>
<td>mg/L</td>
<td>3.19</td>
<td>2.01</td>
<td>0.8</td>
<td>45%</td>
</tr>
<tr>
<td>Total Phosphorous</td>
<td>mg/L</td>
<td>0.29</td>
<td>0.43</td>
<td>0.3</td>
<td>-39%</td>
</tr>
<tr>
<td>Dissolved</td>
<td>mg/L</td>
<td>0.18</td>
<td>0.14</td>
<td>0.11</td>
<td>25%</td>
</tr>
</tbody>
</table>

Ortho-Phosphate
As discussed above, collection of representative flow-weighted composite samples is necessary for discharge characterization; enforcement of water quality standards and objectives; and planning, design, and operation of treatment BMPs. For a flow-weighted composite sample to be deemed representative, it must: 1) reflect the specific site of interest, 2) be comprised of the discharge’s characteristics, and 3) be accurately measured. Advancement in technology and monitoring planning is needed in each of the three areas to ensure accurate representation. Although some of the advancements proposed below would improve sample representativeness, it is also recognized that sophistication of design may impede the true practicality of its use. Listed below are some ideas that could be advanced.

**Study Design/Site Selection**

- Develop Data Quality Objectives to:
  - Clarify the study objective;
  - Define the most appropriate type of data to collect;
  - Determine the most appropriate conditions from which to collect the data; and
  - Specify tolerable limits on decision errors, which will be used as the basis for establishing the quantity and quality of data needed to support the decision.
- Develop a well-defined Siting Plan so that the monitoring point(s) accurately represent the type of watershed or discharge to be studied.
- Use a consistent monitoring approach so that data is comparable from site to site. Consistent monitoring approach includes but is not limited to:
  - Site selection;
  - Equipment selection and installation;
  - Sample collection and handling procedures;
  - Analytical methods and reporting limits;
  - Data validation protocols including establishing sample representativeness criteria such as percent storm capture and minimum number of required aliquots; and
  - Data evaluation and statistical analysis processes.

**Sample Collection**

- Investigate and research the site to select the most appropriate sampling type and technique. Always remember that “one size doesn’t fit all.” Monitoring programs should not be allowed to blindly use a sampling type or technique because it was used on a previous study.
- Devise a mechanism to aid in stratified sampling. For example, if floatables needed to be sampled, then a float system could be used to properly locate the intake (refer to Figure 6). This float system could ride along guides and move vertically as the flow depth fluctuated. Consideration should be given to develop a technology for sampling very course bottom solids and bed loads.
- Properly select equipment considering their materials of construction so that sample contamination is prevented.

![Figure 6](image-url)
• Properly position the intake at a point far enough downstream from any confluence, in a straight reach, and in an area of greatest turbulence (i.e., where there is presumed homogeneity).
• Devise sampler intake that affords sampling isokinetically, and integrated by depth. Accordingly, the sample intake would be capable of sampling both laterally and vertically across the stream, while drawing a sample in at the same velocity of the discharge.

**Flow Measurement**

• Properly select equipment considering criteria established in the Flow Measurement Accuracy Section.
• Properly install, operate, and maintain equipment to maintain accuracy.
• Develop a low-flow area-velocity meter that allows flow measurement in low-flow, turbulent conditions.

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**References**


