STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION

Stormwater Monitoring Guidance Manual

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This manual is not intended for use as a textbook or a substitute for engineering knowledge, experience, or judgment. It establishes uniform standards and procedures to use when performing activities related to stormwater monitoring.

CALTRANS STORMWATER MONITORING GUIDANCE MANUAL

ISSUED BY

STATE OF CALIFORNIA
CALIFORNIA STATE TRANSPORTATION AGENCY
DIVISION OF ENVIRONMENTAL ANALYSIS
STORMWATER PROGRAM

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18. Abstract:

This manual contains all the current standards and practices for stormwater monitoring for Caltrans.

For individuals with sensory disabilities, this document is available in alternate formats upon request.

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ACRONYMS AND ABBREVIATIONS

AADT	average annual daily traffic
AAS	atomic absorption spectroscopy
ASBS	Areas of Special Biological Significance
ASTM	American Society for Testing and Materials
AV	area-velocity
BMP	best management practice
BOD	biological oxygen demand
CCD	charge-coupled device
CD	compact disk
CEDEN	California Environmental Data Exchange Network
CEQA	California Environmental Quality Act
CFU	colony-forming units
CGP	Construction General Permit
COC	chain-of-custody
COD	chemical oxygen demand
CPU	central processing unit
CTR	California Toxics Rule
CWA	Clean Water Act
DQO	data quality objectives
EDD	electronic data deliverable
ELAP	Environmental Laboratory Accreditation Program
EMC	event mean concentration
FSP	fine sediment particles
GC	gas chromatography
GSRD	gross solids removal devices
HAS	hydrologic sub-area
HSP	health and safety plan
ICP/AES	inductively coupled plasma/atomic emission spectroscopy
ICP/MS	inductively coupled plasma/mass spectroscopy
ICW	instream waste concentration
ID	identification
ISE	ion-specific electrode
LCS	laboratory control spike
LMPS	Litter Management Pilot Study

MDL	method detection limit
mL	milliliter
MPN	most probable number
MS	mass spectrometer
MS4	municipal separate storm sewer system
MS/MSD	matrix spike/matrix spike duplicate
NADP/NTN	National Atmospheric Deposition Program/National Trends Network
NELAP	National Environmental Laboratory Accreditation Program
NEPA	National Environmental Policy Act
NPDES	National Pollutant Discharge Elimination System
NTU	nephelometric turbidity units
NWS	National Weather Service
OM&M	operation, monitoring, and maintenance
PAH	polynuclear aromatic hydrocarbon
POP	probability of precipitation
PSGM	Pilot Study Guidance Manual
PSTM	Post-Storm Technical Memoranda
RDC	Regional Data Center
QA/QC	quality assurance/quality control
QPF	quantitative precipitation forecast
RAM	random access memory
RL	reporting limit
ROW	right-of-way
RPD	relative percent difference
SAP	sampling and analysis plan
SER	Caltrans Standard Environmental Reference
SEZ	stream environment zone
SOQ	statement of qualifications
SRP	soluble reactive phosphorous
SSC	suspended sediment concentration
SWPPP	Storm Water Pollution Prevention Plan
SWB	State Water Board
TDS	total dissolved solids
TIE	toxicity identification evaluation
TKN	total Kjeldahl nitrogen
TMDL	total maximum daily limit

TOC	total organic compounds
TP	total phosphorous
TRPA	Tahoe Regional Planning Authority
TSS	total suspended solids
TST	test of significant toxicity
USACE	US Army Corps of Engineers
USFWS	US Fish and Wildlife Service
VOA	volatile organic analysis
VOC	volatile organic compound
WET	whole effluent toxicity
WLA	Waste Load Allocation
WPCP	water pollution control program
WQO	water quality objectives
µg/L	micrograms per liter

Changes to this document from the previous version

Section Number	Section Name	Document Change
Entire Document	N/A	Created a “Manual Change Transmittal” document that contains summary information about the document. It has been proposed that this summary accompany all future submittals.
Entire Document	N/A	Changes made to text, tables, figures, captions, and headers in order to make the document ADA compliant.
Entire Document	N/A	Throughout the document, hyperlinks were updated as necessary so that they continue to lead to the correct resources.
Entire Document	N/A	Equation numbers removed from equations throughout the manual.
Entire Document	N/A	Added bulleted chapter summaries to the introductions to Chapters 8, 11, 12, 14, 15, 16, and 18.
Section 3.8	Project Resources	Removed language about using TSS as a surrogate for metals.
Section 4.10	Checking Out and Returning Monitoring Equipment	Added section about how to check monitoring equipment into and out of the storage yards and included figures for the equipment checkout and turn-in forms.
Section 4.10.1	Checking Out Monitoring Equipment	Added website URL for Caltrans equipment inventory.
Section 4.10.2	Returning Monitoring Equipment	Added website URL for Caltrans equipment inventory.
Section 4.2.2	Flow Rate Measurement with a Primary Flow Measurement Device	Added language addressing the need for a relative straight section upstream and the requirement that normal depth be realized at the measuring point.
Section 4.2.3	Bucket and Stopwatch Method	Added language about checking the accuracy of flow rates based on Manning’s equation, if the flow rate is low enough for it to be feasible.
Section 4.2.6	Depth Measurement	Changed the order in which sensors are listed in order to be consistent with Figure 14.8.
Figure 5.1	Figure 5.1	Figure added, shows a decision tree for insufficient sample volume.
Section 5.1.1	Considerations for Method Selection	Added language about how to select monitoring constituents in TMDL areas.
Table 5.5	Table 5.5	Volume changed to 500 ml for TSS. Row added to table for SSC.

Section Number	Section Name	Document Change
Section 5.1.3	Comparability of Different Methods	Added a short section about how different analytical methods compare, and some guidelines about how to choose and/or accept alternate methods. This issue was raised by CASC concerning TSS vs. SSC, which has been an ongoing discussion with other consultants for several years.
Section 6.14	Requesting New Monitoring Station IDs	Added a section describing the process for requesting new Station IDs and specified what information is required when a new site ID is issued.
Section 6.14	Requesting New Monitoring Station IDs	Added a paragraph stating that a Caltrans Task Order Manager should conduct a visit to all new monitoring sites before they are selected for monitoring.
Table 7.1	Table 7.1	Timelines amended to reflect more realistic goals.
Table 7.1	Table 7.1	Word “checklist” removed.
Table 7.2	Table 7.2	Made changes to requirements to reflect more realistic goals.
Section 7.3.2	US Army Corps of Engineers, Clean Water Act Section 404 Permit	Section removed.
Section 7.3.3	Clean Water Act Section 401 Water Quality Certification	Section removed.
Section 7.3.4	California Fish and Game Code - Streambed Alteration Agreement	Section removed.
Section 8.2.2	Weirs	Language about how to decommission a monitoring site correctly so that the equipment is secured in good working condition.
Section 8.3	Flow Meters	Removed text about upstream velocity requirements for weirs.
Section 8.4.1.4	Area-Velocity Sensor	Added text to indicate that backwater effects are important.
Section 8.10.1.1	Solar Panel Installation	Added language about flow with very little solids.
Section 8.14	Equipment Demobilization and Summer Equipment Maintenance	Added language that bolts be installed so that they are not exposed.

Section Number	Section Name	Document Change
Section 10.2	Definition of a Storm Event	Added standard language for storm selection criteria. Used the original MGM, 40 CFR Part 122, and discussions with consultants. Added Figure 10.1 to illustrate aspects of antecedent dry and storm definition.
Section 10.2	Definition of a Storm Event	Moved to just before Section 10.3 to improve the clarity between action levels and selection criteria.
Section 10.2	Definition of a Storm Event	Clarified that the stated storm event definition comes from the Code of Federal Regulations.
Section 10.3	Storm Action Levels	Added text directing consultants to check with the Caltrans Task Order Manager when considering whether to monitor with less than 72-hour antecedent dry period.
Section 11.2.3.3	Oil and Grease/Petroleum Hydrocarbons	Added that only glass containers will be used for oil and grease.
Section 11.2.3.5	Low-Level Mercury Samples	Re-wrote the method for low-level mercury sampling. The old language contained a lot of unneeded instructions that are not appropriate for Caltrans monitoring.
Section 11.2.5	Sampling Snowmelt Runoff	Added section to discuss collection of snowmelt runoff.
Section 11.3	Field Filtration for Dissolved Metals	Added text about splitting samples for field and lab analysis.
Section 11.3	Field Filtration for Dissolved Metals	Added text that field filters must be certified-clean from the vendor and blank-tested prior to use.
Section 11.3	Field Filtration for Dissolved Metals	Updated text on field filtration procedures.
Section 12.1	QA/QC for Water Chemistry Analysis	Text changed to add some examples of the more exotic types of analyses.
Section 12.1.1	Precision	Lab Duplicate section rewritten for clarity.
Table 12.2	Table 12.2	Updated the table that shows correct frequency to collect field QC samples.
Section 13.2	Table 13.2	“Heterogeneous” changed to “non-homogenous.”
Figure 13.3	Figure 13.3	Figures removed; these were the validation schemes used by the old ADV utility.

Section Number	Section Name	Document Change
Figure 13.4	Figure 13.4	Removed item about COD vs. TOC check.
Figure 13.5	Figure 13.5	Added guidance that the PDF version of a document must contain all material, such as appendices. The Word version may be the body of the document only, but the PDF version must be the complete version.
Table 13.5	Table 13.5	Added guidance for how to put together a DVD deliverable, particularly how the folder structure should be laid out.
Section 14.1.1	Nomenclature for Electronic Deliverables	Added language to the EDD nomenclature section to the effect that Caltrans district numbers should be used as part 1 of the file name, but that in ASBS areas, the ASBS number should be used instead.
Section 14.1.1	Nomenclature for Electronic Deliverables	Added language that PSTMs must include all data and observations from an event, not just the information on the template, and that measurement such as water levels should be presented in graphic format.
Section 14.1.1	Nomenclature for Electronic Deliverables	Section header changed to reflect final reports only.
Section 14.2	Post-Storm Technical Memoranda	In subsections, text added that suggests the maximum number of pages for each report section.
Section 14.3	Interim and Final (End-of-Project) Reports	A lot of unnecessary material removed.
Section 14.3 (subsections)	Interim and Final (End-of-Project) Reports (Subsections)	Added text to the effect that if a separate siting tech memo exists, it can be used in place of this section.
Section 14.3.7	Monitoring Project Plan	Added a revised layout for interim reports.
Section 14.3.8	Site Characteristics and Project Design	Figures added to replace photos of older GSRDs. The new photos are more recent and depict more modern equipment. Text in Section 15.8.2.1 changed to match new photos.
Section 14.3.8	Site Characteristics and Project Design	Added text that coring would likely be highly effective at differentiating in situ soils from those recently deposited.

Section Number	Section Name	Document Change
Section 14.3.9	Monitoring Method	Removed language that freeway off-ramps are a trash generation area.
Section 14.4	Interim (End-of-Season) Reports	Appendix removed, historical data summary.
Figures 15.1a, 15.1b	Figures 15.1a, 15.1b	Text replaced with the language from Section 10.2.
Section 16.3.3	Depth Measurement	Section removed, language about hardcopies of reports being submitted to depository libraries.
Section 18.1	Selection of Trash Monitoring Areas	Minimum detection limit' changed to 'maximum detection limit' in two places.
Appendix B	Historical Data Summary	Changed from nearest gram to nearest 0.1 pounds.
Section E.3.1	Storm Selection Criteria	Text added for clarity.
Section G.1.2	Library Distribution	Removed references to individual laboratory methods.
Section I.3	Permit Requirements	Minimum detection limit' changed to 'maximum detection limit' in two places.
Section H.6	Reporting Limits	Changed from nearest gram to nearest 0.1 pounds.
Section K.2	Methods for Nutrients	Text added for clarity.

1 Introduction

The Caltrans Stormwater Monitoring Guidance Manual (Manual) is an update of the Caltrans Comprehensive Protocols Guidance Manual (Caltrans 2003a).

The Manual provides guidance for California Department of Transportation (Department) staff and consultants to use in the planning and implementation of the Caltrans Stormwater Monitoring Program (Program). The Program provides statewide support for implementing the Caltrans Stormwater Management Plan and assists the Department in complying with various regulatory and legal requirements.

Data produced as part of the monitoring program must satisfy the objectives defined in the Caltrans Stormwater Management Plan and the current Caltrans National Pollutant Discharge Elimination System (NPDES) Permit (State Water Resources Control Board [State Water Board] 2013). Program data must be scientifically defensible so they can be used for regulatory purposes, and the data must be as representative as possible of actual environmental conditions. In addition, program data must be produced using consistent sample collection and analytical protocols so they can be compared in a meaningful way.

The purpose of this manual is to provide guidance on standardized procedures for sample collection, sample analysis, and data reporting to ensure all monitoring is performed in a consistent way throughout the state and monitoring data are of satisfactory quality. This manual also provides guidance on data quality objectives that should be adhered to by all program laboratories and information on other aspects of stormwater monitoring, such as equipment maintenance, training, and health and safety.

1.1 Monitoring Objectives

Stormwater monitoring is conducted by Caltrans to achieve one or more of the following objectives:

- Characterize stormwater discharges.
- Comply with regulatory requirements.
- Evaluate the design and performance of stormwater-related best management practices (BMPs).

For detailed guidance on planning and conducting BMP pilot studies, the reader should first consult the Caltrans BMP Pilot Study Guidance Manual (Caltrans 2009a), also referred to as the PSGM in this document.

1.2 TYPES OF MONITORING

This manual contains guidance for monitoring of stormwater and gross solids. Stormwater monitoring consists of collecting water samples from a discharge stream and analyzing them for physical, chemical, and biological characteristics. Gross solids monitoring consists of collecting samples of litter and vegetation from trash collection systems and assessing them for chemical composition and for physical characteristics such as weight and volume. Other types of monitoring, such as sediment monitoring and bioassessment, are not covered in this manual.

1.3 HOW TO USE THIS MANUAL

This manual is intended to provide step-by-step guidance for planning and implementing a stormwater or gross solids monitoring program that is tailored to transportation-related facilities, as shown in Figure 1-1.

This manual is organized into three parts:

- Part I: Planning. This material is presented in Chapter 2 through Chapter 7 and is intended primarily for characterization studies. For planning BMP pilot studies, the user should refer to the Pilot Study Guidance Manual.
- Part II: Monitoring. This material is presented in Chapter 8 through Chapter 12, and covers topics such as monitoring methods and equipment, training, pre-storm preparation, sample collection, and quality control.

Part III: Reporting. This material is presented in Chapter 13 through Chapter 14, and covers topics such as post-storm memoranda, laboratory data deliverables, data evaluation, and reporting. The guidance for gross solids monitoring is presented separately in Chapter 15.

Figure 1-1 guides the user through the planning, preparation and logistics, monitoring, and reporting processes, and shows which chapters of this manual contain the material for each step.

1.4 Other Resources

A great deal of technical literature exists on the science of environmental monitoring. For further information, the reader may find it useful to refer to the sources listed on the References page of this document. The following list of resources may be especially helpful:

- BMP Pilot Study Guidance Manual (Caltrans 2009a). Chapters 1, 2, 3, 4, 7, and 8 are relevant for monitoring projects
- California Department of Transportation Statewide Stormwater Management Plan (Caltrans 2003b)

Additional websites of value include:

- Caltrans Division of Environmental Analysis: http://www.dot.ca.gov/hq/env
- Caltrans Standard Environmental Reference: http://www.dot.ca.gov/ser/
- USEPA: Guidelines Establishing Test Procedures for the Analysis of Pollutants Under the Clean Water Act: http://water.epa.gov/scitech/methods/cwa/upload/methods_prepub.pdf
- USGS: National Field Manual for the Collection of Water-Quality Data: http://water.usgs.gov/owq/FieldManual/
- American Society of Civil Engineers: https://www.asce.org
- California Stormwater Quality Association: https://www.casqa.org/

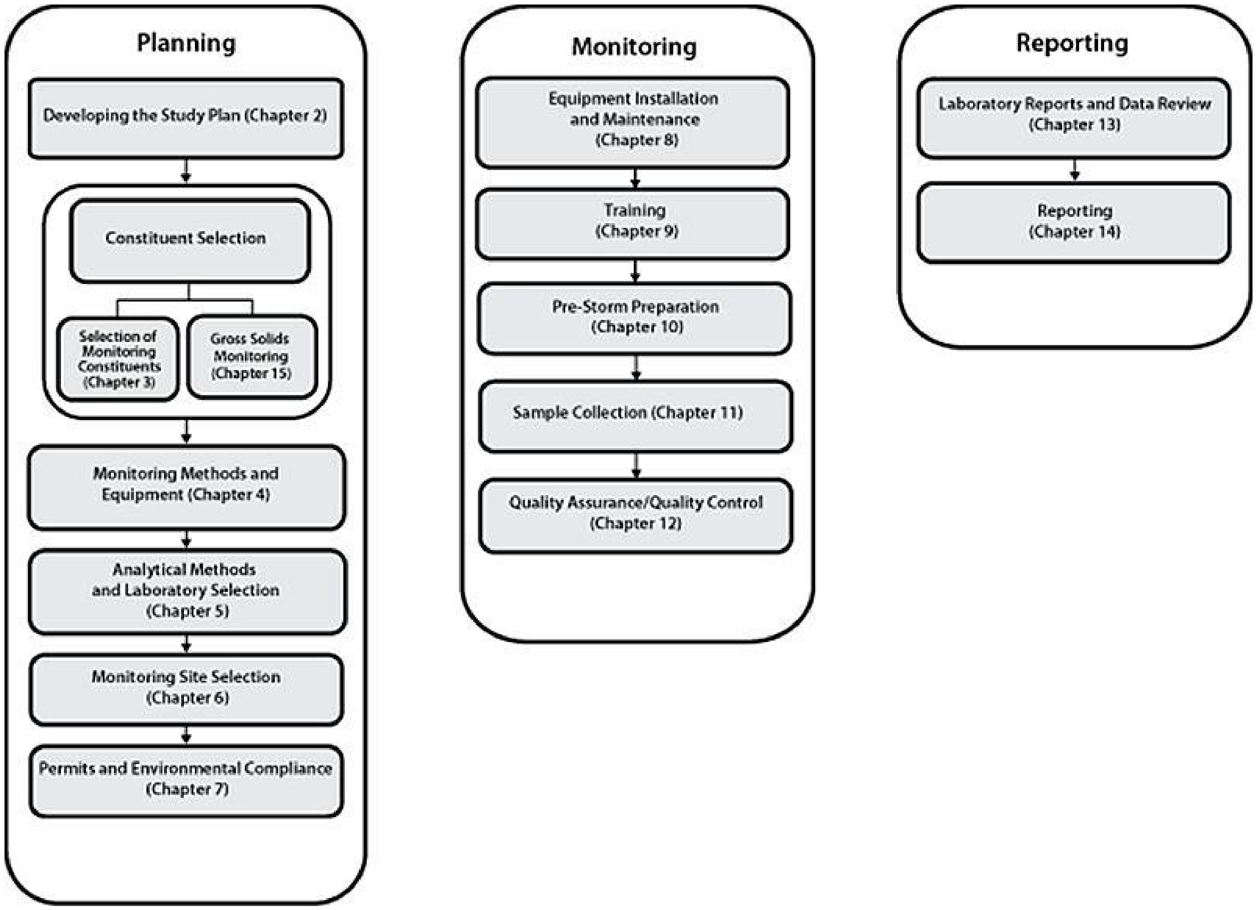


Figure 1-1 Stormwater Monitoring Guidance Manual Organization

2 Development of the Study Plan

The Study Plan is the initial planning document for a monitoring project. It is written at the beginning of the project and provides a framework for implementing the project. This document addresses the questions that drive a monitoring project, such as:

- What problem is being addressed?
- What question(s) must be answered?
- What is the specific goal of the project?
- What data are required to answer the study questions?
- How will the data be used?
- What resources, such as money, equipment, and personnel, will be required, and what resources are available?

These kinds of questions must be answered before the initial stage of planning begins so the project planning team has a clear understanding of what will be required and what resources they have.

The initial stages of the planning phase consist of understanding the problem or question that drives the study, evaluating what data will be required to answer the study question, and determining what monitoring methods can be used to produce the required data.

Although this phase of the project occurs before any monitoring is performed, the project planning team should include individuals who have field experience in stormwater monitoring. An experienced field technician may see potential pitfalls in the study approach that might not be obvious to the rest of the project development team.

The process of developing a Study Plan shown in Figure 2-1 can be broken down into the following eight steps:

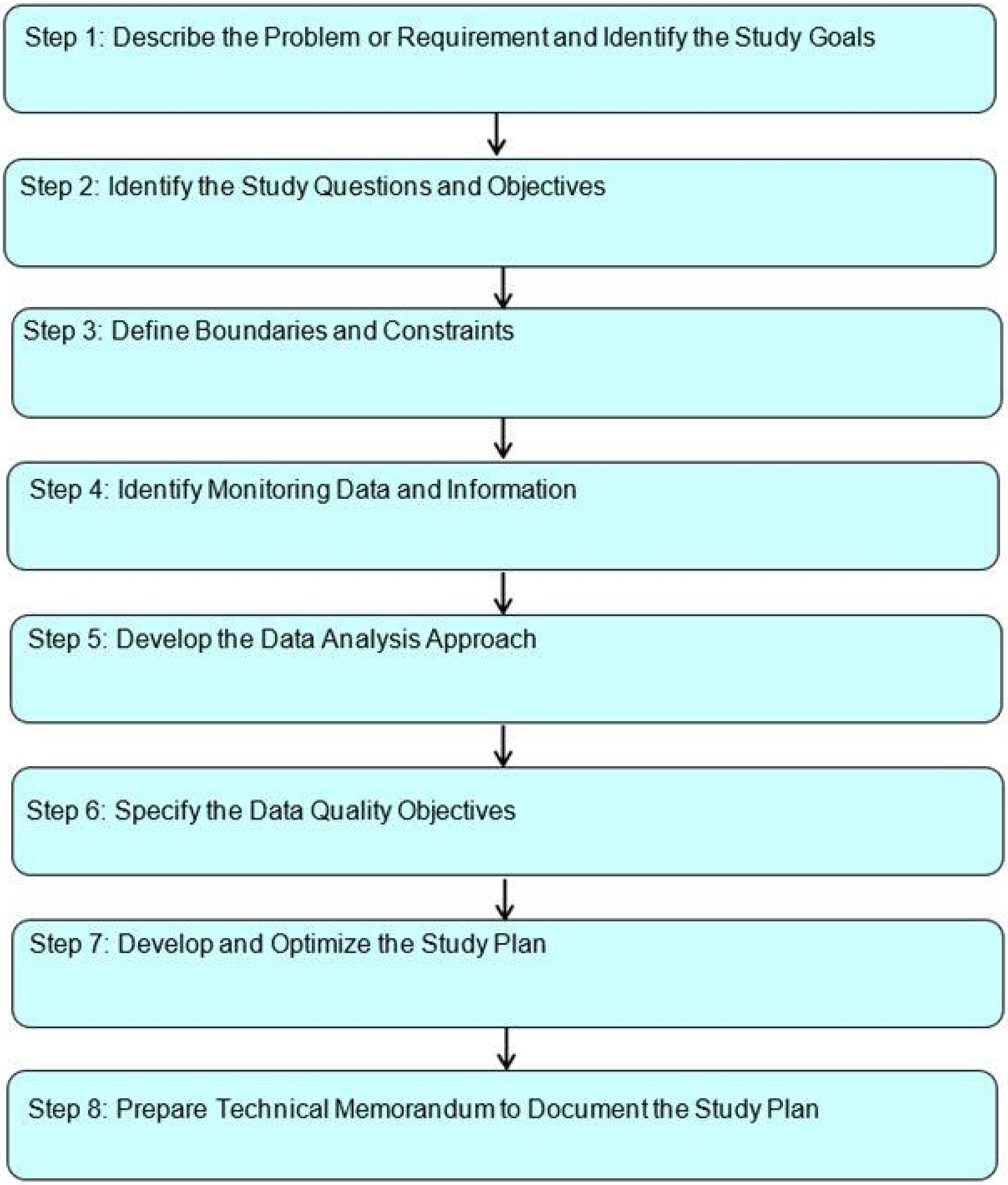


Figure 2-1 Process for Developing a Study Plan

The planning steps shown in Figure 2-1 are only guidelines. For projects such as permit compliance required by the State Water Board, the planning process may be modified to fit the monitoring requirements.

2.1 STEP 1: DESCRIBE THE PROBLEM OR REQUIREMENT AND IDENTIFY THE STUDY GOALS

The first step in developing a study plan is to define the requirement or problem that has initiated the need for monitoring. Monitoring projects are often driven by regulatory requirements in NPDES permits or total maximum daily load (TMDL) limits, but they may also be motivated by the need to obtain information from a specific area or facility type. It is critical to the success of the monitoring project to define the requirement or problem completely and to describe it clearly.

This planning step consists of the following tasks:

- Concisely describe the requirement or problem.
- Describe the overall goals of the study.
- Develop a conceptual model of the environmental problem.

Identify project or regulatory requirements.

The project goals should be expressed as qualitative statements of the desired end results. For example, the goal of a monitoring project could be to characterize a stormwater discharge, to decide how best to comply with a regulatory requirement, or to determine the effect of stormwater discharge on a receiving water body. The stated goals of the study should directly address the study problem.

The project planning team should first describe all information that pertains to the project. Once the problem is defined and the goals of the study are identified, the planning team should develop an outline that summarizes key elements of the study such as the following:

- Known or expected locations or sources of contaminants
- Potential transport pathways for contaminants within the Caltrans right-of-way (ROW)
- Transformation of contaminants
- Media within Caltrans ROW that are contaminated or may become contaminated
- Receptors of Caltrans stormwater runoff
- Lessons learned from previous studies that solved similar problems

The planning team should identify limitations on resources such as budget, personnel schedules, permitting, and time constraints.

The outputs of this step are as follows:

- A concise description of the problem
- An outline or conceptual model of the problem
- A summary of available resources and relevant deadlines for the study

2.2 Step 2: Identify the Study Questions and Objectives

In Step 2 of the planning process, the planning team should develop objectives that are designed to achieve the study goals. Project objectives are developed by identifying specific study questions. Once the study questions have been defined, study objectives should be developed that will be address the study questions. The following important activities are performed in this step:

- Identify the principal study questions
- Define study objectives designed to address the principal study questions

Example study questions include the following:

- What are the most prevalent constituents detected in stormwater?
- What species of biota are present in a watershed?
- What is the distribution of constituent concentrations over space and time?
- How does the constituent concentration compare to the water quality standard?
- Is the constituent concentration below background levels?

Following are the outputs of this step:

- Well-defined study questions
- Specific objectives to address the study questions

2.3 Step 3: Define Boundaries and Constraints

In Step 3 of the planning process, the project planning team defines the spatial and temporal constraints that will affect the study.

This planning step consists of the following tasks:

- Determine spatial and temporal boundaries that will constrain the study

- Identify practical constraints

Spatial boundaries define the physical area where monitoring will take place. Unambiguous location coordinates such as post mile, length, area, volume, names, or legal boundaries should be used to clearly define spatial boundaries.

Temporal boundaries define the time period over which monitoring will occur. The project planning team should determine when samples should be collected to produce data that are representative of the target population. For example, stormwater samples are usually collected during the rainy season, which forms a natural temporal constraint for the study.

Practical constraints that could interfere with sampling must be identified. It may not be possible to collect data over the entire physical area being studied, or over the entire time period called for by the project objectives. In these cases, the project planning team should determine whether it will be possible to conduct a monitoring study that will yield data that satisfy the study goals and plot the best course of action given the external constraints.

The following are outputs of this step:

- A description of geographic limits (spatial boundaries) that pertain to the project
- A determination of the time that is most appropriate for collecting data (temporal boundaries)
- Practical constraints that may interfere with data collection

2.4 Step 4: Identify Types of Monitoring Data

In this step of the planning process, the project planning team must decide what data are needed to answer the study questions.

This planning step consists of the following tasks:

- Identify what types of monitoring data are needed.
- Identify key monitoring constraints.
- Identify the basis for specifying the performance criteria.
- Identify and confirm availability of sampling and analysis methods.

2.4.1 Identify Types of Monitoring Data

The planning team must decide what types of data must be obtained to answer the study questions. There are three kinds of data that are usually associated with stormwater monitoring:

- Site Data – Information about the physical location from which samples are collected. Examples of site data include where a station is located (longitude and latitude, roadway, and post mile), the catchment area at the station, traffic, vegetation type and coverage, slope, land use, receiving water, point of collection, annual rainfall, eco-region, and the percentage of the catchment area that is paved.
- Event Data – Data recorded about the monitoring events as they occur, such as the time and duration of an event, how much precipitation was measured during the event, and how much runoff volume was produced.
- Sample Data – Data produced from the analysis of the samples. Samples are almost always water samples collected from a stormwater discharge stream, but may also be solid materials such as trash, sediment, or vegetation.

It may be tempting to omit one or two of these kinds of data if they are not needed to answer the study question. However, it is always advisable to collect all three of these kinds of data when conducting stormwater monitoring. This information may be of use during the data evaluation phase of the project, and it will almost certainly make the final project data more useful to researchers in the future.

Sample data for most stormwater monitoring projects can be further divided into four types:

- Chemical Characteristics – The concentration of specific substances contained in a sample. Examples include metals, organic compounds, and nutrients such as nitrogen and phosphorus.
- Physical Characteristics – Material aspects of the composition of the sample itself. Examples in water samples include temperature, odor, color, and the concentration of solid materials suspended in the water. Although pH is a measure of the concentration of hydrogen ions in water it is sometimes treated as a physical property.

- Biological Characteristics – The concentrations of microorganisms such as coliform bacteria and enterococci in the sample.
- Toxicological Characteristics – The degree to which exposure to a sample causes harm to living organisms.

2.4.2 Key Monitoring Constraints

Monitoring constraints are factors that affect where and when samples are collected, which storms are selected for monitoring, how often monitoring is conducted, what types of samples (grab or composite) are collected, and what methods are used to analyze them. Constraints could include road hazards, potential for erosion, potential for landslides, low annual rainfall, remoteness of the study area, freezing temperatures, snow, and required maintenance activities. The project planning team must identify these kinds of constraints before the monitoring phase of the project begins in order to reduce the chance that an unforeseen problem will arise. The better these constraints are understood, the more efficiently the monitoring data can be collected.

2.4.2.1 Site Selection Constraints

Monitoring sites should be selected that are representative of the study area and appropriate for the study objectives. For example, if the objective of a monitoring study is to characterize runoff from highways with congested traffic, then only sites in high average annual daily traffic (AADT) areas would be considered.

2.4.2.2 Monitoring Constraints

The number of sites and events to be monitored should be determined based on the number of data points that are necessary to provide statistically valid answers to the study questions. It is advisable to consult with a statistician to determine the number of data points that will be required.

The types of storms to be monitored and the temporal distribution of monitoring events should also be considered in this stage of the planning process. For example, if the project objectives include characterizing seasonal variation in stormwater toxicity, then monitoring events must be adequately distributed throughout the study period. Besides seasonal distribution, several other variables should be considered when selecting types of storms to monitor. These variables could include storm size (rainfall depth), storm duration, and antecedent conditions (such as number of days since the previous rainfall).

Monitoring only certain storms and excluding others (for example, monitoring only storms that have a 72-hour antecedent dry period) may introduce bias in the project data set. This should be considered when planning which storms to monitor and which storms to skip. Avoiding bias in storm event selection is especially important when data is used in cumulative or average load analysis.

2.4.3 Identify the Basis for Performance Criteria

The purpose of a monitoring project is to answer the study questions based on data that satisfy specified performance criteria. It is necessary to identify the basis or source for the performance criteria. For example, a Basin Plan Water Quality Objective (WQO) may be the basis for evaluating the monitoring results for a certain monitored constituent; or, a regulatory document such as the California Ocean Plan might be used as the basis for characterizing background concentrations. Other potentially relevant regulatory documents are the California Policy for Toxicity Assessment and Control (State Water Board 2012b), Policy for the Enclosed Bays and Estuaries (State Water Board 1974), and the California Toxics Rule (USEPA 1997).

2.4.4 Identify Sampling and Analysis Methods

The project planning team must identify a set of sample collection and analysis methods that are appropriate for the study objectives and for collecting high-quality data.

One important factor to consider when developing a monitoring strategy is sample representativeness. A sample is representative if it has the same composition as the matrix from which it was collected. In the context of stormwater monitoring, the sample is representative if concentrations of target constituents in the sample are the same as those in the storm discharge.

The planning team must establish what environmental condition must be represented, and this comes from the study question. For instance, if the purpose of the study is to determine how much of some constituent enters a receiving water as a result of stormwater runoff, then it would be necessary to collect samples that represent the entire storm. But if the purpose of the study is to evaluate a portion of a storm, then the samples would have to represent only that portion. Monitoring methods must be selected with the study objective in mind.

Representativeness criteria are discussed in detail in Section 6.5.

The timing of sample collection must also be considered. Possible approaches may include collection of a single grab sample at a specific point on the hydrograph, collection of a single grab sample at a discrete point during the storm (ascending, peak, and/or descending portions), collection of multiple grab samples at points throughout the event, or collection of a composite sample that represents the entire storm event.

The outputs of this step are as follows:

- A listing of the data required to address the study question
- A list of constraints that may affect monitoring or data quality
- A written specification of the basis of performance criteria for project data
- A list of appropriate sampling and analysis methods

2.5 Step 5: Develop the Data Analysis Approach

This step of the planning process involves developing an approach for analyzing the study data and drawing conclusions. The analytical approach usually involves statistical analysis and, in some cases, hypothesis tests. The approach is developed by assuming the data collected will meet the data quality and sufficiency requirements. This planning step consists of the following task:

- Specify the population parameters (e.g., mean, median, percentile) and statistical test methods that are suitable for analyzing the data to answer study questions. In some cases, the required statistical analysis approach may be specified by a regulation such as a Basin Plan. Otherwise, the selection of a data analysis strategy is based on project-specific needs. This should be done by the project statistician.

The outputs of this step are as follows:

- A list of the most important population parameters
- A data analysis approach that will adequately address the study questions

2.6 Step 6: Specify the Data Quality Objectives

Any monitoring program can be expected to have some level of error associated with both sample collection and sample analysis. Performance criteria, also called Data Quality Objectives (DQOs), are developed in this planning step to specify acceptable levels of error. For a typical Caltrans project, DQOs are developed for the following aspects of the data:

- Precision – The degree to which duplicate sample results agree with each other
- Accuracy – A measurement of how close an analytical result is to the true value
- Contamination – The degree to which samples are kept free of substances that might interfere with the analysis
- Reporting limits – The lowest concentration that can be measured reliably
- Completeness – The number of samples that pass all quality control checks and produce usable data, expressed as a percentage of all samples collected

Table 2-1 provides an example of some DQOs for a typical Caltrans monitoring project. This information is presented only as an example; DQOs should always be developed based on the individual requirements of a monitoring project.

Table 2-1 Example of a Set of Data Quality Objectives

Constituent	Accuracy	Contamination	Precision	Completeness
Total Suspended Solids	N/A	<RL	<20%	95%
Total Kjeldahl Nitrogen	80% - 120%	<RL	<20%	95%
Nitrate	80% - 120%	<RL	<20%	95%
Oil and Grease	79% - 114%	<RL	<18%	95%

NOTE: This table is only for illustration. DQOs must be developed individually for each project.

N/A – Not Applicable

RL – Reporting Limit

RPD – Relative Percent Difference

The DQOs shown in Table 2.1 are for water quality data. Separate DQOs must be developed for other kinds of monitoring data such as toxicity and gross solids data. USEPA methods for toxicity testing define performance criteria as well as specifications for test conditions. Details on specifying performance criteria for stormwater gross solids monitoring are discussed in Chapter 15.

The output of this step is:

- Written data quality objectives for sample collection and analysis.

2.7 STEP 7: DEVELOP AND OPTIMIZE THE STUDY PLAN

The next step in the planning process is to assemble a draft study plan from all of the information gathered in the previous planning steps. Because resources are always finite, a monitoring approach must be selected that will be resource-efficient but will also adequately address the study questions. This requires optimization of the study plan.

Activities typically performed during Step 7 include the following:

- Gather information on:
  - Objectives and intended use of data (hypothesis testing or estimation);
  - Outputs from Steps 1 to 6 of the planning process;
  - Expected variability of data based on similar studies or expert judgment
  - Preliminary assessment of underlying distribution of the data; and
  - Background information such as expected site characteristics, contaminant and media characteristics, regulatory requirements, and known spatial or temporal patterns of contamination.
- Determine "optimal" amount of data to collect using statistical and cost considerations.
- Modify study parameters and optimize data collection methods based on assessment of the information available.
- Review the budget, schedule, and all other constraints that could affect the monitoring program.

Optimization can be performed at any point during a monitoring program, but it is especially important during the project planning phase.

In some cases, it may be necessary to modify study parameters and optimize data collection methods based on newly collected data and field observations. This can be done during natural break points of the study, for example, at the end of each wet season. Of course, the Caltrans Task Order Manager must approve any changes to an existing study plan.

Following are the outputs of this step:

- A preliminary, optimized study plan
- An assessment of key assumptions and constraints

2.8 Step 8: Prepare Technical Memorandum to Document the Study Plan

When the preceding steps have been completed, the project planning team can then document this material in a written Study Plan, which ordinarily takes the form of a technical memorandum.

The Study Plan provides a framework for performing all subsequent project planning, including the development of the Quality Assurance Project Plan (QAPP). The QAPP is a written work plan that describes all phases of the monitoring project in detail and is used as a kind of project blueprint by field personnel, project managers, and laboratories. A standard part of the QAPP is the Sampling and Analysis Plan (SAP), which is included as an appendix. The SAP describes standard Caltrans methodologies and procedures for stormwater monitoring. The relevant sections of the SAP are referenced in the QAPP whenever appropriate.

For a pilot or applied research study, the equivalent of a QAPP may be the Operations, Maintenance, and Monitoring Plan (OM&M Plan), discussed in Section 2 of the Caltrans Pilot Study Guidance Manual (Caltrans 2009a).

In addition to project planning, the Study Plan can also serve as a valuable resource for data quality assessment and for making the final determination as to whether the collected data meet performance criteria.

The output of this step is:

- A technical memorandum that describes the Study Plan

Table 2-2 shows the steps needed to develop a Study Plan.

Table 2-2 Summary of Steps to Develop a Study Plan

Development Step	Output
1. Describe the Problem or Requirement and Identify the Study Goals	• Concise description of the problem • Outline or conceptual model of the problem • Determination of the type of data needed and how it will be used • Summary of available resources and relevant deadlines for the study
2. Identify the Study Questions and Objectives	• Well-defined study questions • Specific objectives to address the study questions
3. Define Boundaries and Constraints	• Description of geographic limits (spatial boundaries) that pertain to the project • Determination of the time that is most appropriate for collecting data (temporal boundaries) • Practical constraints that may interfere with data collection
4. Identify Monitoring Data and Information	• List of the data that are required to address the study question • List of constraints that may affect monitoring or data quality • Written specification of the basis of performance criteria for project data • List of appropriate sampling and analysis methods
5. Develop the Data Analysis Approach	• List of the most important population parameters • Data analysis approach that will adequately address the study questions
6. Specify the Data Quality Objectives	• Written data quality objectives for sample collection and analysis
7. Develop and Optimize the Study Plan	• Preliminary, optimized Study Plan • Assessment of key assumptions and constraints
8. Prepare Technical Memorandum to Document the Study Plan	• Technical memorandum that describes the Study Plan

3 SELECTION OF MONITORING CONSTITUENTS

Stormwater runoff typically contains a variety of suspended and dissolved materials, derived from both natural and manmade sources. Stormwater monitoring projects characterize stormwater quality by analyzing the physical/aggregate, chemical, and biological characteristics of runoff.

- Physical Characteristics – Characteristics that are not defined by direct measurement of specific chemical constituents. Examples include pH, hardness, temperature, turbidity, electrical conductivity, dissolved and suspended solids, and biological or chemical oxygen demand (BOD, COD).
- Chemical Characteristics – Characteristics that are defined by measurements of specific chemical constituents. Chemical constituents may be dissolved in the water associated with particles that are suspended in the sample. If the sample is filtered, the dissolved and suspended (particulate) fractions may be analyzed separately. If the sample is not filtered, the analysis includes both the dissolved and particulate fractions. Common chemical constituents include nutrients (nitrogen and phosphorus compounds) and metals.
- Biological Characteristics – Measurements of the numbers of certain types of living microorganisms suspended in stormwater. In bacteriological tests, stormwater samples are analyzed for indicator bacteria such as total coliform, fecal coliform, E. coli, and Enterococcus. The presence of these indicator organisms indicates the possible presence of human pathogens in the runoff.
- Toxicological Characteristics – In toxicity tests, live organisms are exposed to stormwater samples in the laboratory under controlled conditions to evaluate whether the stormwater exhibits toxic effects. If toxic effects are observed, further testing is sometimes performed to identify the substances in the sample that are causing the toxicity. This process, called Toxicity Identification Evaluation (TIE), is discussed in Chapter 17.

Several factors must be considered when deciding which stormwater constituents to include in a monitoring project. This chapter provides guidance for initial and ongoing constituent selection and a discussion on which constituents could be expected from different kinds of Caltrans facilities.

The following considerations for constituent selection are discussed in this section:

- Project objectives
- Common monitoring constituents
- Particle size distribution
- Historical monitoring data
- Regulatory requirements
- Constituents helpful for data interpretation
- Receiving water quality
- Project resources
- Sources of constituents in the study area
- Modifying the constituent list

3.1 Project Objectives

The list of constituents to be included in a monitoring study depends on the objectives of the study. For example:

- BMP evaluation would select monitoring constituents that characterize the performance of the BMP design
- Regulatory requirements studies, such as monitoring provisions of a TMDL or runoff characterization in Areas of Special Biological Significance, would typically require a focus on the constituent(s) regulated by the associated regulatory agency
- Stormwater discharge characterization would typically include a variety of common runoff pollutants

3.2 Common Monitoring Constituents

There is a standard set of constituents that is common to nearly all stormwater monitoring projects that Caltrans has conducted throughout the state. These constituents are included in most projects because they appear commonly in discharge regulations and are almost universally important for the health of receiving waters. They are also common pollutants in highway runoff.

A list of these common constituents appears in Table 3-1. These constituents, sometimes referred to as the Caltrans Minimum Constituent List, should be considered when planning a Caltrans stormwater monitoring project. Using a common set of analytical constituents in all monitoring projects allows Caltrans to make direct comparisons of stormwater quality between monitoring studies and among monitoring sites.

The list of analytes in Table 3-1 should be used as a base constituent list for any project during the planning phase. Other constituents may be added to the list based on the project objectives or the other considerations discussed in this section.

Table 3-1 Common Water Quality Constituents

Constituent	Preferred Analytical Method
Physical/Aggregate Characteristics	
pH	EPA 150.1
Conductivity	SM 2510B
Turbidity	EPA 180.1
Hardness as $CaCO_3$	SM 2340B
Total Suspended Solids	EPA 160.2
Total Organic Carbon	EPA 415.1
Chemical Characteristics	
Nutrients	
Total Kjeldahl Nitrogen	EPA 351.3
Nitrate as Nitrogen[1]	EPA 300
Total Phosphorus	EPA 365.2
Orthophosphate	EPA 365.2, EPA 365.3
Metals	
Cadmium	EPA 200.8
Copper	EPA 200.8
Lead	EPA 200.8
Nickel	EPA 200.8
Zinc	EPA 200.8
Biological Characteristics	
Total Coliform	SM 9221B
Fecal Coliform	SM 9221E
Enterococcus	SM 9230B

This list is an example. Actual constituent lists are project specific.

[1]If the project constituents include Total Nitrogen, Nitrite-N should be added to the analyte list.

3.3 PARTICLE SIZE DISTRIBUTION

In addition to the common water quality tests discussed in Section 3.2, Caltrans also analyzes samples for Fine Sediment Particles (FSPs) in water at some monitoring locations. The term “fine sediment particles” refers to very small particles, ranging from about 0.5 to 16 microns in size, which are suspended in Caltrans stormwater runoff and can be carried into receiving waters. Suspended particles in this size range cause turbidity in water, which can be a problem in areas where the clarity of receiving water is a concern. Figure 3-1 shows the range of particle sizes that cause turbidity relative to the size of particles associated with standard analyses such as Total Suspended Solids (TSS) and Total Dissolved Solids (TDS).

FSP refers to particles that are suspended in water, not to particles that have settled out of the water column. FSP analyses are performed on a liquid matrix. Collection and analysis of sediment that settles out of stormwater discharges and is treated as a solid matrix is discussed in Chapter 16.

FSP analysis consists of physically examining a fresh stormwater sample to determine the number of particles it contains per unit volume. Caltrans performs this test using two types of instruments that use different analytical principles:

1. Laser Diffraction – A beam of laser light is passed through the sample. The light is scattered when it strikes particles in the sample, and the angle at which the light is scattered is proportional to the size of the particles. Large particles scatter light at smaller angles relative to the path of the laser beam and small particles scatter light at larger angles. By measuring the amount of light that is diffracted at various angles, the instrument can determine the numbers and sizes of particles suspended in the sample. The laser diffraction instrument and methodology used by Caltrans can resolve particles from 0.496 to 17.156 microns in size.
2. Photometric/Flow Cytometry – A portion of the sample is suspended in a stream of fluid and passed by a high-speed charge-coupled device (CCD) camera. The camera takes photographs of the stormwater sample as it passes, and the instrument software analyzes each photograph to determine the number and size of the particles in the sample. The photometric instrument used by Caltrans can resolve particles from 0.83 to 16.57 microns in size.

FSP analysis is performed using methods that are based on the equipment manufacturers’ instructions. The laser diffraction method was developed in accordance with Standard Method 2560D.

FSP is reported both as count and as mass, and both units are of potential interest to regulators. FSP count is defined as the number of FSPs per volume of sample. FSP mass is defined as the mass of FSPs per volume of sample.

Whenever stormwater samples are collected for FSP analysis, samples should also be analyzed for TSS and turbidity. TSS is necessary for converting the laser diffraction data into particle counts, and turbidity is often useful when interpreting FSP data.

No special sample collection procedures are required for FSP analysis. Samples are collected as described in Chapter 11.

Samples for FSP analysis must be taken from the bottom or invert of the channel so heavier particles are included in the sample. Larger, heavier particles are often carried in a discharge stream near the bottom of the channel and may not be represented adequately in a sample collected near the surface of the stream.

FSP analysis should be performed as quickly as possible after collection, ideally on the same day they are collected, but no later than 36 hours after collection.

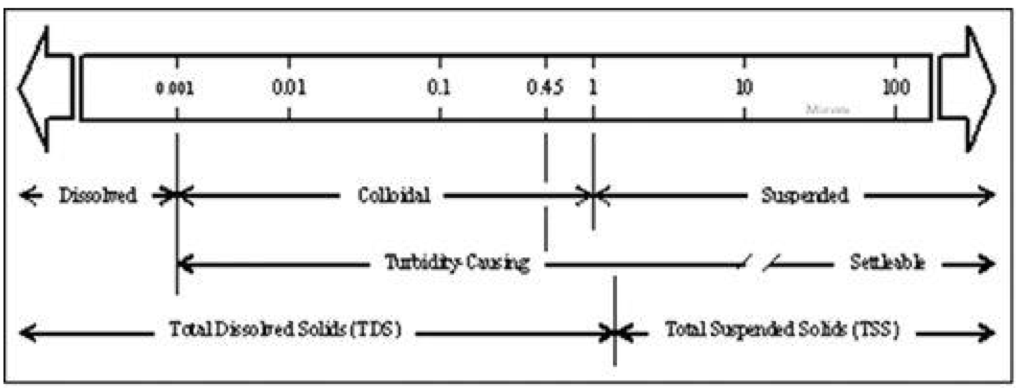


Figure 3-1 Sizes in Microns and Ranges of Fine Sediment Particles

3.4 HISTORICAL MONITORING DATA

When planning a monitoring project, it is often useful to review historical monitoring data from the study area or from locations that are similar to the study area. Historical data may be useful when planning what constituents to include in the study. In earlier versions of this manual past data (1997-2007) was included as an appendix. This is being discontinued due to changes in analysis methods, analysis detection limits and requirements in the reissued NPDES Permit. All data from 2012 onwards is now available on the State Water Resources Control Boards CEDEN web portal.

3.5 Regulatory Requirements

A monitoring project can be initiated in response to water quality regulations such as the Construction General Permit, NPDES permit, receiving water quality objectives, or TMDL monitoring requirements. In these cases, the regulations usually specify which water quality parameters or constituents must be measured.

When regulatory requirements are not part of the study objectives, water quality regulations in the study area should be taken into consideration when planning any monitoring project. This is particularly true in the case of water quality objectives that apply to receiving waters located within or adjacent to the study area, especially when stormwater runoff from a Caltrans study area discharges directly into a receiving water. Collection of pertinent data may be useful in interpreting monitoring project results.

All projects at sites that discharge to surface waters must include chronic toxicity testing using at least one organism in order to satisfy the Caltrans NPDES permit. If an applicable TMDL contains specific toxicity tests, then that TMDL requirement must also be satisfied. Organism selections for toxicity testing shall be as specified in the regulation and approved by the Task Order Manager.

Toxicity data must be calculated using the test of significant toxicity method (Section 17.2) and reported as either pass or fail. To calculate either a Pass or Fail of the effluent concentration chronic toxicity test at the Instream Waste Concentration (IWC), the instructions in Appendix A in the National Pollutant Discharge Elimination System Test of Significant Toxicity Implementation Document (EPA/833-R-10-003) must be used. For Caltrans discharges, the IWC is 100% (i.e., either is 100% stormwater or 100% non-stormwater)

3.6 Constituents Helpful for Data Interpretation

Some water quality data require additional supporting data for proper interpretation. When deciding which constituents will be monitored for a project, it is important to consider how the data will be interpreted, and make sure any supporting data will also be collected.

Here are some common examples:

- pH – Many chemical properties of natural water bodies are affected by pH. It is always a good idea to record the pH of a water body when collecting samples for laboratory analysis.

- Temperature – Many chemical processes are temperature-dependent. Temperature may also provide insight into physical factors such as stream mixing that may be of interest to data reviewers.
- Ammonia – The degree to which ammonia is toxic to aquatic life directly depends on the pH and temperature of the water body. Therefore, whenever ammonia is part of a project constituent list, temperature and pH must also be measured so the toxicity of ammonia can be properly assessed.
- Metals – The toxic effects of many heavy metals vary as a function of hardness, and the California Toxics Rule (CTR) (USEPA 1997) lists the receiving water quality objectives for most metals as hardness-dependent equations. Whenever testing of metals in a receiving water is included in a monitoring project, hardness must also be included as a monitoring constituent to properly interpret metals results.
- Toxicity – When toxicity testing is included in the monitoring project constituent list, field crews should measure temperature, conductivity, and dissolved oxygen in the sample stream, since these properties are also important for the proper interpretation of toxicity data.
- Dissolved Constituents – Many common chemical constituents in stormwater runoff and receiving waters exist both in dissolved and particulate form. Aquatic life is usually able to ingest or absorb substances more easily from the environment if the substances are in the dissolved state. This is true of both potentially toxic substances, such as heavy metals, and beneficial substances, such as nutrients. Therefore, it is important to measure the dissolved fraction of such chemical constituents in stormwater runoff when the project objectives include assessing the impact of stormwater runoff on receiving water biota.

3.7 Receiving Water Quality

When developing a project constituent list, consideration should be given to receiving water quality in the project watershed. Some constituents of highway runoff may be deleterious to the biota of surface water bodies in the area, and constituents should be added to the project constituent list if there is a reason to believe discharges from Caltrans facilities in the project area may cause problems in local receiving waters.

The Caltrans Water Quality Planning Tool (http://svctenvims.dot.ca.gov/wqpt/wqpt.aspx) is an online utility for information on watersheds and water quality objectives. By selecting a county, route, and post mile, the user can get information on a hydrologic sub-area (HSA). The tool provides a topographical map and an aerial photograph of the selected HSA as well as the following information:

- 303(d)-listed (impaired) water bodies and TMDLs in the HSA
- Water quality objectives and beneficial uses for water bodies in and near the HSA
- Caltrans facilities located in the HSA

3.8 Project Resources

The limiting factor in the scope of a monitoring project is usually the amount of funding available for a project. Therefore, when choosing constituents for a monitoring project, it is often necessary to weigh the desirability of optional constituents against their cost and include them only if permitted by the project budget.

One way to save cost is by measuring a less expensive, surrogate property. Also, if a large majority of analytical results show that the target analyte is not detected, this can be used as a basis to eliminate a constituent from a project's constituent list.

3.9 Sources of Constituents in the Study Area

Certain characteristics of the study area or catchment may be useful in selecting constituents for monitoring projects. Constituents selected for monitoring are generally driven by regulatory requirements. The following questions may be useful in identifying site characteristics to inform constituent selection:

- What are the characteristics of the study site that could affect the quality of stormwater runoff?
- What physical and chemical mechanisms could affect the mobilization, transport, and transformation of constituents from the study site?

The potential constituent sources associated with various types of transportation-related facilities can differ. Based on prior monitoring studies, the constituents expected in runoff are known for the following types of Caltrans facilities.

- Highways
- Maintenance Yards

- Commercial Vehicle Inspection Facilities
- Roadside Rest Areas
- Park and Ride Lots
- Construction Sites

These types of facilities are discussed in the following sub-sections.

3.9.1 Highways

Many sources contribute to the quality of stormwater runoff from highways, including fossil fuel combustion byproducts; deterioration and wear of tires and brake pads, bearings, bushings, and other moving parts; leaking lubricants and hydraulic fluids; pavement maintenance; and road de-icing.

Various monitoring projects have been conducted on or near highways by Caltrans and others. These studies have detected numerous constituents in highway runoff, including metals, petroleum hydrocarbons, polynuclear aromatic hydrocarbons, phenols, nutrients, and bacteria.

It is also important to consider nearby land uses when monitoring runoff from a highway, because any highway is affected to some degree by its surroundings. For example, if a monitored stretch of highway is surrounded by farmland, it may be wise to determine which herbicides, insecticides, or nutrient fertilizers have been used in the area, and to consider including them in the project constituent list.

3.9.2 Maintenance Yards

Activities that take place in maintenance yards, such as vehicle and equipment cleaning, fueling, and repair, may contribute various constituents to stormwater, including synthetic organic compounds (adhesives, cleaners, sealants, and solvents), petroleum hydrocarbons, and metals. In addition, eroded sediment and other particulate matter (primary sources of suspended material in stormwater runoff) may also be a site-specific concern in some maintenance yards.

3.9.3 Commercial Vehicle Inspection Facilities

Vehicle inspection stations are often occupied by large trucks that are either parked or moving very slowly. Under such conditions these vehicles can leak fuels, oil, grease, and solvents and other cleaners. Constant acceleration and deceleration can cause significant wear on tires and brake pads, which can contribute heavy metals and heavy organic compounds to stormwater runoff. A great deal of litter is also found in these areas.

An additional factor at these facilities is the cargo carried by large commercial vehicles. Some truck cargo, for example raw vegetables or cattle, can leak substances that can enter stormwater runoff. The kinds of cargo that are carried by trucks should be considered when planning a monitoring study that involves a vehicle inspection station.

3.9.4 Roadside Rest Areas

The most common constituents found at rest areas include litter and food waste, oil and grease, eroded sediments, metals, nutrients, and bacteria.

It is particularly difficult to predict what materials will be carried in stormwater discharge from rest areas because of the diverse uses to which the public puts these facilities. People have been seen using rest areas for vehicle maintenance, cookouts and parties, impromptu automotive swap meets, automobile racing, and even for painting vehicles. Rest areas are frequently the sites of illegal dumping. Food waste at these facilities often attracts animals, which can lead to increased levels of pathogens in stormwater runoff.

For this reason, a great deal of variability may be expected in the runoff from roadside rest areas. Both the types and the concentrations of water quality constituents can be expected to vary significantly from site to site and from event to event.

3.9.5 Park and Ride Lots

Park and Ride lots are most frequently occupied by private vehicles that are parked for extended periods. This exposes these facilities to leaking fuels, oil, transmission fluid, and antifreeze. Vehicle acceleration and deceleration causes wear on engine parts and brake pads, which can contribute metals. Litter, food waste, and bacteria are also commonly found at Park and Ride lots.

Park and Ride lots share the problem discussed above regarding unpredictable use by the public at roadside rest areas, although usually to a lesser degree. Nevertheless, because it is not possible to completely control what members of the public do at Park and Ride lots, the monitoring team should not be surprised to find unusual or unexpected constituents in the stormwater runoff from these facilities.

3.9.6 Construction Sites

The disturbed earth at construction sites can contribute a great deal of sediment to stormwater runoff. This sediment is both a pollutant and a transport mechanism for other water quality constituents. Vehicles and heavy equipment at a construction site have the potential to contribute fuels, oil, grease, solvents, and metals. Construction materials can enter stormwater and be carried to the receiving water. For example, if concrete waste from a construction site enters stormwater runoff, it can be expected to contribute considerable amounts of solids and metals and affect pH significantly.

Caltrans construction projects are subject to the terms of the statewide Construction General Permit and may be subject to other permits. These permits usually specify which water quality constituents must be monitored. The permits should be consulted for guidance whenever a monitoring project is being planned in an area that will be affected by construction activity.

3.9.7 Modifying a Constituent List

As a monitoring study progresses, analytical data should be evaluated against the project objectives. In some cases, it may be possible to identify constituents that may be removed from the project constituent list to reduce analytical costs. For example, if a test for petroleum hydrocarbons was part of the original project constituent list, but petroleum hydrocarbons were routinely not detected during the first year of monitoring, the project manager might consider removing this analysis from the constituent list.

In other cases, constituents might be added to a project. For instance, if observed toxicity levels were higher than expected, the project manager might increase the frequency of testing for field temperature, conductivity, pH, and dissolved oxygen, or add analysis for potential toxicants such as an additional class of organic chemicals, to better understand the toxicity data.

Any modification of the project constituent list must be authorized by the Caltrans task order manager.

4 SELECTION OF MONITORING METHODS AND EQUIPMENT

Stormwater runoff quality varies both spatially (laterally and vertically throughout the cross section of flow), and temporally (over time). Monitoring methods and equipment must be selected with knowledge of the expected characteristics of stormwater runoff, as well as the objectives of the monitoring study.

Temporal variation derives from the differential availability of constituents within a catchment area over time, and the relative degree to which those constituents are washed off exposed surfaces. The first few hours of a storm often contain higher concentrations of monitored constituents than any other period of the storm (this is called the “event first flush” effect). A “seasonal first flush” effect is commonly observed in California as well, when early season storms wash constituents off landscapes where they have been accumulating throughout the dry season. Generally, stormwater quality improves during the later phases of a storm event, but runoff from periods of high-intensity precipitation can mobilize, or “scour,” sediment from the study area, causing temporary increases in sediment-bound constituents.

Spatial variation reflects the nature of the various constituents entrained within stormwater runoff, as well as the differential contributions of various sources within a catchment area. Petroleum and other buoyant materials tend to float near the surface of a runoff stream, while constituents associated with heavier particles tend to be carried along the bottom of the conveyance. Within the water column itself, concentrations of constituents may vary randomly due to turbulence in the flow.

Stormwater samples can be collected as “grab” samples or as “composite” samples. A grab sample is a singular, instantaneous collection of a sample to characterize water quality at a specific place and time. Enough volume is collected to perform the intended water quality analysis with each sample. A composite sample is comprised of some number of individual grab samples or sample aliquots mixed together. A composite sample can be collected over some period of time at a given location (temporal composite), or at a particular time over some spatial range, such as a creek cross-section (spatial composite). Temporal composites can be either “flow-based” or “time-based.” While grab samples and spatial composites are typically collected manually, temporal composite samples may be collected either manually or via automated means. See Chapter 11 for a detailed description of sample collection methods, including the various types of composite sampling approaches that can be used.

For most Caltrans stormwater monitoring projects, temporal variation is of primary concern. For this reason, most Caltrans stormwater monitoring involves the use of automated equipment for collection of flow-proportioned composite samples to characterize runoff over the duration of the storm.

This chapter covers the methods and equipment that Caltrans uses to monitor stormwater runoff. These methods have been developed to ensure monitoring data are adequately representative of the characteristics of stormwater runoff from the study area.

Stormwater monitoring typically involves sample collection, flow measurement, precipitation measurement, and field measurements of water quality. When monitoring is performed with the use of automatic equipment, additional ancillary equipment and functions are normally necessary, including remote communications, data logging, power supply, and security enclosures. This chapter is organized by function, in the following categories:

- Sample collection
- Flow measurement
- Precipitation measurement
- Field measurements
- Telemetry
- Power supply
- Data logging and system integration
- Security enclosures

4.1 Sample Collection

A sample may be collected manually or with the use of automatic sampling equipment. Manual sample collection involves filling a sample container by hand or operating a pump in manual mode to collect a sample through a sampling tube placed in the runoff stream. Automated sample collection involves securing a sampling tube in the runoff stream and programming an autosampler pump to draw samples from the runoff stream into a sample container. Both approaches are described below.

The advantages and disadvantages of manual and automated stormwater monitoring are summarized in Table 4-1.

Table 4-1 Comparison of Manual and Automated Sample Collection Methods

Monitoring Method	Advantages	Disadvantages
Manual	• Manual grab sampling is easier • Negligible equipment costs • Less rigorous training required • No equipment wear, theft, vandalism • Can be used where automated monitoring stations cannot be installed • May be more economical when automatic flow measurement or sampling is not practical	• May require extended personnel presence to collect composite samples • Labor-intensive, and usually more expensive for large monitoring projects • Difficult to monitor first stages of runoff reliably • Can be less safe than using automated equipment • Flow measurement may be less reliable
Automated	• Greatly simplifies collection of composite samples • Saves considerable personnel expense – usually more cost-effective for large projects • More reliable for monitoring the first stages of runoff • Extremely flexible, can be programmed for a wide variety of sampling schemes • Safer under some circumstances • Many optional devices can be added to extend functionality	• Large up-front equipment cost • Requires installation of semi-permanent station • Requires more rigorous training of field crews • Equipment wear and maintenance • Possibility of theft and vandalism • May be inappropriate for very large or very small flow volumes • Not permissible for specific constituents such as oil and grease, bacteria, and low-level mercury

4.1.1 Manual Sample Collection

Manual sample collection involves filling a container from a runoff stream during a storm event. This can be done either by collecting the sample directly into laboratory-supplied bottles or by using an intermediate container to pour the sample into the lab bottles. Note that samples for certain constituents, including oil and grease, bacteria, and low-level mercury, must be collected directly into the appropriate sample bottle without use of an intermediate container. See Chapter 11 for a discussion of sample collection methodology.

An intermediate sample container can be an unused laboratory bottle. Sample collection can be assisted by a device that is extended to dip, lower, or reach the sample container into a runoff stream. This method is ordinarily used when the runoff stream is difficult to access, and an intermediate container must be lowered into the stream or reached across a long distance to collect a sample.

Use of an intermediate container is preferred when filling pre-preserved laboratory bottles because it eliminates the risk of accidentally rinsing out the preservative while filling the bottles.

4.1.2 Automated Sample Collection

Automated samplers are designed to automatically collect and preserve samples from stormwater runoff, eliminating the need for field crews to be present during the entire sampling event. The samples are removed from the automated sampler at the end of the monitoring event and sent to the laboratory for analysis.

Automated sample collection involves placing a sampling tube in the discharge stream and using a pump to draw samples from the runoff stream into a sample container. An automatic sampler is used to perform this work. Automatic samplers are comprised of a peristaltic pump, flexible pump tubing, Teflon® sample tubing, a sample container, control electronics, and a power supply. The peristaltic pump creates suction by compressing a flexible tube with a rotating roller and draws a sample up through the sample collection tube, through the pump, and into the sample container. The power source is generally an external 12-volt battery or an AC adaptor. In addition, an automated sample collection setup requires a device to actuate the sampler, such as a flow meter or rain gauge. Automated sample collection stations can also integrate many other types of devices, such as telemetry, rain gauges, and in-line analytical instruments such as pH meters and temperature sensors.

A schematic representation of an autosampler installation appears in Figure 4-1.

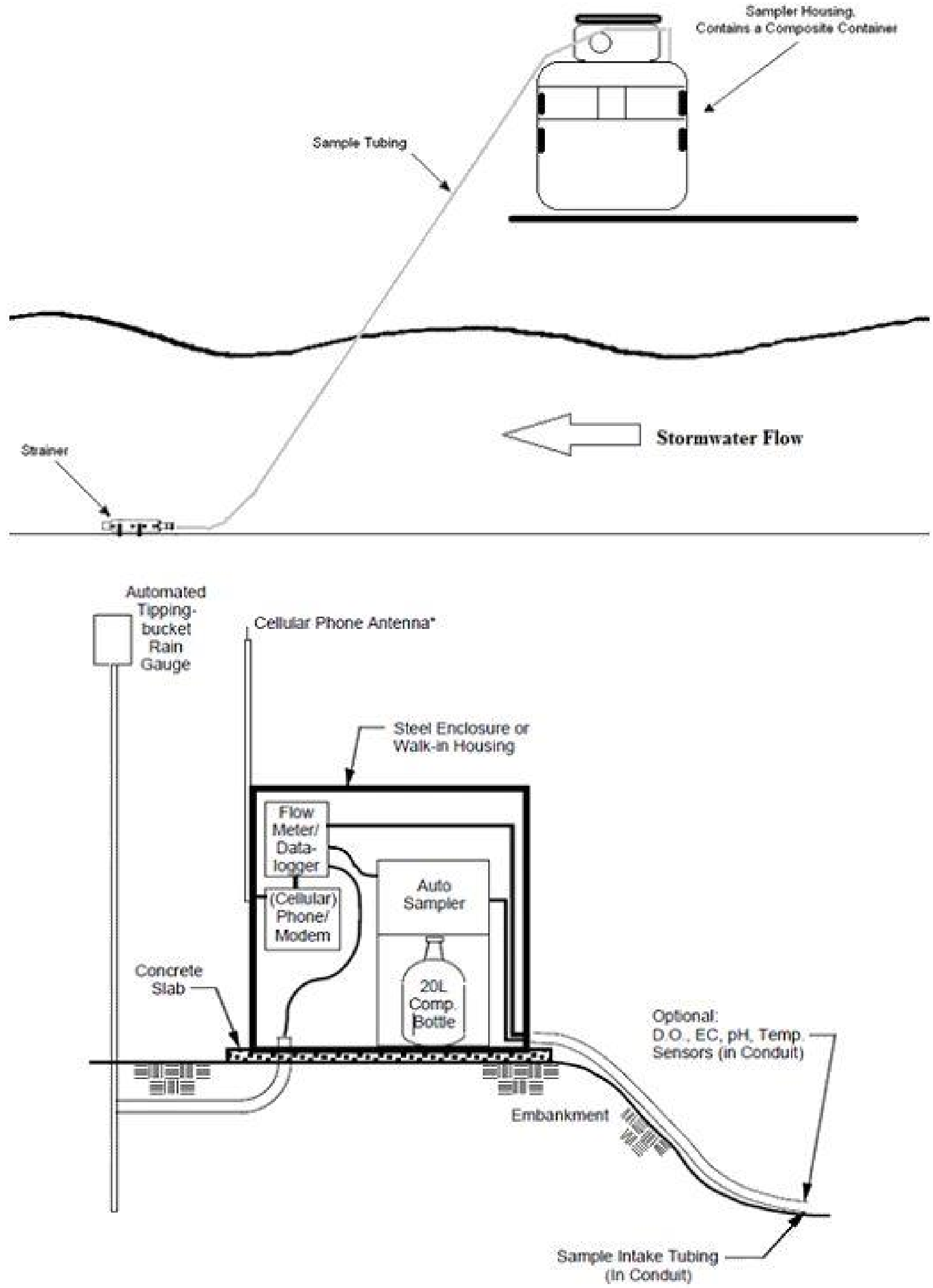


Figure 4-1 Diagrams of a Basic Automated Sampler Installation

Use of a peristaltic pump does not allow the sample to come into contact with any part of the pump except the tubing. This minimizes the chance that a sample will be contaminated as it is collected, and makes equipment cleaning very easy. Therefore, using peristaltic pumps is preferred for stormwater sample collection. A peristaltic pump-style automatic sampler is shown in Figure 4-2.

Figure 4-2 Automatic Sampler - Peristaltic Pump

Peristaltic pumps have limited capacity to pump water vertically. The vertical distance a sample travels between the runoff stream and the pump is called the vertical lift. Pumps that are used by Caltrans for stormwater monitoring have a vertical lift capacity of about 25 feet, and this must be considered when installing a monitoring station.

Automatic samplers can be programmed to fill one large composite carboy (five- to 15-gallon rigid plastic or glass container) or to fill multiple smaller sample bottles. In a multiple-bottle configuration, tubing from the discharge port of the pump is connected to a rotating distributor arm that dispenses the samples into the selected sample bottles. A single-bottle configuration is useful for characterizing a storm in its entirety, because all aliquots are combined into one bottle; a multiple-bottle configuration is useful when different phases of a storm must be characterized discretely, because samples collected from different parts of the storm are stored separately.

More than one sampler can be installed at a single monitoring station if large volumes of sample must be collected over a short duration, or if samples for specialized analyses must be collected in different bottles at the same time. Stations with multiple samplers can be programmed so all samplers are actuated by a single flow meter or electronic rain gauge.

4.1.3 Tubing and Strainers

An automated sampler pumps water through tubing that runs from the runoff stream, through the peristaltic pump, and into a sample container. The portion of tubing within the peristaltic pump is made of a flexible silicon material. The silicon pump tube is connected just before the pump intake to a length of tubing that runs between the pump and the sample stream. The sampling tube is made of or polyethylene that is Teflon®-

coated on the inside. The silicon tube on the discharge end of the pump may run directly into the sample container or be connected to another length of Teflon®-coated polyethylene tubing that runs into the sample container.

A strainer is used to prevent small rocks, vegetation, and other debris in the sample stream from being sucked up into the sample tube and clogging or damaging the tube or the pump. Figure 4.3 shows photographs of a custom-made strainer that is suitable for most Caltrans monitoring projects. This strainer was fabricated by cutting a Teflon® tube to a length of 100 mm, drilling holes in it with a drill press, and creating a lip with a lathe to fit the strainer snugly into a sample collection tube. Custom-made strainers may be preferable because they can be made to size for individual projects and be constructed of materials that are suitable for the project constituent list.

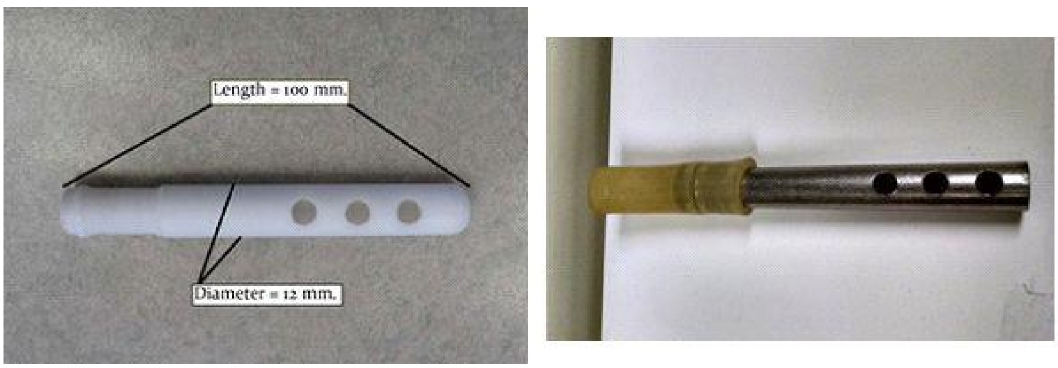


Figure 4-3 Custom-Made Strainer and Commercially Available Strainer

The sample collection tube is anchored in the middle of the runoff stream, usually near the bottom of the stream. This end of the sample tube is fitted with a strainer made of Teflon® or stainless steel that has been thoroughly coated with Teflon® to eliminate exposed steel. If no metal analytes are included in the monitoring program, then the strainer may be made of uncoated stainless steel.

4.1.4 Sample Containers

An automated sample collection system can pump all composite aliquots into a single large container, or into several smaller containers. These containers store the collected aliquots as the monitoring event progresses and are picked up by field personnel after the event and sent to the laboratory for analysis. In cases where a monitoring event lasts longer than one day, sample containers should be switched out after each 24-hour period and sent to the laboratory so short-hold time analyses can be performed within the hold time.

Composite containers may be made of polyethylene, borosilicate glass, or Teflon®, depending on the project constituent list. Polyethylene containers are much less expensive than other kinds of containers, they are lighter and easier to transport than glass, and they do not break if dropped. Analytes such as metals and nutrients may be collected in polyethylene containers. Samples for most organic constituents must be collected in glass. Guidance on which sample containers to use for different kinds of constituents appears in Table 4-2.

4.2 Flow Measurement

For most Caltrans stormwater monitoring projects, flow rate is monitored using an automated flow meter to measure and record the depth of flow and then convert the depth to volumetric flow rate (also called "discharge" or "flow rate"). This is normally done by measuring the depth of flow at a primary flow measurement device (a flume or weir) or other structure where there is a known relationship between depth and flow rate. The flow depth also can be measured manually and converted through a table or formula into flow rate. Manual measurement is most often done for short-term studies where installation of automated equipment is not warranted. Manual measurements are also used in circumstances when use of automated equipment is not practical, such as in cases of very large or very small flows or in locations where an automated monitoring station cannot be securely installed.

4.2.1 Depth Measurement/Flow Rate Conversion

Where there is not an established depth-to-flow-rate relationship, an "area-velocity" flow meter is often used to measure flow velocity directly, as well as depth of flow. The meter then computes instantaneous flow rate from the measured velocity and the cross-sectional area of flow (derived from the measured depth). It is also possible to measure velocity manually ("Float Velocity Method," below).

Where there is a known relationship between the water depth and the volumetric flow rate (discharge), flow rate may be determined by measuring water depth, with conversion to flow rate using a table or formula. The measurement of depth and conversion to flow rate can be done manually or automatically using an automated flow meter.

For rivers, creeks, and channels, the depth-to-flow-rate conversion is typically referred to as a "stage-discharge relationship," where "stage" refers to water level as referenced to an established datum. A detailed hydrologic study is performed initially over a range of flow conditions to establish the stage-discharge relationship; the result is often called a rating curve. Using this relationship, discharge flow rate can be determined by simply measuring the water level in the channel, typically by reference to a staff gauge or similar device on site.

For larger channels where a stage-discharge relationship has not been established, a control structure may be used as an approximate rectangular weir, provided the control structure is approximately level horizontally, and there is uniform free-fall off the downstream edge. In such cases, the depth of flow over the structure is used to estimate flow rate from a weir-discharge table or equation (Teledyne ISCO 2008).

For smaller channels or pipe flows, flow rate can be determined based on flow depth using a manufactured, primary flow measurement device, such as a flume or weir. Such devices are calibrated by the manufacturer for a specific range of flow rates, and flow rate through the device can then be determined reliably by measurement of depth of flow. For flumes, the manufacturer provides a rating curve for the specific flume for use in converting flow depth to flow rate. For weirs, a head-discharge table or equation is used to convert depth of flow ("head") to flow rate over the weir. Primary flow devices are often used in automated monitoring systems; see details below.

4.2.1.1 FLUMES

Flumes are shaped, open-channel flow sections that force flow to accelerate through a constriction. A depth-discharge relationship (the rating curve) is established by the manufacturer in accordance with the geometry of the flume. When using a custom-made flume or when a flume cannot be set up in accordance with the manufacturers' instructions, a rating curve must be developed in the field once the flume is installed.

A flume must be sized appropriately for anticipated normal and maximum flows. Flow rates through a flume that are outside the limits of the flume's rating curve will not be measured accurately. A properly sized and installed flume can achieve ±10% accuracy; however, manufacturers often identify this accuracy for flows occurring within ten to 100% of the flume's design capacity. The smallest flume of adequate capacity for the expected flow range should be selected, but a flume is a restriction on the flow through the channel. Choosing a flume that is too small may create backwater effects that cause upstream flooding, damage to drainage systems, or inconvenience to the travelling public.

An H-flume, a very common flume used for Caltrans monitoring projects, appears in Figure 4-4.

Figure 4-4 H-Flume

Table 4-2 Types of Flumes Used by Caltrans

Flume Type	Advantages
H, HS, HL	• Wide operating range; suitable for measuring flows that vary widely, such as seasonal runoffs and overflow from dams • Passes sediment well without clogging; good for flows with high solids content • Minimal head requirement • Simple form and construction
Parshall	• Wide operating range; intended for use in open channels; use extreme care when adapting to round pipes • Low head/energy loss • Passes sediment well without clogging; good for flows with high solids content
Palmer-Bowlus	• High accuracy • Low head/energy loss • Designed for use in round pipes flowing partly full and at low velocities; simple installation in existing pipes
Trapezoidal	• Wide operating range intended for use in open channels; use extreme care when adapting to round pipes. • Low head/energy loss • Passes sediment well without clogging; good for flows with high solids content • Good for low flows • Conforms to the shape of natural conveyances; minimal upstream transitional length needed • Operates under relatively high degrees of submergence
Cutthroat	• Simple form and construction • Easy to install on existing channel bed
Long-Throat	• Minimal head loss • Low construction cost • Ability to measure a wide range of flows • Can be custom designed for a variety of channel shapes • Rating curve can be determined from a mathematical model within two percent without laboratory calibration

4.2.1.2 Weirs

A weir is an overflow structure of specified geometry built across the flow path of a channel or conveyance. The section of the weir that is designed to overflow (the “crest”) can have several configurations; each one allows the water to flow over the weir in a controlled, predictable way that establishes the required depth-to-flow relationship. Some weirs are designed to overflow across their entire crest; others have a notch with a rectangular, trapezoidal, or “V” shape. Water pools against the weir plate and passes over it in a controlled way, such that the depth of water above the weir crest (head) at a specified location upstream of the weir is proportional to the rate of flow.

Figure 4-5 and Figure 4-6 show two common types of weirs and a schematic of a weir installation.

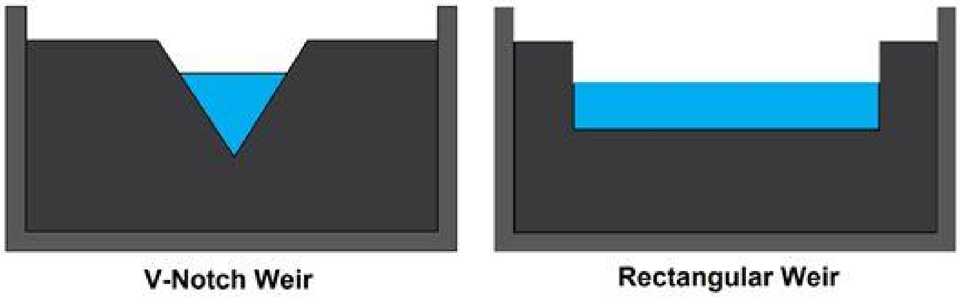


Figure 4-5 V-Notch and Rectangular Weirs Viewed from the Front

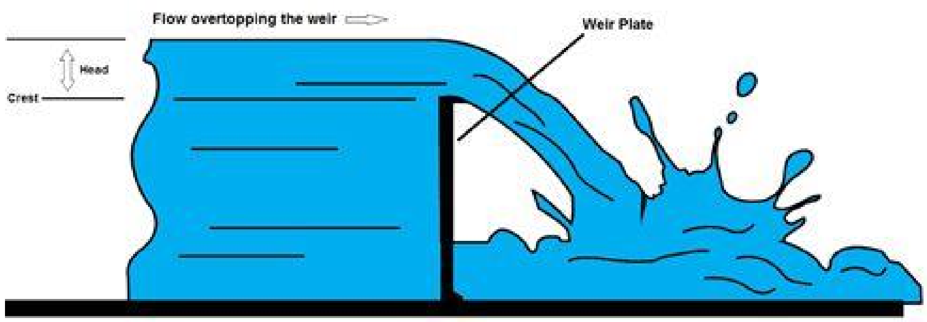


Figure 4-6 Weir Viewed from the Side

4.2.2 Flow Rate Measurement Without a Primary Flow Measurement Device

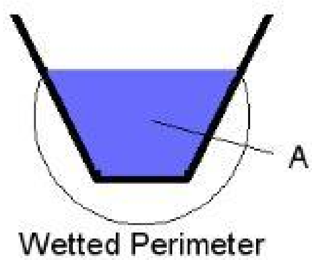
When it is not practical to install a primary device, the flow rate through an existing stormwater conveyance can be calculated from the measured depth using Manning's Equation, an empirical formula that estimates flow rate in a free-flowing channel or pipe.

Manning's Equation can be used in a channel or pipe of any geometry if the slope, roughness, depth of flow, and conveyance geometry are known. The cross-sectional area of flow and hydraulic radius terms (see equation below) are typically determined by measuring the depth of flow. The depth of flow can be measured manually or by using an automated flow meter, which also can be programmed to compute flow rate from the measured depth, using Manning's Equation:

$$Q = VA = \frac{1.49}{n} AR^{2/3} S^{1/2}$$

Where:

Q = Flow Rate (cubic feet /second)
V = Velocity (feet/second)
A = Cross-sectional area of flow (square feet) – see diagram
n = Manning's Roughness Coefficient
R = Hydraulic Radius (feet) = ratio of cross-sectional area of flow to wetted perimeter – see diagram
S = Channel Slope (feet/feet)



The roughness parameter in Manning's Equation is a measure of the resistance to flow offered by the walls of the conveyance. Estimated roughness coefficients for various kinds of conveyances are listed in Table 4-3.

It is also necessary that the depth in the approach be as equal as possible to the depth in the conveyance so that the depth of flow does not change near the point of measurement.

Use of Manning's Equation to compute flow in an existing pipe or open channel does not allow as precise an estimate of flow as can be achieved using a manufactured primary device such as a flume or weir. Real-world application of the Manning's Equation generally can achieve accuracy of ±25 to 30%. This flow-measurement method should only be used if it is not possible to install more accurate primary devices.

Table 4-3 Examples of Typical Manning Roughness Coefficients

Conveyance Type	Minimum	Typical	Maximum
Closed Conduit – partly full			
Corrugated storm drain	0.021	0.024	0.03
Brick-lined with cement	0.012	0.015	0.017
Concrete culvert, straight	0.01	0.011	0.013
Concrete culvert with bends, connections, and 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	0.02
Rubble masonry, cemented	0.018	0.025	0.03
Lined or Built-up Channels			
Corrugated metal	0.021	0.025	0.03
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	0.02
Cemented rubble masonry	0.017	0.025	0.03
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	0.03	0.04
Unmaintained channels	0.04	0.07	0.14
Natural Channels			
Fairly regular section	0.03	0.05	0.07
Irregular section with pools	0.04	0.07	0.1

Source: ISCO Open Channel Flow Measurement Handbook, 6th ed. (Teledyne ISCO 2008).

4.2.3 Bucket and Stopwatch Method

The bucket and stopwatch method is a fully manual flow measurement technique that can be used in low-flow conditions where there is free-fall of the flow from the end of a pipe. The method consists of simply catching a measured volume of flow in a bucket during a measured period. The flow is then calculated by dividing the volume of water in the bucket by the time recorded using this equation:

$$\text{Flow Rate} = \text{Volume of Sample Collected} / \text{Time}$$

When using this method, the discharge should be allowed to fill the bucket for at least 15 seconds. Longer measurement times usually result in more accurate flow measurement. For this reason, this method is suitable only for small or moderate flows that will not overflow a bucket quickly.

This flow-measurement method may also be used to check the results obtained from Manning's Equation in cases where the flow volume can be measured by both methods.

4.2.4 Float Velocity Method

The float velocity method is a fully manual method of measuring flow velocity. This method is commonly used in large channels such as rivers, especially when it is difficult to establish a stage-discharge relationship for a channel, and when it is not practical to install an area-velocity meter to measure flow velocity. The velocity measured via the float method is used in conjunction with some means of estimating cross-sectional area of flow to compute instantaneous flow rate.

To use this method, first it is necessary to determine the cross-sectional area of the flow at a specific location. This requires estimation of flow depth and width. Then field technicians mark two places on the bank of the channel at least five feet apart (using a longer distance between the two points will result in a more accurate flow measurement).

When this setup is complete, the flow can be measured by releasing a buoyant object into the channel upstream of the two marked points on the bank and measuring the time it takes to flow between them. The rate of flow can be calculated by the following formula:

$$\text{Flow Rate} = \frac{\text{Distance Between Points}}{\text{Traverse Time}} * \text{Cross Sectional Area}$$

There are some disadvantages to the float method: (1) measuring the cross-sectional area of a large natural water body can be difficult, and inaccuracies in this value will affect the accuracy of the flow measurement, and (2) the method measures velocity of flow only at the surface of a channel, which may not be representative of the velocity throughout the entire cross section of flow. Therefore, when using this method, multiple measurements should be taken at different points across the channel and the results averaged.

The accuracy of the float method is improved by using an object that has a similar density to water and that tends to float totally submerged. For example, oranges are good floating objects for this method because they are easy to see and environmentally safe.

As with the bucket-and-stopwatch method, this flow-measurement method may also be used to check the results obtained from Manning's Equation in cases where the flow volume can be measured by both methods.

4.2.5 Automated Flow Meters

Automated flow measurement is preferred for Caltrans stormwater monitoring projects, particularly when composite samples are collected.

The standard type of automated flow meter is principally used to measure depth of flow in a primary device or other structure. The measured depth is used to compute flow rate from information on primary device geometry, which is stored in the flow meter's memory. The "area-velocity" type of flow meter measures flow velocity as well as flow depth, for use in locations where a reliable stage-discharge relationship or rating curve has not been established.

The flow meter also serves as a data logger for storing discharge data, rainfall data, and sample history data. During storm events the flow meter records flow rate at pre-set intervals, and cumulatively sums the discharge volume for each monitoring event. Measured discharge is typically used by the flow meter to automatically trigger the autosampler to draw a sample aliquot each time a preset volume of runoff passes through a monitoring location. Flow meter functions may also include communication capabilities from an off-site location through telemetry. Figure 4-7 shows a combination flow meter/data logger of the type commonly used by Caltrans.

Flow meters can be programmed to compute flow rate by the methods described above, including the following:

- From measurement of the water depth in a primary flow measurement device (flume or weir), and computation of flow rate from the known depth-discharge relationship of the calibrated primary flow measurement device
- The product of the measured flow velocity and cross-sectional area of flow, (computed from the measured depth, based on the known conveyance geometry)

- From measurement of the water depth, applied to Manning's Equation in conjunction with the known conveyance geometry and other factors

Figure 4-7 Flow Meter/Data Logger

4.2.6 DEPTH MEASUREMENT

Flow meters measure the depth of water in a conveyance and convert this value to a flow rate using one of the techniques listed above. Caltrans uses three types of depth-based sensors:

Pressure Transducer – An electronic pressure sensor is placed at the bottom of a conveyance and attached to the flow meter by an electrical cable. As the water level in the primary device increases, the pressure on the sensor increases. The change in pressure is converted into water depth by the flow meter. Pressure transducers may also incorporate a thermometer to measure water temperature. The measured temperature is used to compensate for changes in water density, resulting in higher accuracy of flow measurement.

Bubbler –The bubbler flow meter uses a small air compressor that forces bubbles of pressurized air out of the end of a tube. The end of the tube is placed at the invert of a conveyance. As the water level rises, more pressure is required to force bubbles out the end of the tube, and this force is measured by the flow meter. The flow meter converts the pressure output to a water level reading. Bubblers are susceptible to error at high velocity where flow rates exceed five to six feet per second.

Ultrasonic Sensor – An ultrasonic sensor is placed above the flow stream. The sensor emits an ultrasonic pulse that bounces off the surface of the water. The time it takes for a pulse to bounce from the surface of the water back to the sensor is measured and converted into a water level. The flow meter converts this measurement of water level into depth.

Figure 4.8 illustrates the operation of these three kinds of flow measurement devices.

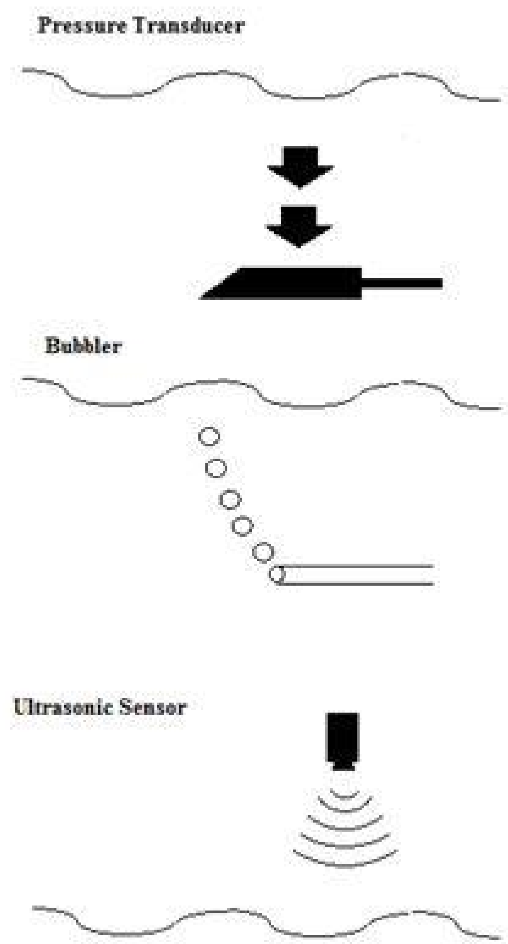


Figure 4-8 Depth-Based Flow Measurement Devices

Area-velocity type flow meters measure both the velocity of flow and depth of flow in a conveyance to calculate discharge. The area-velocity sensor is installed at the bottom of a pipe or channel.

Flow depth is measured either by an integrated bubbler or an ultrasonic sensor and is converted into cross-sectional area of flow based on the known geometry of the conveyance.

Flow velocity is measured by an integrated velocity sensor via an ultrasonic Doppler signal continuously transmitted into the water in the upstream direction. This high-frequency sound is reflected back to the sensor from particles or bubbles suspended in the liquid. If the fluid is in motion, the echoes return at an altered frequency that is proportionate to flow velocity. Area-velocity meters are useful when an existing stormwater conveyance must be used for flow measurement without a primary flow measurement device. They are also used when the flow is impeded by downstream conditions such as ponding; when this happens, the depth-to-flow relationship of the conveyance can be compromised, and it is necessary to know how fast the water is moving in order to calculate flow rate accurately.

Because an area-velocity sensor must be completely submerged in order to work properly, this technology is not useful for low-flow conditions. Although some manufacturers make area-velocity sensors with very flat profiles, this kind of flow measurement device is usually not preferred for very low flows.

Table 4-4 lists sensors suitable for various environmental conditions. Table 4-5 provides recommendations for secondary devices that may be used with different primary devices.

Table 4-4 Appropriateness of Level Sensors in Various Environmental Conditions

Sensor Type	Environmental Conditions
Bubbler Level Meter	• Not affected by wind, turbulence, liquid, surface foam, debris, or periods of dry weather. • Susceptible to error at high flow velocities (> five to six feet/second).
Pressure Transducer	• Affected by dry conditions between storms, contaminants in the water, debris, and freezing conditions.
Ultrasonic Depth Sensor	• Downward-facing sensors can be affected by wind conditions, loud noises, turbulence, and foam. • Upward-facing sensors are susceptible to interference from sediment and debris in the water. The minimum distance above the water necessary for installing these sensors is oftentimes not achievable in small spaces.
Area-Velocity Sensor	• Can be mounted in open channels or in locations with pressurized flow. • Accuracy is affected by high concentrations of suspended solids and low flow conditions when the probe is only partially submerged. • Some velocity meters may also have depth measurement capability.

Table 4-5 Recommendations for Selecting Secondary Flow Measurement Devices

Type	Ultrasonic Sensor	Pressure Transducer	Bubbler	Area-Velocity
Suitability for Different Applications				
Weirs and flumes	Excellent[1]	Excellent	Excellent	Excellent
Channels less than 6 inches deep	Not recommended	Excellent	Excellent	Not recommended
Small round pipes 6 to 8 inches in diameter	Good[2]	Excellent	Excellent	Good
Medium round pipes 10 to 15 inches in diameter	Good[2]	Excellent	Excellent	Excellent
Large round pipes 15 to 96 inches in diameter	Excellent[2]	Good	Excellent	Excellent
Irrigation channels and small streams	Excellent[2]	Good	Excellent	Good
Rivers and large streams	Excellent[2]	Good	Excellent	Good
Performance Under Adverse Conditions				
Strong wind	Not recommended	Excellent	Excellent	Excellent
Air temperature fluctuations	Very good[3]	Excellent	Very good[3]	Excellent
Foam on liquid	Not recommended	Excellent	Excellent	Excellent
Flow stream turbulence	Not recommended	Excellent	Excellent	Excellent
Floating debris	Not recommended	Excellent	Excellent	Excellent
Floating oil or grease	Not recommended	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 recommended	Not recommended	Not recommended	Excellent
Full pipe flow	Not recommended	Not recommended	Not recommended	Excellent
Surcharged flow	Not recommended	Not recommended	Not recommended	Excellent
Reverse flow	Not recommended	Not recommended	Not recommended	Excellent

Type	Ultrasonic Sensor	Pressure Transducer	Bubbler	Area-Velocity
Requirements Caused by Adverse Conditions				
Silting in	None	Occasional	Occasional	Occasional
Suspended solids	None	Occasional	Occasional	Occasional
High grease concentration	None	Occasional	Occasional	Occasional

Source: Teledyne Isco, Inc. (2008)

Notes:

[1] Use with caution in small flumes.

[2] Adequate space needed above for mounting sensor.

[3] Large air temperature fluctuations will affect accuracy.

[4] Large water temperature fluctuations will affect accuracy.

4.3 Precipitation Measurement

Precipitation can be measured manually by reading a standard rain gauge periodically or at the end of a storm event. Automated precipitation measurement uses a tipping bucket rain gauge and data logger for continuous recording of precipitation. If it is not possible to install a rain gauge at a monitoring site for some reason, other sources of precipitation data are available. For example, the USGS has rain gauges installed across California and they are a good resource for precipitation data.

Manual precipitation measurement is performed using a standard rain gauge. Field technicians can take multiple readings during a storm event to create a detailed record of rainfall throughout an event or take a single reading at the end of a storm to determine the total precipitation of the storm event.

Caltrans typically uses tipping bucket rain gauges to measure precipitation at automated stormwater monitoring stations. A tipping bucket rain gauge consists of a cylinder with a funnel built into the top. As rain falls it lands in the funnel and drips into one of two small buckets that are balanced under the funnel on a pivot, like a seesaw. When the first bucket has filled to a specific, calibrated volume, its weight causes the mechanism to tip, emptying the first bucket and aligning the second bucket under the funnel. This happens each time a bucket fills. Each “tip” is recorded by a sensor attached to the pivot, which sends a signal to the data logger. Figure 4-9 shows a tipping bucket rain gauge installed in the field.

Continuously recorded precipitation data can be superimposed on flow data in a hydrograph/hyetograph to provide a comprehensive overview of a storm event. Comparing precipitation volumes to runoff volumes can be helpful when investigating the hydrology of a monitoring site.

Figure 4-9 Tipping Bucket Rain Gauge

4.4 Field Measurements of Water Quality

The most commonly performed field tests for stormwater are temperature, pH, conductivity, dissolved oxygen, and sometimes turbidity. Results of these tests are considered “grab” sample data since they are performed on a single sample collected from the runoff stream at a single point in time.

A variety of instruments are available that can be placed directly in the runoff stream and provide measurements of these constituents. The instruments are available both as hand-held field meters for manual measurement by field technicians and as automated probes that connect into the data logging features of automated flow meters. These instruments can be connected to a data logger that records data either as discrete events (in manual operation) or continuously over the life of a monitoring event (in automated operation).

An important advantage of these instruments is that they make it possible to collect data for every storm event, including short-duration events that would otherwise be impractical to monitor. They also collect data continuously over the life of a storm event, which is a more accurate representation of the entire discharge than “grab” tests performed manually.

There are some drawbacks to using these devices. Field measurements are not subject to the same level of quality control that a laboratory uses when analyzing samples, so the data they produce are not as reliable. The sensors are subject to clogging or fouling from algae, sediment, and debris, and must be maintained regularly in order to work properly. Some of these devices may require relatively large flows to provide accurate data. And some types of sensors cannot be allowed to dry out, which makes them impractical for long-term field use.

The use of field instruments for stormwater analysis is discussed in more detail in Appendix I.

4.5 Telemetry

Automated monitoring stations can be equipped with telemetry, which allows them to be accessed remotely. Telemetry systems typically are comprised of a wireless transmitter/receiver and antenna that can communicate via a wireless link to a remote computer. The transmitter/receiver is connected to the communication port on the sampling equipment. Although third-party products exist that can interface with monitoring equipment and communicate over radio, landline, and the internet, Caltrans typically uses telemetry equipment that communicates via cell phone. Telemetry units must be compatible with the monitoring equipment so that various pieces of equipment work together efficiently and reliably.

Using telemetry, field technicians at a central location can program monitoring stations for impending storm events, check station operational status, and place stations in standby mode so they begin operating automatically when a storm starts.

During a monitoring event, field personnel can use a cell phone to check the remaining battery power at a monitoring station, find if any errors have occurred, determine how full the composite sample containers are, and check other details about the operational status of the station. Using this technology, a single field crew can operate several monitoring stations during a storm event, because they can check on a site without having to travel to the site. This can greatly reduce the number of times field personnel must visit each site during a storm event.

Site telemetry has a few drawbacks. Cell coverage is not always available at every monitoring site, and is sometimes sporadic, even if it exists. Some kinds of errors do not trigger and might not be picked up by a telemetry unit; for example, clogged bubbler or sampler lines can cause serious problems with flow measurements that are not registered by a telemetry unit. Although remote communications equipment is very useful and can significantly increase productivity, it is no substitute for site visits by trained field personnel. Therefore, it is recommended that monitoring stations be inspected by personnel at least every four hours during a monitoring event.

4.6 Power Supply Equipment

Field monitoring equipment typically operates on 12-volt battery power. Although most manufacturers offer adaptors for use with 110-volt power sources, it is almost never practical to install landline 110-volt power to stormwater monitoring sites. Instead, Caltrans normally uses deep-cycle marine batteries to power monitoring equipment and solar panels to keep the batteries charged.

A deep-cycle battery is designed to be charged and discharged repeatedly over its entire operational life. Deep-cycle batteries can be repeatedly charged and discharged from 20 to 80% of their capacity without degrading their functionality or sustaining damage. This makes them ideal for powering stormwater monitoring sites because they can be charged from low, continuous current from a solar panel and can power equipment for long periods during a storm. The design of a deep-cycle battery is different from starting (or automotive) batteries, which are designed to provide a large burst of power quickly but not to trickle power continuously for long periods. Deep-cycle marine batteries are a hybrid of deep-cycle and starting designs.

A solar panel is used to charge the batteries in conjunction with a voltage regulator, which is installed between the solar panel and the battery. A voltage regulator prevents the battery from overcharging during sunny weather, when the monitoring equipment is not drawing current, and from being completely depleted during storms. Both overcharging and discharging too deeply can damage a deep-cycle battery.

4.7 Data Logging and System Integration

The many kinds of automated monitoring devices discussed in this chapter must work in coordination with each other. One piece of equipment must act as a controller and data logger for all these devices to control them, coordinate their operations, and record the data they produce. Data records from each monitoring event are stored on the data logging system at each station. These records contain information used for creating hydrographs, hyetographs, and sample history.

Data logging functionality is built into many flow meters and automatic samplers and can also be provided by third-party hardware. Built-in functionality of monitoring equipment may be less expensive than third-party hardware, and using equipment designed by a single manufacturer usually ensures a more efficient and reliable system.

For more complex programs, dedicated data loggers may be used to record data from multiple sensors or for better programming flexibility. Such data loggers for field use typically comprise a central processing unit (CPU) or microprocessor, random-access memory (RAM) for recording data, one or several data input ports, a data output port, a power source, and an internal telephone modem. Most data loggers have an input panel or keyboard and a display screen for field programming. The CPU processes the input data for storage in RAM, which must have an internal backup power source (such as a lithium-ion battery) to ensure data are not lost in the event of a primary power failure. Data stored in RAM are retrieved by downloading to a portable personal computer or to an offsite computer via modem.

Most data loggers can be programmed in the field as well as remotely via telemetry to record data at user-selected intervals, trigger sample collection at specified intervals, and communicate alarms based on pre-set criteria.

4.8 Security Enclosures

Stormwater monitoring stations containing automated monitoring equipment require a proper protective enclosure that can be locked, is resistant to vandalism and tampering, and provides protection from the elements.

There are many different styles of enclosure that are suitable for stormwater monitoring installations. They can be made of plastic, fiberglass, or metal, and come in various sizes and shapes. Monitoring enclosures should be selected based on conditions at the monitoring site. For example, in areas where equipment tampering is a concern, protective enclosures can be made of metal and surrounded with chain-link fencing with a locked gate and razor wire along the top. Refrigerated enclosures are available that keep samples cool without the need for ice. Taller, outhouse-style enclosures provide a sheltered area where field technicians can work, which can be convenient.

Some areas may be regulated by state or local agencies that only allow smaller, less obtrusive enclosures on site. Some agencies require enclosures be painted a particular color to blend in with the surroundings. The consultant should check with local agencies before installing a monitoring station to obtain any aesthetic guidelines or other requirements for the appearance of a monitoring station.

4.9 Damaged, Lost, and Stolen Equipment

Monitoring consultants are responsible for keeping track of Caltrans-owned equipment in their custody, and for assuring all equipment is returned to Caltrans when it is no longer needed. Occasionally equipment is damaged in the field. When this happens, the consultant must report the incident to the Caltrans Task Order Manager as soon as possible so the equipment can be replaced and the damaged piece of equipment can be removed from inventory.

Sometimes monitoring equipment is vandalized or stolen. When a piece of equipment is stolen, the consultant must take the following actions:

- Notify the Caltrans Task Order Manager immediately. The Task Order Manager will provide instructions on how to proceed.
- Write a brief memorandum describing the equipment and the theft, including any other pertinent information.
- Report the theft to the local California Highway Patrol office and obtain a police report.

The memorandum and the police report should be forwarded to the Caltrans Task Order Manager as soon as they are available.

4.10 Checking Out and Returning Monitoring Equipment

Caltrans operates two storage yards for stormwater monitoring equipment and supplies. One is located at the intersection of 28th and X Streets in Sacramento and the other is located at 6533 Marine Way in Irvine. Monitoring consultants check equipment out of these two locations and return it for storage when it no longer needed.

Neither of these storage facilities is staffed, so equipment pickups and drop-offs must be scheduled in advance. Consultants must notify their Caltrans Task Order Manager to arrange a date and time to pick up or drop off equipment. Access to the Sacramento facility can usually be arranged any time with a few days' advance notice. The facility in Irvine is open on pre-scheduled days about six times per year, and monitoring consultants coordinate with Caltrans to pick up and drop off equipment on those days.

4.10.1 Checking Out Monitoring Equipment

Consultants request monitoring equipment by filling out an Equipment Checkout Form and emailing it to the Caltrans Task Order Manager. The Equipment Checkout Form lists the type and quantity of equipment being requested. The Task Order Manager checks availability and coordinates a date and time to meet at one of the storage yards. The Equipment Checkout Form shown in Figure 4.10 is available for download on the Caltrans Online Equipment Inventory web site (http://www.owp.csus.edu/ct_inventory).

Caltrans Equipment Checkout Form

Date of Equipment Transfer:			
Consultant Name:			
Contract #:		Task Order #:	
Project:			
Field Technician Name:			

Barcode	Manufacturer	Model	Serial	Part Number	Description	Comments
SW-						
SW-						
SW-						
SW-						
SW-						
SW-						
SW-						
SW-						
SW-						
SW-						

Figure 4-10 Equipment Checkout Form

The consultant must bring a printed copy of the Equipment Checkout Form when meeting Caltrans at the storage yard. Each piece of equipment transferred is checked against the form and the equipment ID (the field beginning with "SW-") is recorded. The consultant signs the completed form to certify they have taken custody of the equipment.

4.10.2 Returning Monitoring Equipment

When returning equipment to Caltrans custody, the consultant fills out an Equipment Turn-In Form that lists each piece of equipment to be turned in. The consultant emails the form to the Caltrans Task Order Manager, who then coordinates a date and time to meet at the storage yard. The Equipment Turn-In Form shown in Figure 4-11 is available for download on the Caltrans Online Equipment Inventory web site (http://www.owp.csus.edu/ct_inventory).

The consultant must bring a printed copy of the Equipment Turn-in Form when meeting Caltrans at the storage yard. Each piece of equipment that is returned can be checked off on the form and then a Caltrans representative will sign the form as having received the equipment. The form becomes the consultant's permanent record that the equipment has been returned to Caltrans custody.

Caltrans Equipment Turn-In Form

1) Fill out this form a completely as you can. This form must be filled out electronically, not by hand.
2) Shaded items are required.
3) Fill out this form before the equipment is turned in. Print a copy and bring it with you when you turn in equipment so that the equipment can be checked off against this list.
4) In the "Description" column, put the type of instrument (Sampler Pump, Rain Gauge, etc.)
5) If the Description is "Flow Meter", include the kind of flow meter it is; for example, "Flow Meter - Bubbler" or "Flow Meter - Ultrasonic". In the comments column, include any inputs or other features, such as "Rain Gauge Input" or "Extended Memory".
6) Include any comments you think might be useful.
7) In the "Deployable" column, enter "Y" if the equipment can be used as is, or "N" if you have any reason to think that the equipment has a problem that should be looked at before it is put back into the field. **If you put "N" in the "Deployable" column, you must enter a comment describing the problem.**
8) Print out a copy of this completed form and bring it with you when you turn in the equipment. This will be used as a checklist.
9) This completed form must be submitted via email to the Caltrans Task Order Manager no later than three days after the equipment transfer has been completed.

Date of Equipment Transfer:			
Consultant Name:			
Contract #:		Task Order #:	
Project:			
Field Technician Name:			

Barcode	Manufacturer	Model	Serial	Part Number	Description	Deployable	Comments
SW-							
SW-							
SW-							
SW-							
SW-							
SW-							
SW-							
SW-							
SW-							
SW-							
SW-							

Figure 4-11 Equipment Turn-In Form

5 Analytical Methods and Laboratory Selection

Once constituents have been selected, it is necessary to specify analytical methods and select a laboratory or laboratories to perform the analyses.

Laboratories vary widely in their capabilities and the services they offer. A laboratory that is right for one project may not be for another. This chapter describes the characteristics of environmental laboratories that should be considered when selecting a lab for a monitoring project.

Additional information regarding analytical protocols and laboratory procedures appears in Appendix M. Project managers should be familiar with the basics of water quality analysis to better understand and interpret laboratory data and to facilitate knowledgeable and constructive guidance to the lab.

The following topics are covered in this chapter:

- Analytical methods
- Laboratory selection
- Understanding laboratory data

5.1 Analytical Methods

It is the laboratory's responsibility to ensure that samples are analyzed using the specified and approved methodologies, and to produce data consistent with regulatory requirements, approved quality assurance/quality control (QA/QC) protocols, and industry best practices. Nevertheless, a working knowledge of environmental laboratory methods helps project managers and monitoring personnel to properly specify laboratory analytical requirements, communicate with laboratory personnel, and interpret results.

Appendix M provides a review of some of the more common analytical methods laboratories use to test stormwater samples. Project team members should familiarize themselves with this material. This material is intended only as an introduction for stormwater professionals who may not be familiar with laboratory methods.

NPDES permits require permittees to use EPA-approved analytical methods that are sensitive enough to quantify pollutants at or below applicable water quality criteria.

5.1.1 Considerations for Method Selection

Most Caltrans stormwater monitoring projects include analyzing samples for a standard set of water quality constituents using established analytical methods. Constituents are discussed in Chapter 3 and standard analytical methods are shown in Table 5-1.

However, project managers should review the analytical methods proposed for each new monitoring project, even if they have been used on previous projects. Laboratory technology changes over time, and there may be improvements in methodology that could be used to improve data quality.

Certain monitoring projects may have special requirements, and it may be necessary to review available analytical methods to satisfy those requirements. For instance, a project may require measurement of a constituent that is new or unusual for stormwater monitoring, and a new analytical method may be required.

When evaluating standard analytical methods or selecting new ones, the following questions should be answered:

- Does the method conform to the legal or regulatory requirements that apply to the project?
- Is the method appropriate for stormwater samples?
- Can the method meet the project Data Quality Objectives (reporting limits and QA/QC requirements)?
- Will the data produced by the method be comparable to historical data?
- Is the method recognized by the appropriate accreditation agency, and is the laboratory properly accredited?

Method references for most common stormwater monitoring constituents appear in Table 5-1. It is important to note that the decision to use methods that are not appropriately accredited, or to use laboratories that are not accredited for all of the methods they use, must be approved by the Caltrans Task Order Manager.

5.1.2 Considerations for Method Selection in TMDL Areas

If the monitoring location lies within one or more TMDL areas, then the TMDLs must be checked to determine if they specify preferred analytical methods.

- If an analytical method has been specified in the TMDL resolution or Basin Plan Amendment, the laboratory should be consulted to confirm they can satisfy the appropriate water quality objective or TMDL target detection limit using that method. The TMDL resolutions and Basin Plan Amendments are listed in Attachment IV of Caltrans Permit (Order WQ 2014-0077-DWQ).

- If an analytical method has not been specified in the TMDL resolution or Basin Plan Amendment, the laboratory should use a method that complies with 40 C.F.R. §136 methods (40 CFR Part 136 Analytical Methods) and ensure the reporting limit will meet the appropriate water quality objective or TMDL target concentration.
- The Caltrans Task Order Manager must be notified if a method is not specified in the TMDL documents and the approved 40 C.F.R. §136 method(s) are unable to meet the water quality objective or TMDL target concentration.
- There are cases where a TMDL specifies an acceptable analytical method, but where other method exist that can reach significantly lower detection limits. In these cases, the Caltrans Task Order Manager should be notified so Caltrans can consider using the alternate method.

This applies only to TMDL constituents, not to constituents listed in Attachment II of the Caltrans Permit. However, the approach described here should be used for any TMDL constituent already listed in Attachment II of the Permit. If there is a conflict between the TMDL and Attachment II of the Permit, the method specified in the TMDL should take precedence.

5.1.3 Comparability of Different Methods

Many Caltrans stormwater monitoring constituents may be analyzed by more than one method. In many cases, both Standard Methods (Standard Methods, 2012) and the United States Environmental Protection Agency may have written methods for a constituent. Other sources such as the American Society for Testing and Materials (ASTM) may also have methods that can be used to conduct these analyses.

Sometimes different methods for a single analyte may be very similar or even identical; in other cases, methods may differ significantly in the chemistry or technology they employ. Different methods have the potential to produce results for the same constituent that are substantially different from each other. This must be considered when selecting which analytical method to use.

The Caltrans NPDES permit contains a list of standard constituents that should be tested for at all monitoring sites. This list includes the analytical method that should be used. Other water quality regulations such as California Ocean Plan may specify analytical methods that must be used. For monitoring projects conducted to comply with these regulations the analytical method that is specified in the regulatory language should be used.

There are circumstances in which it may be acceptable to use analytical methods other than those specified by the regulatory language. For example, the test for coliform bacteria must be started within eight hours of sample collection, which is usually a logistical challenge for the field technicians and the laboratory. If a laboratory receives samples with a very short period to begin the test, and if they are only prepared to perform the test using a method that allows a longer hold time than the one specified on the chain-of-custody form, the laboratory should proceed with the alternate method to avoid exceeding the hold time for the analysis. This change must be noted in the laboratory report and the electronic data deliverables.

Some analytical methods may have advantages over others. A frequently encountered example in Caltrans stormwater monitoring concerns Total Suspended Solids (TSS) analysis. Both Standard Methods and USEPA have written methods for TSS, and the methods are identical. However, ASTM has developed a slightly different method called Suspended Sediment Concentration (SSC), which is identical to the other methods except the laboratory is required to analyze the entire sample rather than a subsample. There is general agreement that this makes the ASTM method more reliable than the others. So, when a monitoring project requires that samples be analyzed for suspended solids and the results must be as accurate as possible, Caltrans may consider using the ASTM method, even though the permit specifies the USEPA method.

There are cases where laboratory technology improves more quickly than the regulations can adapt. For example, many methods for organic substances such as pesticides and PCBs have been superseded by improvements in method EPA 8270/625. Newer technology and methodology can achieve detection limits that are an order of magnitude lower than the methods that appear in the regulations. Regulatory agencies are expected to eventually adopt the newer methodologies. In the meantime, Caltrans commonly directs the labs to use the newer methods, even if the older methods are still referenced in the regulatory language.

Any deviation from the methods specified in the permit or in local regulations must be approved in advance by Caltrans. If a consultant has reason to believe an alternate method might be better, the substitution should be discussed with the Caltrans Task Order Manager before the monitoring season begins.

Table 5-1 Common Monitoring Constituent Method Information

Analyte	Recommended Analytical Method	Holding Time	Container Type[1]	Preservation	Recommended Reporting Limit[8]	Units
Physical and Aggregate Properties						
BOD	5210B	24 hours	Glass or PE	Between 0 and 6˚C	3	mg/L
COD	EPA 410.3; EPA 410.4; SM 5220B, C, D	28 days	Glass or PE	Between 0 and 6˚C HNO_3 or H_2SO_4 to pH<2	10	mg/L
Conductivity	SM 2510B	28 days	Glass or PE	Between 0 and 6˚C	±1	uS/cm
Hardness as $CaCO_3$	SM 2340B	6 months	Glass or PE	HNO_3 or H_2SO_4 to pH<2	2	mg/L
pH	EPA 150.2; SM 4500-H+B-2000	Field/Immediate[2]	N/A	N/A	±0.1	pH units
Temperature	SM 2550B	Field/Immediate[2]	N/A	N/A	±0.1	˚C
TOC; DOC	SM 5310B, C, D-2000	28 days	Glass or PE	Between 0 and 6˚C HNO_3 or H_2SO_4 to pH<2	1	mg/L
TDS	SM 2540C-1997	7 days	Glass or PE	Between 0 and 6˚C	1	mg/L
TSS	SM 2540D-1997	7 days	Glass or PE	Between 0 and 6˚C	1	mg/L
Turbidity	EPA 180.1; SM 2130B-2001	48 hours	Glass or PE	Between 0 and 6˚C	0.5	NTU
Fine Sediment Particles	SM 2560 D/ Manufacturer's Instructions	36 hours	Glass or PE	Between 0 and 6˚C	None	Particles/mL
Nutrients						

Analyte	Recommended Analytical Method	Holding Time	Container Type[1]	Preservation	Recommended Reporting Limit[8]	Units
NH_3-N	EPA 350.2; EPA 350.3	28 days	Glass or PE	Between 0 and 6˚C H_2SO_4 to pH<2	0.1	mg/L
NO_3-N	EPA 300.0, 300.1-1, Rev 1.0 (1997); SM 4500-NO3-E-2000	48 hours	Glass or PE	Between 0 and 6˚C	0.1	mg/L
NO_2-N	EPA 300.0, Rev 2.1 (1993) and 300.1-1, Rev 1.0 (1997)	48 hours	Glass or PE	Between 0 and 6˚C	0.1	mg/L
Phosphorus	EPA 365.2	28 days	Glass or PE	Between 0 and 6˚C H_2SO_4 to pH<2	0.03	mg/L
Orthophosphate-P	EPA 365.3; 300.1-1, Rev 1.0 (1997)	48 hours	Glass or PE	Between 0 and 6˚C filter immediately	0.03	mg/L
Kjeldahl Nitrogen	SM 4500-NorqB-1997 or C-1997 and 4500-NH3B-1997	28 days	Glass or PE	Between 0 and 6˚C HNO_3 or H_2SO_4 to pH<2	0.1	mg/L
Metals						
Aluminum	EPA 200.8	See Footnote 9	Teflon®, PE, or Borosilicate Glass	Between 0 and 6˚C HNO_3 to pH < 2	25	ug/L
Arsenic	EPA 200.8	See Footnote 9	Teflon®, PE, or Borosilicate Glass	Between 0 and 6˚C HNO_3 to pH < 2	1	ug/L
Cadmium	EPA 200.8	See Footnote 9	Teflon®, PE, or Borosilicate Glass	Between 0 and 6˚C HNO_3 to pH < 2	0.2	ug/L
Chromium	EPA 200.8	See Footnote 9	Teflon®, PE, or Borosilicate Glass	Between 0 and 6˚C HNO_3 to pH < 2	1	ug/L
Copper	EPA 200.8	See Footnote 9	Teflon®, PE, or Borosilicate Glass	Between 0 and 6˚C HNO_3 to pH < 2	1	ug/L
Iron	EPA 200.7; EPA 200.8	See Footnote 9	Teflon®, PE, or Borosilicate Glass	Between 0 and 6˚C HNO_3 to pH < 2	25	ug/L

Analyte	Recommended Analytical Method	Holding Time	Container Type[1]	Preservation	Recommended Reporting Limit[8]	Units
Lead	EPA 200.8	See Footnote 9	Teflon®, PE, or Borosilicate Glass	Between 0 and 6˚C HNO_3 to pH < 2	1	ug/L
Nickel	EPA 200.8	See Footnote 9	Teflon®, PE, or Borosilicate Glass	Between 0 and 6˚C HNO_3 to pH < 2	2	ug/L
Selenium	EPA 200.8	See Footnote 9	Teflon®, PE, or Borosilicate Glass	Between 0 and 6˚C HNO_3 to pH < 2	2	ug/L
Silver	EPA 200.8	See Footnote 9	Teflon®, PE, or Borosilicate Glass	Between 0 and 6˚C HNO_3 to pH < 2	0.2	ug/L
Zinc	EPA 200.8	See Footnote 9	Teflon®, PE, or Borosilicate Glass	Between 0 and 6˚C HNO_3 to pH < 2	5	ug/L
Mercury	EPA 245.1; SM 3112B	28 days to analysis	Teflon® or Glass	Between 0 and 6˚C 5 ml/L 12N HCl	0.2	ug/L
Low-Level Mercury	EPA 1631	28 days to analysis	Low-level Mercury Collection Kit[3]	Between 0 and 6˚C Collection Kit[3]	0.5	ng/L7
Total Petroleum Hydrocarbons (TPH)						
TPH (gasoline)	EPA 8015M; EPA 8260	14 days	VOA Vial	Between 0 and 6˚C	50	ug/L
TPH (diesel)	EPA 8015M	Extract - 7 days; Analyze - 40 days	Amber Glass[5]	HCL to pH < 2	50	ug/L
TPH (motor oil)	EPA 8015M	Extract - 7 days; Analyze - 40 days	Amber Glass	HCL to pH < 2	50	ug/L

Analyte	Recommended Analytical Method	Holding Time	Container Type[1]	Preservation	Recommended Reporting Limit[8]	Units
Oil and Grease	EPA 1664	28 days	Amber Glass	Between 0 and 6˚C HCl or H_2SO_4 to pH<2	5	mg/L
Pesticides and Herbicides						
OP Pesticides	EPA 8141; ELISA	Extract - 7 days; Analyze - 40 days	Amber Glass	Between 0 and 6˚C	0.05	ug/L
OC Pesticides	EPA 8082	Extract - 7 days; Analyze - 40 days	Amber Glass	Between 0 and 6˚C	0.05 -1.0	ug/L
Chlorinated Herbicides	EPA 8151	Extract - 7 days; Analyze - 40 days	Amber Glass	Between 0 and 6˚C	0.1-1.0	ug/L
Carbamate Pesticides	EPA 8321	Extract - 7 days; Analyze - 40 days	Amber Glass	Between 0 and 6˚C	0.07 - 3.5	ug/L
Miscellaneous Organic Constituents						
Volatile Organics	EPA 624; EPA 8260	14 days	VOA Vial	Between 0 and 6˚C	0.5 - 50	ug/L
Semivolatiles	EPA 625; EPA 8270	Extract - 7 days; Analyze - 40 days	Amber Glass	Between 0 and 6˚C	0.05 to 0.256	ug/L
Polynuclear Aromatic Hydrocarbons	EPA 8310	Extract - 7 days; Analyze - 40 days	Amber Glass	Between 0 and 6˚C	0.05	ug/L
Microbiology						
Fecal Coliform	SM 9221E	8 hours	Sterile Plastic	Between 0 and 6˚C Sodium thiosulfate	2	MPN (CFU/100 mL)
Total Coliform	SM 9221B	8 hours	Sterile Plastic	Between 0 and 6˚C Sodium thiosulfate	2	MPN (CFU/100 mL)

Analyte	Recommended Analytical Method	Holding Time	Container Type[1]	Preservation	Recommended Reporting Limit[8]	Units
Enterococcus	SM 9230B	24 hours	Sterile Plastic	Between 0 and 6˚C Sodium thiosulfate	1	MPN (CFU/100 mL)
Acute Toxicity						
Water Flea	EPA 821-R-02-012	36 hours	Plastic or Glass[4]	Between 0 and 6˚C	Survival (Endpoint)	N/A
Fathead minnows	EPA 821-R-02-012	36 hours	Plastic or Glass[4]	Between 0 and 6˚C	Survival (Endpoint)	N/A
Rainbow trout	EPA 821-R-02-012	36 hours	Plastic or Glass[4]	Between 0 and 6˚C	Survival (Endpoint)	N/A
Chronic Toxicity						
Water Flea	EPA 821-R-02-013	36 hours	Plastic or Glass[4]	Between 0 and 6˚C	Pass/Fail	N/A
Fathead minnow	EPA 821-R-02-013	36 hours	Plastic or Glass[4]	Between 0 and 6˚C	Pass/Fail	N/A
Green algae	EPA 821-R-02-013	36 hours	Plastic or Glass[4]	Between 0 and 6˚C	Pass/Fail	N/A

[1] PE – Polyethylene

[2] Field analyses should be performed on a grab sample collected from the discharge stream during the storm event.

[3] Low-level mercury must be collected directly into pre-cleaned, preserved sample containers obtained from the laboratory.

[4] Toxicity laboratories normally provide special containers called Cubitainers that are ideal for collection and transport of toxicity samples.

[5] Some laboratories may prefer volatile organic analysis (VOA) vials to wide-mouth glass containers. Check with the laboratory for the preferred container type.

[6] Reporting limits for semi-volatile hydrocarbons may vary considerably between laboratories, and common laboratory contaminants such as phthalates may have much higher reporting limits than this range.

[7] ng/L – Nanograms per liter

[8] Lab results are reported based on MDL which is much lower than RL indicated in this table.

[9] Filter for dissolved fraction and preserve within 24 hours; six months to analysis.

5.2 Laboratory Selection

Stormwater monitoring studies sometimes have specific requirements that some environmental labs may not be able to satisfy. Several important items need to be considered when selecting a laboratory such as laboratory accreditation; experience in analysis of stormwater samples and project-specified analytical methods; and ability to meet project-specified analytical reporting limits, logistics, subcontracting, data reporting, and cost. It is important that an experienced project manager and a staff chemist be involved in the laboratory selection process, particularly if the study includes atypical analytical or reporting requirements.

5.2.1 Laboratory Accreditation

Environmental laboratories in California must be accredited in order to produce data for state agencies, including Caltrans. California labs are accredited either by the California Department of Public Health through the Environmental Laboratory Accreditation Program (ELAP), or by the national equivalent, the National Environmental Laboratory Accreditation Program (NELAP). Only data produced from ELAP- or NELAP-accredited laboratories are acceptable for regulatory purposes.

Laboratories are accredited for each individual test they perform. When selecting a laboratory, the monitoring consultant must verify the lab is accredited for every required constituent. This should be done by providing the laboratory with a copy of the QAPP and requesting the lab verify in writing that they are accredited for all constituents required for the project.

There may be times when a required constituent cannot be analyzed by an accredited laboratory or method. For example, Caltrans may occasionally perform monitoring studies, for research purposes, that utilize methods that are not recognized by ELAP or NELAP. These may include ASTM methods or DNA tests for identifying pathogenic bacteria. In other instances, there may be a need to achieve extremely low reporting limits for some constituent that are beyond the capabilities of certified commercial labs.

The decision to use non-accredited analytical methods or laboratories must be approved by the Caltrans Task Order Manager.

5.2.2 Experience with Stormwater Samples and Analytical Methods

It is important for the selected laboratories to have experience in analysis of stormwater samples, because the stormwater matrix is somewhat different from other types of water quality samples, such as those for drinking water. An experienced laboratory will have knowledge of how to handle potential issues associated with stormwater samples, such as matrix interference, the expected range of results for dilution purposes, and other matrix-related technical issues.

It is similarly important for the laboratory to have the necessary analytical equipment and an established record of performance with the project-specified analytical methods.

5.2.3 Analytical Reporting Limits

For every constituent, the laboratory establishes a minimum concentration that can be reliably quantified using a given analytical method. These minimum concentrations, usually called reporting limits (RLs), can vary considerably from method to method and from lab to lab. When choosing a laboratory for a monitoring project it is important to ensure the lab's reporting limits are low enough to meet the data quality objectives (DQOs) of the study. For example, if the project DQOs state that copper must be reported at a level of 1.0 microgram per liter (µg/L) or lower, then any laboratory with a reporting limit for copper higher than 1.0 µg/L would not be suitable for the project.

As of 2008, Caltrans has required all chemistry results be reported at the method detection limits (MDLs), where applicable. The MDL is the lowest concentration that can be resolved from method baseline noise with a 99% confidence in a sample that does not contribute any matrix effect except for special circumstances. MDLs are lab- and method-specific and can vary widely from lab to lab. The RL is set for each analyte by the individual lab and is greater than the MDL.

A laboratory's MDLs change periodically, but their RLs will remain constant indefinitely; for this reason, a project's DQOs should specify required reporting limits for project constituents but should not address MDLs.

5.2.4 Logistics

Following are important logistical considerations that bear on laboratory selection:

- Sample delivery/transport options
- Sample container service
- Laboratory capacity
- Sample handling and preparation processes
- Composite carboy cleaning

- After-hours sample receiving

Samples must be transported to the laboratory as quickly as possible after collection. This is particularly important for constituents that must be analyzed within a short period of time after collection. This logistical constraint is important to consider when selecting a laboratory for a monitoring project.

Many environmental laboratories offer free sample courier service. Laboratory personnel can often pick up samples at consultants' offices and even at monitoring sites. The coverage areas and required lead times for these services vary from lab to lab, so it is necessary to determine the details of this service before the project starts, and to make sure field personnel are familiar with them. Laboratory courier services should be used whenever possible to lower costs.

Laboratories usually supply sample containers at no extra cost. Monitoring consultants should always use sample containers supplied by the laboratory. Besides saving the cost of purchasing sample containers, the bottles supplied by the lab are certified to be clean and contain the correct preservatives for each analysis.

The laboratory must have capacity to accept and analyze the volume of samples to be expected after a heavy storm event. One laboratory may have many stormwater monitoring clients, and these clients usually all submit samples immediately after a storm. It is essential to select a laboratory that will not be overwhelmed by large numbers of samples at the same time. Longer sample acceptance and analysis hours should be negotiated if this is likely to be a problem.

During the laboratory selection and contracting process, it is important to discuss the laboratory's responsibilities for sample handling and preparation. For example, some water quality and toxicity test methods require sample filtration prior to analysis. For composite sampling, the laboratory is required to split the composite sample into the appropriate container for each required analysis and add preservatives if necessary. In some cases, multi-bottle compositing is also performed by the laboratory. These and other project-specific sample preparation issues should be discussed with the laboratory before the monitoring phase of the project begins.

Most Caltrans monitoring projects involve collecting composite samples in large carboys, and these carboys must be cleaned thoroughly between uses. A laboratory should be selected that can clean carboys using the standard Caltrans bottle-cleaning protocol, and that can clean large numbers of carboys quickly enough so that the monitoring consultant has them ready for the next storm.

Laboratories' hours of operation also vary. It is important to select a laboratory that is open to receive samples (or has a courier service to transport samples) in the evenings and on weekends, when stormwater samples are often collected. It is also necessary for a stormwater laboratory to have weekend staff available to perform analyses that must be performed immediately, such as pH, turbidity, and microbiological analyses.

5.2.5 Subcontracting

It is not unusual for laboratories to subcontract some tests to other labs. This may be done because the primary lab is not accredited for all the required analyses, because the primary lab cannot meet the required reporting limits or turnaround times for some analyses, because the primary lab is overloaded, or for other reasons. While subcontracting among laboratories is a common and acceptable practice, it raises issues about which the project manager and field technicians should be made aware.

If a primary laboratory proposes to subcontract some analyses, the subcontractor lab must be accredited to perform all analyses that they will perform on the project. Before the project begins, the project manager should establish with the primary laboratory what subcontract labs, if any, they normally work with, and obtain a Statement of Qualifications (SOQ) from each lab. The SOQ is a document that describes the capabilities and certifications of a laboratory, including a list of each individual analysis it is certified to perform. When the monitoring consultant receives a lab report that includes data from a subcontract lab, the project manager should check the subcontract laboratory's SOQ to make sure the work was done in accordance with ELAP/NELAP requirements.

Samples that must be analyzed within a short period of time after collection should not be subcontracted unless necessary. Tests such as turbidity and orthophosphate, which must be analyzed within 48 hours of sample collection, are very difficult to transfer between labs in time for the subcontract lab to perform the analyses without exceeding holding time. If these kinds of samples must be subcontracted, then the monitoring consultant should arrange to transport them directly to the subcontract laboratory to save time. The logistics of subcontracting should be arranged with the primary laboratory before the monitoring phase of the project begins.

It is the responsibility of the primary laboratory to guarantee the quality of all data they report, including data obtained from subcontract labs. It is the primary lab's responsibility to make sure all analyses are performed in accordance with approved methods, all project DQOs are met, and the data are ready on time. Only the primary laboratory should present invoices for payment for lab services, and any failure on the part of a subcontract lab should be treated as a failure of the primary laboratory.

5.2.6 Laboratory Data Reporting

Caltrans receives laboratory data in both hardcopy and electronic formats.

The standard hardcopy laboratory report for water chemistry data should contain the following elements:

- Cover page bearing the laboratory name and ELAP/NELAP certification number, laboratory director's and project manager's names, statement that all analyses were performed in accordance with state and federal regulations, and the electronic signature of the individual who reviewed and is responsible for the data (usually the project manager).
- Analytical data, including test result, units, reporting limit, MDL, client sample identification (ID), lab sample ID, analytical method reference, date and time of analysis, and quality control batch number.
- Quality control data. Depending on the analysis, this normally includes some combination of results obtained from method blanks, laboratory control spikes (LCSs) or blank spikes, matrix spikes, laboratory duplicates, and the details of sample preparation (usually digestion or extraction).
- A narrative that discusses any anomalies or problems encountered, any corrections made, or any other observations that may be relevant.
- Completed chain-of-custody form.

Standard hardcopy reports for toxicity data should contain the following elements:

- Information about the test method used, including method reference, definition of test end points, analysis start and stop dates and times, test volumes used, number of chambers used, number of organisms used per chamber, acclimation information, temperature and water quality data of test water, and feeding schedule for test organisms.

- Specific information about the organisms used, including name, age at the time of analysis, life stage, size and weight, and where they were obtained.
- Quality control information, usually the results of most recent reference toxicant tests.
- Analytical results. These are usually presented as the raw toxicity data displayed in tabular form with a plot of observed toxicity, a final result such as an LC50 (concentration at which the test water is lethal to 50% of the organisms) if appropriate, water quality data for the water used in the analysis, and the statistical methods used to calculate the end points.

A PDF version of hardcopy reports should be emailed to the monitoring consultant as soon as it is available. Normally, reports should be received from the laboratory no later than ten business days after the samples are submitted, although longer turnaround times can be negotiated if they are required for some reason (consultants must obtain approval from the Caltrans Task Order Manager before changing standard turnaround times). Paper copies are not required if the PDF copies are complete and bear a signature page and a scanned chain-of-custody form but may be requested from the laboratory at the discretion of the monitoring consultant. Paper hardcopies should be supplied by the laboratory at no additional cost to Caltrans. Final PDF versions of the laboratory reports must be submitted to Caltrans after all data quality issues have been addressed.

All analytical data must also be submitted in electronic form. An electronic data deliverable (EDD) is a file that contains the analytical data and associated quality control data.

5.2.7 Cost

Before the monitoring phase of a project begins, a monitoring consultant must add one or more laboratories that meet the needs of the program to their consulting contract. The contact laboratories can then be used as needed. Sometimes it may not be possible to use the laboratory that submitted the lowest bid. For example, if the lowest bidder does not have reporting limits that meet the project DQOs then it cannot be used on the project. The consultant must evaluate the capabilities of each prospective project laboratory and select the lowest bidder that meets the project DQOs.

Most of the following services are usually provided by environmental laboratories at no additional cost:

- Certified clean, pre-preserved sample containers
- Deionized water to be used for field blanks and equipment rinsing
- Travel blanks
- Delivery of sample containers, coolers, and deionized water
- Sample pickup at the consultant office and project sites
- Sample preparation, including filtration for dissolved constituents
- After-hours sample receipt
- After-hours analysis of short-hold-time samples
- Full QC package with each report
- Reports in both hardcopy and EDD formats

Some labs may charge a nominal fee for some of these services but may still be selected for a project if their overall price is still the lowest and if the lab meets the project DQOs. These services should be negotiated before the project begins so they do not appear as unexpected costs.

5.2.8 Laboratory Kickoff Meeting

Before the monitoring phase of a project begins, the consultant should hold a kickoff meeting with the laboratory to go over the material discussed in this chapter. A kickoff meeting may not be required when using a laboratory that has been used on other Caltrans projects, but it is necessary when using a lab that has not worked previously with Caltrans or with the consultant. Table 5.2 lists the general topics that should be discussed at a kickoff meeting.

Table 5-2 Laboratory Kickoff Meeting Discussion Topics

Category	Discussion Item
Laboratory Performance Requirements	Reporting limits
	Analytical methods
	Project Data Quality Objectives (DQO)
	Reporting and data management
	Sample containers, carboy cleaning
Sample Handling	Volumes required for environmental and QC samples
	Holding times
	Preservatives
	Compositing instructions
	Prioritizing analyses for samples with insufficient volume
	Hours of operation for sample receiving
	Performing short-hold-time analyses outside regular business hours
	Laboratory sample pickup and bottle delivery services
Contact Information	Project manager email and telephone
	Sample receiving department contact information
	After-hours contact information
Lead Time Requirements	Laboratory's desired lead time
	Any special lead time requirements for certain tests or after-hours services
	Lead time requirements for bottle delivery and sample pickup, carboy cleaning
Costs	Negotiated costs for the project
	Costs for accelerated turnaround times
	Additional costs that may be incurred

5.3 Understanding Laboratory Data

This section covers the basic concepts of sample handling, preparation, and analysis that monitoring consultants must be familiar with in order to work effectively with the laboratory. The information presented in this section should also be part of any training program for new field technicians and for project managers who are unfamiliar with stormwater monitoring.

The following topics are covered in this section:

- Limits of quantitation
- Holding time and sample preservation
- Total and dissolved fractions
- Sample preparation

- Insufficient sample volume
- Interference

5.3.1 Limits of Quantitation

A laboratory does not report a measured result for a target analyte as zero; every measurement is reported either as the measured concentration of target analyte or as less than a minimum threshold concentration. Each analytical method has a minimum threshold concentration that can quantify accurately. If the target analyte is not detected at or above this minimum concentration, then the laboratory reports it as “less than” this value.

There are two kinds of minimum quantitation limits commonly used by environmental laboratories: MDLs and RLs. As of 2008, Caltrans requires analytical results be reported down to the MDLs.

5.3.2 Method Detection Limits

The MDL is defined as the minimum concentration of analyte that can be identified, measured, and reported with 99% confidence that the analyte concentration is greater than zero. MDLs must be calculated separately for each constituent and for each analytical instrument used to perform the analysis. For instance, if a lab uses two instruments to analyze samples for trace metals, then MDLs for each element would have to be established for both instruments. If both instruments analyze samples for copper and lead, then separate MDLs are required for both elements on both instruments.

An MDL is determined from analysis of a sample in a given matrix containing the analyte. The material, such as water and sediment, that composes the sample, is called the “sample matrix” or simply “matrix.” In strict terms, “matrix” refers to the components of a sample other than the analyte.

As indicated earlier, Caltrans now requires all constituents must be reported to the MDL. Concentrations reported between the MDLs and the RLs should be considered to be estimates.

5.3.3 Reporting Limits

For most constituents, laboratories establish RLs for the purpose of reporting analytical results. A reporting limit is the minimum concentration of an analyte that can be measured within specified limits of precision and accuracy. If the concentration of a target analyte is measured at or above the RL then it is reported at that concentration; if it is detected below that value, then it is reported as “less than” the RL.

Unlike MDLs, there is no rigorous mathematical process for establishing a reporting limit. Laboratories usually define the RL as three to five times the MDL.

A reporting limit is established above the MDL so that the lab does not need to report concentrations down to the ideal MDL, but has a kind of “comfort zone” above that ideal value. Environmental samples that may not behave ideally can still be reported down to the RL with confidence.

Limits of quantitation can be defined in various ways by different labs, which can create confusion if these terms are not defined properly and used consistently. Some common acronyms used for quantitation limits are summarized in Table 5-3. These may be encountered when communicating with a laboratory or reviewing lab data.

Table 5-3 Some Common Acronyms Used for Limits of Quantitation

Acronym	Name	Description[1]
RL	Reporting Limit	Lowest concentration reported by the laboratory. Any concentrations detected below this value are usually reported as “less than” this value.
DL	Detection Limit	Commonly used synonymously with RL.
EQL	Estimated Quantitation Limit	Commonly used synonymously with RL.
IDL	Instrument Detection Limit	Lowest concentration that can be detected by an instrument. Does not take methodological factors into account.
LLD	Lower Limit of Detection	Commonly used synonymously with IDL.
LLQ	Lower Limit of Quantitation	Commonly used synonymously with RL.
LOD	Limit of Detection	Commonly used synonymously with MDL, and sometimes with IDL.
LOL	Limit of Linearity	Highest concentration that is within the linear calibration range of the instrument or method.
LOQ	Limit of Quantitation	Commonly used synonymously with RL.
MDC	Minimum Detectable Concentration	Commonly used synonymously with MDL
MDL	Method Detection Limit	Lowest concentration that can be resolved from method baseline noise with a 99% confidence in a sample that does not contribute any matrix effect.
MQL	Method Quantitation Limit	Commonly used synonymously with RL.
PQL	Practical Quantitation Limit.	Commonly used synonymously with RL.
SDL	Sample Detection Limit	The MDL adjusted to take specifics of sample matrix and preparation into account.
SQL	Sample Quantitation Limit	Commonly used synonymously with SDL.
UCL	Upper Calibration Limit	Commonly used synonymously with LOL.

[1]These descriptions are intended to be used only as a reference for non-laboratory personnel who may run across them. Many of these terms have more specific, rigorous definitions that are beyond the scope of this manual.

5.3.4 Holding Time and Sample Preservation

A holding time (or hold time) is the amount of time a sample can be stored, between the time it is collected and the time the analysis begins, without significantly affecting the analytical results.

Holding times vary by constituent. Some holding times are very short; USEPA guidelines require that pH be tested no later than 15 minutes after the sample has been collected. Testing for coliform and for particle size distribution must be conducted within eight hours of sample collection. Conductivity should be tested within 24 hours of sample collection. Certain ions such as nitrite and orthophosphate should be tested within 48 hours of collection. Other tests have much longer hold times; for example, most total metals have holding times of six months. Holding times may also vary by matrix, sometimes significantly. For example, hexavalent chromium has a holding time of 24 hours in water, but 30 days in soil.

It is important that the laboratory begin all analyses within their specified holding times, but it is particularly critical that hold times be met for samples that will be used for regulatory purposes. Analytical data for samples that have been analyzed past their holding times may be scientifically sound under some circumstances but are never acceptable for regulatory compliance. If samples are analyzed past holding time, the resulting data are flagged as “estimated” by the laboratory.

Samples often must be preserved when they are collected. Sample preservatives are chemicals that are added to stabilize a sample, so the concentrations of target analytes do not change before the sample is analyzed. Sample holding times are applicable only to samples that have been preserved properly.

Like holding times, preservatives vary by constituent. In the context of stormwater monitoring, preservation methods are generally limited to pH control, chemical addition, filtration, and refrigeration. Sample preservation is generally intended to retard chemical reactions in the sample, to retard microbiological action, to reduce adsorption of constituents onto the surface of the sample container, and to reduce volatility.

Refrigeration is one universal form of sample preservation. All stormwater samples should be kept between 0 and 6° C during collection, transport, and storage. Various kinds of acids are also common preservatives. Other analyses require a high pH, or the addition of some other chemical to preserve samples. Common preservatives used in stormwater monitoring are listed in Table 5-1.

Laboratories add the correct amounts of preservatives to sample containers provided to monitoring consultants. Pre-preserved containers are convenient for field technicians and are certified by the lab to be free of contamination. Pre-preserved containers obtained from a laboratory should always be used for Caltrans stormwater monitoring projects. Under normal circumstances, monitoring consultants should never have to preserve their own sample containers.

5.3.5 Total and Dissolved Fractions

It is common for some constituents to be analyzed in both total and dissolved form. The total fraction is a measure of all target analyte in a sample. The dissolved fraction is a measure of the target analyte that is not associated with particulate matter, either as a material component of particles or adsorbed onto particles. This distinction is of interest to regulators and researchers because dissolved constituents are often absorbed by aquatic life much more easily than constituents that are associated with particulate matter. Total and dissolved fractions may also be of interest when evaluating experimental treatment systems.

To determine a total concentration, the laboratory performs the analysis on an unfiltered sample. To determine dissolved concentration, the lab performs the same analysis on a sample that has been passed through a filter. A filter size of 0.45 microns is almost always used when testing for dissolved metals, nutrients, organics, or other dissolved constituents. An exception to this rule is total dissolved solids (TDS), which are analyzed after the sample is passed through a glass filter with a pore size of approximately one to two microns.

For chemical analysis of the dissolved fraction, a sample must be filtered before a chemical preservative is added. This is because preservatives very often change the ratio of total versus dissolved constituent in a sample (this ratio is sometimes referred to as the partition ratio). For example, total metals are preserved with acid, but lowering the pH of a sample dissolves some particles that might contain metals. Therefore, to determine the true concentrations of trace metals in the total and dissolved fractions, the sample must be filtered before lowering the pH.

The ratios of total and dissolved fractions of many constituents can be highly dynamic in a stormwater sample. For this reason, samples that require dissolved analyses must be filtered as soon as possible after they are collected and should always be filtered within 24 hours of collection.

5.3.6 Sample Preparation

Some analytical methods require a preparation step. There are two with which stormwater monitoring personnel should be familiar – digestion and extraction.

Sample digestion is the process of mixing the sample with strong acid and heating it. Digestion drives all the target analyte into dissolved form. The sample digest is then analyzed for the target constituent. Trace metals and total phosphorus are two examples of analyses that normally involve a digestion step, although very clean water may sometimes be analyzed without digestion.

Sample extraction is the process of removing some constituents from a sample. In the context of an aqueous sample like stormwater, this is done by adding an organic solvent to the sample and agitating it vigorously. Organic molecules in the sample are extracted out of the aqueous phase and into the solvent phase. The solvent, which now contains the target analyte, is separated from the sample, and this extract is then analyzed.

5.3.7 Insufficient Sample Volume

Occasionally, stormwater samples are collected that do not have sufficient volume to perform all of the required analyses. Laboratories handle this situation either by diluting the sample to increase the volume, or by performing only some of the required analyses and omitting others. Monitoring consultants must understand both approaches so they can give proper guidance to the laboratory when this situation occurs.

A laboratory can dilute the sample with deionized water to bring it up to the required volume (or, depending on the analysis, may simply use less sample volume for each analysis, which amounts to the same thing). This is an effective solution, but it has one very important drawback: whenever a sample is diluted in the lab, the analytical reporting limits must be raised proportionately. This is because, as the sample volume is increased, the constituents in the sample are diluted proportionately. For instance, if the concentration of zinc in a sample was 1.2 µg/L and the sample were diluted to twice its original volume, then the concentration of zinc in the diluted sample would only be 0.6 µg/L. If the laboratory's reporting limit for zinc is 1.0 µg/L then the concentration of zinc in the diluted sample would not be detected, even though it was present in detectable amounts in the original sample.

In practice, the laboratory accounts for this effect by raising its reporting limits in proportion to the dilution; in the zinc example, the reporting limit would double from 1.0 µg/L to 2.0 µg/L, because the total volume was doubled. So, while diluting a sample provides the lab with enough sample volume, it may result in an unacceptable rise in reporting limits.

A good way to avoid this problem is to direct the laboratory to perform all analyses with sensitive reporting limits first (this is usually the case with trace metals, for example), and then dilute the remainder of the sample for the rest of the analyses.

Another way a laboratory can handle a sample with insufficient volume is to perform only some of the requested analyses. This approach has the benefit of not affecting reporting limits but has the obvious drawback that the sample will not be analyzed for all project constituents. Table 5-1 shows a decision tree that can be used to decide what course of action should be taken when insufficient sample is collected. Table 5-4 shows an example of how analytical constituents may be prioritized if an insufficient sample volume is collected; the laboratory performs the highest-priority analyses first, then the second highest, and so on. A table in this format should be provided to the laboratory as part of the project Quality Assurance Project Plan (QAPP) so they know which analyses to perform first.

This table should only be used as an example. Monitoring projects differ in which constituents are most important, and this decision must be made on a case-by-case basis, depending on the objectives of the individual project.

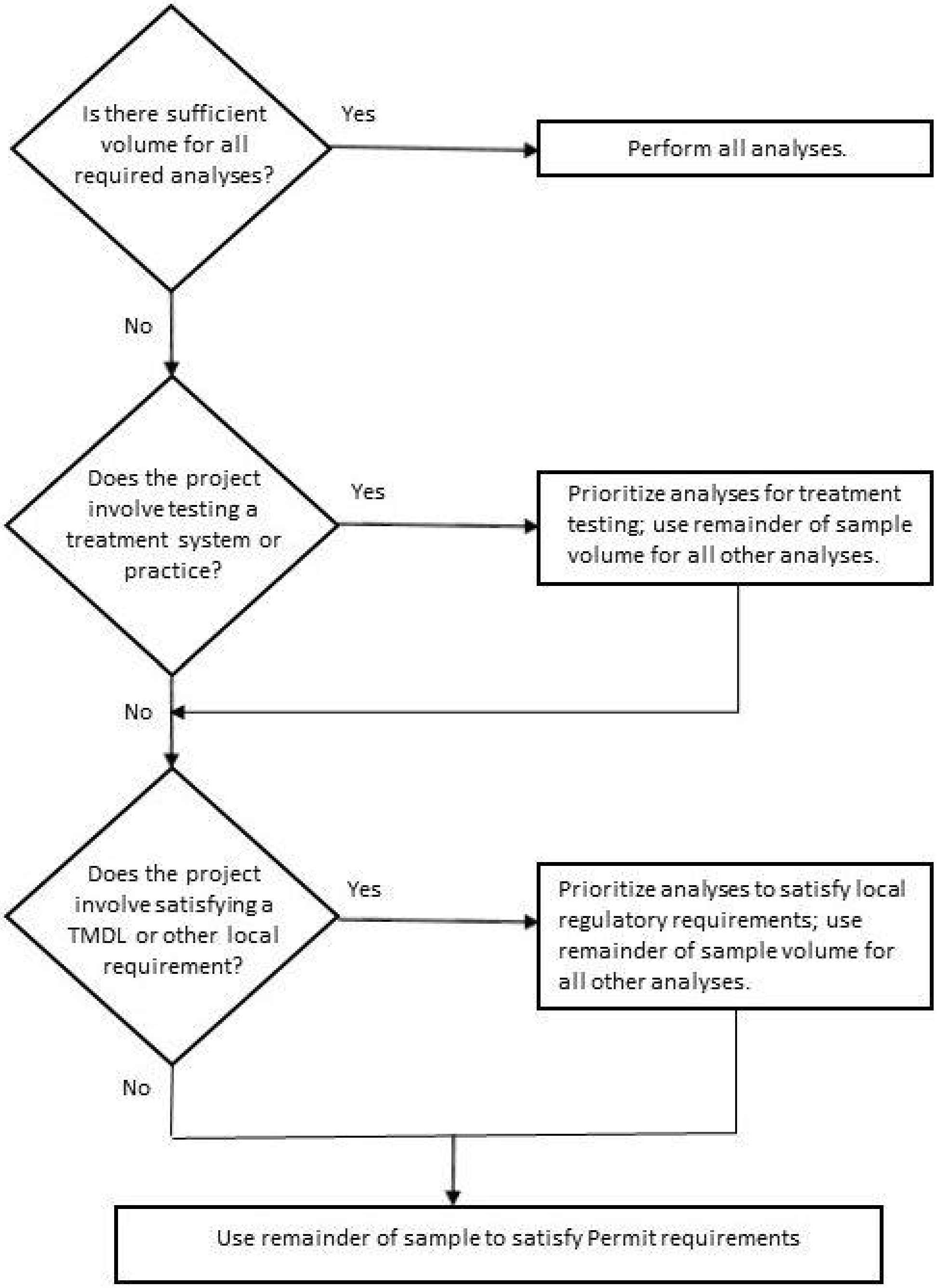


Figure 5-1 Decision Tree for Insufficient Sample Volume

Table 5-4 Example of a Constituent Prioritization List

Constituent	Priority
Hardness as $CaCO_3$	3
Total Organic Carbon	3
Dissolved Organic Carbon	3
TSS, TDS	3
Turbidity	1
Ammonia-N	2
Nitrate-N	2
Nitrite-N	2
Total Phosphorus	2
Orthophosphate-P	2
Arsenic	1
Chromium	1
Copper	1
Iron	2
Lead	1
Mercury	1
Nickel	1
Silver	1
Zinc	1
Oil and Grease	5
Organophosphorus Pesticides	4
Chlorinated Herbicides	4
Polynuclear Aromatic Hydrocarbons	5

Table 5-5 shows the approximate minimum volumes required for the common types of analyses that Caltrans performs. Like the information contained in Table 5.4, the information in Table 5-5 should only be used as a guideline; minimum required sample volumes should be discussed with the laboratory during the planning phase of the project.

Table 5-5 Approximate Minimum Required Sample Volumes

Constituent Type	Minimum Required Volume
TSS and TDS	500 ml
SSC	1 liter
Other Conventionals	250 mL
Nutrients	250 mL
Metals	100 mL
PAHs	1 Liter
Oil and Grease	1 Liter
Organophosphorus Pesticides	1 Liter
Organochlorine Pesticides	1 Liter
Pyrethroid Pesticides	1 Liter
Toxicity - Fathead Minnow	Acute, 1.6 Liter; Chronic, 12 Liter
Toxicity - Water Flea	Acute, 0.25 Liter; Chronic, 1.05 Liter
Toxicity - Green Algae	Chronic, 1 Liter (acute not applicable)

Options for handling samples with insufficient volume must be discussed with the laboratory and with the Caltrans Task Order Manager before the monitoring phase of a project begins. The monitoring consultant must brief the laboratory on which tests, if any, may be performed using diluted samples. The lab should be given a list that prioritizes all project constituents from most to least important, to ensure the most important analyses are performed first, in case of insufficient sample volume.

There are many types of interference:

- An interfering substance can change the chemistry of the analysis. In this case, some non-target constituent in a sample may react in an unpredicted way with one of the reagents used to perform the analysis.
- When an analysis has multiple target analytes, high concentrations of some analytes can mask the presence of others. For example, chloride and nitrate resolve quite close to each other on an ion chromatograph, and a high concentration of chloride may overlap with the nitrate, making it difficult to determine the concentration of nitrate in the sample.
- An interfering substance may directly affect the target of the analysis. For example, high concentrations of iron can form a precipitate with phosphorous, making it more difficult to digest and analyze.

- An interfering substance may compete chemically with the analyte. For example, arsenate reacts with analytical reagents for phosphorous, and may be mistaken for phosphorus by the analytical method.
- Interferences can be physical. For example, high turbidity may make it difficult to perform colorimetric tests, which require that a beam of light be passed through a sample. High concentrations of solids in a sample may clog an analytical instrument, making it difficult to perform the test.

Interferences can be both positive and negative. A positive interference raises the observed concentration of a target analyte, causing a higher analytical result. A negative interference lowers the observed concentration of a target analyte, causing a lower analytical result.

Environmental laboratories usually solve interference problems by diluting the sample and re-analyzing it. When the sample is diluted the interfering substances in the sample are diluted proportionately. The lab continues to dilute the sample until the interfering substance no longer affects the analysis. However, as discussed in Section 5.3.7, diluting a sample also raises the reporting limits proportionately, so this alternative may not be the best in all cases.

Another potential approach to solving interference problems is to analyze the sample using a different analytical method. Some constituents can be analyzed by multiple methods, and very often a substance that interferes with one method will not cause the same problem with a different method. Using methods other than those specified in the QAPP must be approved by the Caltrans Task Order Manager.

6 Monitoring Site Selection

A monitoring site is a specific location within a study area where samples are collected. Samples should be collected at the same place over the life of a monitoring project, so the samples represent the study area in a consistent way. Monitoring sites must be selected before the sample collection phase of a project begins and should not change over the life of the project.

Each monitoring project and study area is unique. A field assessment of the study area should be conducted by experienced project managers and field technicians to locate monitoring sites that will best meet the project objectives.

The following considerations for site selection are discussed in this chapter:

- Personnel safety
- Site access
- Security of monitoring equipment
- Ease of flow measurement
- Representativeness
- Permit requirements
- Electrical power
- Cellular telephones and telemetry
- Use of existing monitoring sites
- Planned changes to the study area
- Use of project data for other studies
- Project-specific considerations

6.1 Personnel Safety

The first thing to consider when selecting monitoring sites is the safety of field personnel. It is common for stormwater monitoring to be performed under heavy storm conditions, at night, on slippery or uneven surfaces, near traffic, and sometimes in relatively remote areas.

There are many hazards that could potentially exist at Caltrans monitoring sites. These include the following:

- Proximity to high-speed traffic
- Poor visibility at night or during adverse weather conditions
- Poor footing on wet surfaces
- Confined spaces (access requires OSHA certification)
- Potential presence of explosive or toxic gases
- Uncovered water conveyances
- Heat – potential for heat exhaustion, heat stroke
- Cold – potential for exposure, frostbite
- Hazardous wildlife and plants
- Strangers – people encountered on site who are not clearly identifiable

This is only a general list of possible hazards that field personnel may encounter. It is important that experienced project managers and field technicians conduct a thorough investigation of each prospective monitoring site to identify possible hazards before the monitoring phase of a project begins. Each potential monitoring site must be evaluated to make sure that field personnel can access the site and perform all required duties safely.

Potential field hazards identified during the site selection process must be noted, and later identified in the project Health and Safety Plan. The Health and Safety Plan is a project-specific document that includes maps of each monitoring site, a list of potential hazards at each site with an assessment of each hazard and rules for avoiding each hazard, and a list of required personal protection equipment (see Appendix C). Any Health and Safety Plan used for Caltrans projects should comply with the requirements discussed in the most recent version of the Caltrans Maintenance Manual (Chapter 8 – Protection of Workers) (Caltrans 2006), available at the following website: http://www.dot.ca.gov/hq/maint/manual/maintman.htm.

Every field crew should be provided a cellular telephone. This allows field crews to keep in touch with each other during monitoring events, and to call for assistance in the event of an accident or other emergency.

6.2 Site Access

When choosing a monitoring site, it is important to consider how field personnel will access the site, both while installing monitoring equipment and when collecting stormwater samples. A site that is easy to access in daylight under dry-weather conditions may be significantly more difficult to access safely during a storm or at night.

The site must be large enough to accommodate a vehicle, at least two field technicians, and all equipment required for monitoring. Some monitoring activities, such as replacing sample carboys and performing equipment and site maintenance, require considerable space, which must be taken into consideration when evaluating a prospective monitoring site. If possible, the site should also have an area where a vehicle can be parked away from the shoulder of the road.

It is advisable to choose monitoring sites that are not located on private property and can be accessed without crossing private property. A property owner may rescind permission to access a site without cause or change the terms of site access in an unacceptable way, and this could make it necessary to change monitoring sites in the middle of a project.

If use of private property for monitoring site access cannot be avoided, it is important to negotiate the terms of site access with the landowner before developing the site, and to obtain the terms in writing with an assurance that the terms will not change over the life of the project.

When evaluating access to a prospective monitoring site, it is necessary to identify the route that field personnel will take to and from the site, and to ensure that field crews will be able to access the site 24 hours a day and on weekends and holidays.

The QAPP should contain precise driving directions to each project monitoring site and a map of each monitoring site that clearly shows how the site should be accessed.

Figure 6-1 shows an example of a monitoring site map.

The QAPP should also contain any other information necessary for site access, such as applicable permits, contact information for people who must be notified prior to site entry, and required keys. These factors should all be noted during the site evaluation process.

The Caltrans Task Order Manager will visit each new stormwater monitoring station before monitoring begins, in order to verify that the site meets Caltrans requirements.

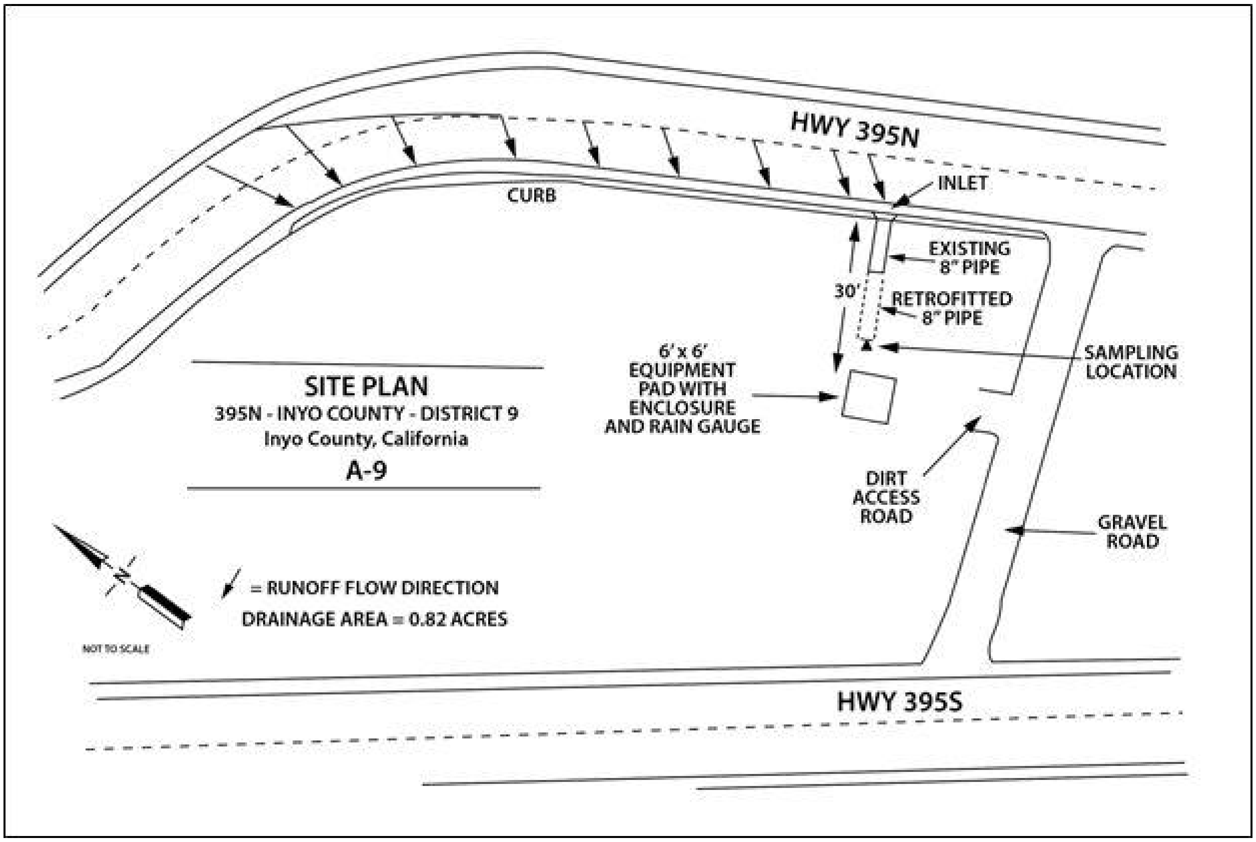


Figure 6-1 Example of a Site Access Map

6.3 Security of Monitoring Equipment

Monitoring equipment that is permanently installed in the field is susceptible to theft, vandalism, and damage due to mishaps such as traffic accidents. Although it is not possible to eliminate these risks, care should be taken to minimize them. Automated monitoring sites should only be selected where equipment can be installed in protective enclosures that are resistant to vandalism and tampering. Ideally it should be possible to secure the site with a fence and locked gate. When possible, monitoring sites should be selected that are away from heavily populated areas and where monitoring equipment is not visible to foot and automobile traffic. For sites where equipment is visible and accessible, the possibility of installing additional security measures such as fences should be considered during the site-evaluation process.

The Highway Design Manual (Caltrans 2009b) requires fixed objects be eliminated or moved outside the clear recovery zone to a location where they are unlikely to be hit. A clear recovery zone is an unobstructed, relatively flat (4:1 or flatter) or gently sloping area beyond the edge of the traveled way which affords the drivers of errant vehicles the opportunity to regain control. Figure 6-1 shows the minimum desirable clear recovery zone widths for the type of facility indicated.

Table 6-1 Clear Recovery Zone Widths

Facility type	Clear Recovery Zone
Freeways and Expressways – 30 feet	30 feet
Conventional Highways – 20 feet*	20 feet

* On conventional highways with posted speeds less than or equal to 40 mph and curbs, clear recovery zone widths do not apply. See minimum horizontal clearance, Index 309.1(3) (c).

Please refer to Highway Design Manual Topic 309.1 for details (Caltrans 2009b).

6.4 Ease of Flow Measurement

Accurate measurement of runoff flow volume is a necessary part of most stormwater monitoring projects and is required for collection of flow-weighted composite samples.

Flow volume is usually measured using a primary flow measurement device, such as a flume or weir, in combination with a flow meter to gauge depth and/or flow velocity. There is a considerable variety of flow measurement devices available that can be used in many different combinations. An experienced field technician can often improvise a system that will measure flow volume accurately under difficult conditions; however, choosing a site with hydraulic characteristics that are favorable to straightforward measurement of runoff flow volume can make it easier and less expensive to install a monitoring station, make monitoring less difficult, and reduce the possibility of flow measurement errors.

Chapter 8 discusses steps for setting up a flow measurement system, and these should be consulted when potential monitoring sites are being evaluated. However, each potential monitoring site poses unique challenges, and a site may have drawbacks that a set of written guidelines might not anticipate. For this reason, it is important that an experienced field technician be involved in the evaluation phase of the site-selection process.

6.5 Representativeness

It is important to collect samples that are representative of stormwater runoff from the entire monitoring site.

It can be difficult to know how runoff behaves on a site without observing the site during wet weather. Prospective monitoring sites must be visited during, or shortly after, a storm to verify that parts of the site do not drain in an unexpected way and the selected sampling point receives runoff that represents the entire site.

Several characteristics potentially impact the representativeness of discharge at a given site, including the following:

- Depth of groundwater table
- Comingled flow (run-on flow from offsite)
- Illegal discharges, illegal dumping, and illicit connections
- Surrounding land uses

These characteristics are discussed below individually.

6.5.1 Backwater and Tidal Influences

A depth-based flow measurement device such as a flume or channel will only work properly if water flowing through it can discharge freely. If the discharge from this type of device is obstructed, then water can back up into the system, breaking the depth-to-flow relationship of the device (see Chapter 4). Accurate flow measurement becomes much more complicated under these conditions. Primary flow measurement devices should always be placed where the runoff is free flowing (gravity flow). Figure 6.2 illustrates how a high downstream water level can affect a monitoring site.

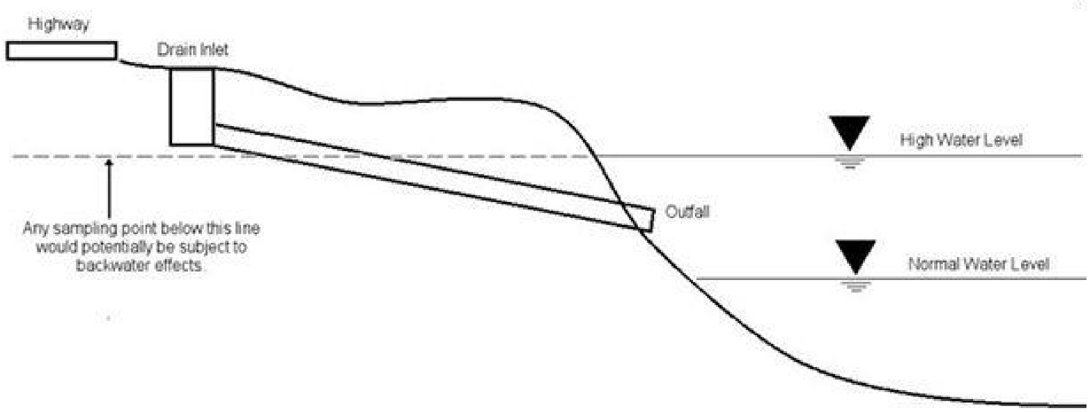


Figure 6-2 Backwater Influence

Ocean tides can cause a backwater problem in coastal areas, and avoiding downstream tidal effects can be tricky. Even if a site appears to be free flowing during a normal high tide, spring tides may be significantly higher than normal high tides and cause an unexpected backwater problem. Also, tides can affect the flow of surface waters at surprising distances from the ocean. Extra attention should be paid to this potential problem when investigating prospective monitoring sites in coastal areas.

A simple way to check for tidal influences in coastal surface waters is to place a flow meter at a prospective monitoring site and collect flow data continuously over several days. If the observed flow velocity varies in synchronization with the tide, the site is almost certainly being influenced by tidal effects and should probably be rejected.

When backwater effects are likely, an area/velocity meter could still provide relatively accurate flor measurement. This may help consultants use sites that would otherwise be rejected.

6.5.2 Depth of Groundwater Table

A high groundwater table may reach the surface if the ground becomes saturated during the wet season. In this case, groundwater could mix with stormwater runoff and influence the measurement of stormwater quality and flow volume. If possible, areas with a high groundwater table should not be selected as monitoring sites.

6.5.3 Commingled Flow

Just as it is essential that runoff from a monitoring site represents the entire site, it is also important that the site does not receive unidentified run-on flow during wet weather. The composition of stormwater runoff from a monitoring site can be changed if it commingles with flow from unknown sources, and this can result in analytical data that do not represent the site. This problem can be particularly serious when run-on flow commingles with site runoff without being detected, because it can lead to misinterpretation of the data.

Prospective monitoring sites must be visited during or shortly after a storm to verify they do not receive run-on flow from off-site. In some cases, it may be possible to intercept run-on flow and prevent it from commingling with flow from the site. If this is not possible, and if it is determined that the run-on flow would cause unpredictable changes in the water quality of site run-off, the site should not be used for monitoring unless the goal is to study run-on flows.

6.5.4 Illegal Discharges, Illegal Dumping, and Illicit Connections

An illicit discharge is defined in 40 Code of Federal Regulations section 122.26(b)(2) as "any discharge to a municipal storm sewer that is not composed entirely of storm water except discharges pursuant to an NPDES permit (other than the NPDES Permit for discharges from the Municipal Separate Storm Sewer System) and discharges resulting from firefighting activities." Illegal dumping is the practice of disposing of solid or semisolid refuse such as trash, electrical appliances, or construction debris in an area that is not intended for waste disposal.

An illicit connection is an engineered conveyance that is connected to the Caltrans storm drain without authorization. The most common type of illicit connection is an unauthorized drainage connection.

Site inspections for these types of problems should be conducted during both dry and wet weather. Illegal discharges and illicit connections often cause dry-weather flows that can be spotted easily, and it may be easier to see signs of illegal dumping (such as stains on the ground or small bits of trash) when the ground is dry. However, a wet-weather search for these problems should also be conducted because some illegal discharges may only occur during storms.

Unauthorized discharges and dumping can come in many forms and from many sources, and field technicians should look for signs of illegal activity each time they visit a monitoring site.

The following are some common signs:

- Presence of trash, construction debris, or other refuse (field personnel should never handle refuse without gloves)
- Unusual or unexplained flow during either dry or wet weather
- Unusual or unexplained stains or discoloration on the ground
- Unusual or unexplained odors in the area
- Unidentified conveyances that attach to existing stormwater discharge systems
- Unexplained damage to existing stormwater conveyances
- Signs of unauthorized construction activity
- Unexplained or unusual disturbances to vegetation
- Abnormal appearance or odor of stormwater runoff during storm events

Any suspicion of illegal discharge or dumping on Caltrans property must be reported to the Caltrans Task Order Manager as soon as possible. If field personnel have any reason to believe that unexplained discharges or refuse may be hazardous, they are to leave the area immediately and contact the Caltrans District NPDES coordinator. If there is any reason to believe that unexplained discharges or refuse may cause an immediate safety concern to the surrounding area, field personnel are to leave the area immediately and contact the county Sheriff's Office or local fire department.

6.5.5 Surrounding Land Uses

Monitoring sites should be selected such that surrounding land uses do not impact the stormwater discharged from department facilities. The most common interference is atmospheric deposition of materials onto the study area from the local surroundings, although run-on flows from off-site can also carry unwanted materials onto the monitoring site.

As an example, if one of the objectives of a study is to detect low levels of residual herbicides in stormwater runoff from the highway, monitoring sites near active agricultural areas where herbicides may be in use should be avoided. Wind could blow freshly applied herbicides from the surrounding area onto the monitoring site, either as aerosols or adsorbed on dust particles, and contaminate the site runoff.

6.6 Permit Requirements

All site development and stormwater monitoring must be performed in accordance with the Caltrans permit. In addition, it is often necessary to obtain other permits before developing a monitoring site. Permitting requirements vary widely from area to area and there are many organizations that could potentially require permits. These organizations can be grouped into three types:

- State agencies: for example, the State Water Resources Control Board or the California Coastal Commission
- Local agencies: for example, a county or municipality
- Non-governmental agencies: for example, local historical societies and Native American tribes

It is important to check with all agencies that may require permits before selecting a monitoring site. Field crews must have copies of all applicable permits in their possession whenever they are deployed to the field (see Chapter 7) for a detailed discussion of the permitting process.

6.7 Electrical Power

Nearly all Caltrans stormwater monitoring stations use a combination of solar panels and deep-cycle marine batteries for electrical power. Monitoring sites should be located in areas where sunlight is not obstructed so batteries can maintain a full charge.

The cost of installing AC power at a monitoring site is almost always cost-prohibitive. Occasionally, AC power may be available near a site. In this case the site may be developed using AC-powered monitoring equipment, which will eliminate the need to charge batteries and maintain solar panels. The reliability of the AC power source should be considered when choosing this option; power outages are most common during heavy storms and could result in missed monitoring events if backup power is not available.

6.8 Cellular Telephones and Telemetry

Cellular telephones can be used by field technicians to coordinate various field activities, sample pickups, and delivery of replacement equipment.

Monitoring stations can be equipped with telemetry equipment that allows them to be programmed and interrogated remotely via cell phone. The use of remote communications allows one technician to monitor multiple monitoring sites from a central location. Automated equipment can also be programmed to send alerts in the event of a malfunction.

In some cases, cell phone coverage will not be available in the study area. But when cellular coverage is available, monitoring sites should be selected in places that have cell phone reception. Before monitoring begins, field personnel should familiarize themselves with areas where cellular coverage is available and areas where cell phones may not work reliably.

6.9 Use of Existing Monitoring Sites

Caltrans has hundreds of historical monitoring sites located around the state. These existing or prior sites should be included in any list of prospective monitoring sites if they fall within the study area and satisfy the project site selection criteria.

Making use of existing monitoring sites offers several advantages. First, hydrologic characteristics of existing sites are usually well known. There is less chance that an unexpected monitoring problem will arise on a site that has already been used successfully to collect stormwater runoff.

When developing monitoring sites, it is often necessary to perform minor construction such as pouring concrete slabs for equipment enclosures or digging trenches for flumes or other primary flow measurement devices. Using historical monitoring sites where this work has already been done can reduce construction time and decrease the cost of site development.

It is also beneficial to use existing monitoring sites because project data can be compared to historical data from the same site. This may help with interpretation of project data or be of interest to Caltrans to compare the quality of stormwater runoff over time.

6.10 Planned Changes to the Study Area

Before choosing a monitoring site it is advisable to check with Caltrans headquarters and the district NPDES coordinator to make sure that there are no plans for construction or other modifications to the area during the planned course of the monitoring project. If the monitoring phase of a project begins and then Caltrans performs a large-scale project in the area such as construction or landscaping, the quality of stormwater runoff could be affected. This could impact data quality mid-project, potentially making it necessary to relocate the monitoring site.

6.11 Use of Project Data for Other Studies

Sometimes data collected as part of one project can be useful for other projects or studies. For example, selecting monitoring sites that discharge directly into surface water bodies might be useful in helping Caltrans evaluate the effects of runoff on receiving waters. When selecting a monitoring site, it may be worthwhile to consider how the data collected at the site could be used in the future.

6.12 Project-Specific Considerations

The guidelines presented in this chapter are general, practical considerations for choosing a monitoring site. These guidelines will almost always have to be considered when planning a monitoring project, regardless of what the purpose of the project is or what other factors are involved.

However, monitoring projects frequently include project-specific requirements in addition to the considerations discussed in this chapter.

An experienced project manager should use the project's monitoring goals to develop a list of characteristics needed for evaluating a hypothetical monitoring site, including site characteristics that are essential to satisfy the study objectives.

The list of site characteristics, together with the general site selection considerations discussed in this chapter, may be used to produce a site evaluation form like the one shown in Figure 6-3. These site evaluation forms should then be used in the site-selection process.

Site Evaluation Form

Date______________________ Name of person conducting site visit______________________
District______________________ Location______________________ Post Mile______________________

TYPE OF SITE:

Roadway ☐ Construction ☐ Park-and-Ride ☐
Landscape ☐ Maintenance Yard ☐ Other ☐

*Describe:*______________________

Is the drainage area 100 percent representative of site type?
*Describe:*______________________

TYPE OF RUNOFF FROM SITE:

Curb and Gutter ☐ Overland Flow ☐ Other ☐

*Describe:*______________________

POTENTIAL SAMPLING LOCATION (WITH ACCESS TO FLOW):

Storm Drain Inlet ☐ Ditch, Swale ☐
Culvert ☐ BMP (e.g., retention basin) ☐
Pipe ☐ Other (describe): ☐

*Comments:*______________________

ACCURATE FLOW ACHIEVABLE? **Yes** ☐ **No** ☐
*Describe:*______________________

ELECTRICAL POWER AVAILABLE? **Yes** ☐ **No** ☐

TELEPHONE LINES AVAILABLE? **Yes** ☐ **No** ☐

CLEAR CELLULAR PHONE RECEPTION AT SITE? **Yes** ☐ **No** ☐

VEHICULAR SITE ACCESS? **Yes** ☐ **No** ☐
*Describe:*______________________

PERSONAL SAFTEY ISSUES? **Yes** ☐ **No** ☐
(e.g., Proximity to traffic lanes, steep embankments, etc.)
*Describe:*______________________

SITE CONDITIONS/OBSERVATIONS ***(if yes, describe)***

Tidal influences______________________ **Yes** ☐ **No** ☐
Illicit connections______________________ **Yes** ☐ **No** ☐
High groundwater table______________________ **Yes** ☐ **No** ☐
Erosion______________________ **Yes** ☐ **No** ☐
Runoff from landscaped areas______________________ **Yes** ☐ **No** ☐
Adjacent commercial farming______________________ **Yes** ☐ **No** ☐
Contributing off-site runoff______________________ **Yes** ☐ **No** ☐
Adjacent industrial sites______________________ **Yes** ☐ **No** ☐
Clear Recovery Zone______________________ **Yes** ☐ **No** ☐
Is site representative of Caltrans Highways and/or Facilities? **Yes** ☐ **No** ☐

*Explain:*______________________

Other observations:______________________

Figure 6-3 Example of a Site Evaluation Form

6.13 Conditions to Avoid

When selecting a monitoring site, field technicians must be aware of factors that might compromise data quality.

For example, Figure 6-4 illustrates a couple of conditions that can interfere with sampling of highway runoff. Solids that overtop a curb will add a significant amount of solid material to the stormwater runoff. Shrubbery overhanging the runoff area sometimes contributes nutrients to the runoff stream. These are just two examples of the kinds of things field personnel should watch for when selecting a monitoring site. Caltrans district maintenance personnel should be notified to rectify such conditions that can impair runoff quality.

Figure 6-4 (Left) Sediment Overtopping a Curb; (Right) Overhanging Shrubbery

6.13.1 Requesting New Monitoring Station IDs

Every Caltrans stormwater monitoring site must be assigned a unique Station ID. Station IDs are necessary when referencing stations in Caltrans documents and when reporting monitoring data.

Station IDs are distributed by Caltrans. When a station is developed, the monitoring consultant fills out the Caltrans Station ID Form with the required information and submits it to the Task Order Manager. The form is returned to the consultant with the new Station IDs filled in. A copy of the Caltrans Station ID Request Form is available at the Caltrans Stormwater Program website under the Forms and Templates Tab (http://www.dot.ca.gov/env/stormwater/). It is also included on the DVD that accompanies this manual and is available from the Caltrans Task Order Managers.

During the site development process, the Caltrans Task Order Manager will conduct a site visit to the selected location and verify that the site meets Caltrans' needs adequately. A representative for the monitoring consultant must be present during these site visits in order to escort the Task Order Manager around the site and to answer questions.

Table 6.2 lists information required when requesting an ID for a new monitoring site.

Table 6-2 Requested Information for New Stations

Field	Description
StationCode	Provided by Caltrans
StationName	The name of the site
StationDescription	Brief description of the site
Position	Location of the site in relation to the discharge (influent, effluent, etc.)
ReceivesFlowFrom	Description of the source of flow entering the station
CaltransDistrict	Caltrans District
RWQCB	Regional Water Quality Control Board (RWQCB)
County	County
Roadway	Number of the highway/roadway associated with the station
Postmile	County postmile nearest the station
Latitude	Latitude of the station in decimal format (not degrees) to five decimal places
Longitude	Longitude of the station in decimal format (not degrees) to five decimal places
Datum	Geodetic system used to calculate latitude/longitude
Elevation	Elevation of site in feet
TotalLanes	Number of lanes of the highway associated with the site (both directions)
SampledLanes	Number of lanes that discharge to the station
AADT	Average Annual Daily annual daily traffic of the closest roadway
AADTSource	Source of AADT figure
PrimaryDevice	Type and size of primary flow measurement device, if any
BMPType	Type of BMP associated with the station, if any
DateInService	Date that the station became an active monitoring site
PavementType	Type of pavement of the highway associated with the station
DatePavementInstalled	Date that the pavement was installed
CutFill	Whether the station is in a cut or fill area, if applicable
CatchmentArea	Catchment area that produces runoff entering the station (hectares)
ImperviousFraction	Fraction of the catchment area the is impervious (0 to 1.0)
RunoffCommingle	Y or N, does the discharge include non-Caltrans run-on flow?
RunoffTreatment	Any site condition that naturally treats runoff before BMP
EdgeOfRow	Y or N, is the station located on the edge of Caltrans right of way?
ReceivingWaterType	Type of water body that receives the discharge
ReceivingWaterName	Name of water body that receives the discharge
AnnualPrecipitation	Annual precipitation at the site (inches)

Field	Description
HydrologicSubArea	Hydrologic region as designated by California Department of Water Resources (DWR)
EcoRegion3	Level III Ecoregion designation (USEPA)
EcoRegion4	Level IV Ecoregion designation (USEPA)
PlanningWatershed	USEPA watershed designation for planning
SWRCBWatTypeCode	Water type code from State Water Resources Control Board (State Water Board)
LevelOfService	Level of traffic flow per specifications from the Highway Capacity Manual (HCM)
LandUse	Type of use of the surrounding land
NRCSSoilType	Soil type per specifications from the Natural Resources Conservation Service (NRCS)
VegetationTypes	Type of vegetation that predominates the surrounding area
Contract	Caltrans contract number for the site
TaskOrder	Caltrans task order number for the site
StationNotes	Any other information that might be pertinent or useful

Shaded entries are required.

7 PERMITS AND ENVIRONMENTAL COMPLIANCE

Once the study plan is developed, monitoring methods and equipment are identified, and monitoring sites are selected, applicable regulatory permits and approvals must be obtained. Permits may be required if the monitoring project will involve installation of monitoring equipment and related structures within jurisdictional drainages or for activities within a public right-of-way. This must be done prior to proceeding with project implementation.

Regulatory requirements for monitoring projects should be identified by the affected District's Environmental Unit. Planning and implementation of the monitoring project should be closely coordinated with District environmental staff, and the local NPDES coordinator(s) must be consulted during the planning stages for every monitoring project.

For statewide or broader regional projects, monitoring project planners should consult with Caltrans headquarters Office of Stormwater Program Development (contact information is also available at above web link).

Permits and approvals that may be required are briefly summarized in the following sections. A more thorough discussion of environmental laws and regulations that may affect monitoring projects can be found in the Caltrans Standard Environmental Reference (SER), available at the following website:

http://www.dot.ca.gov/ser/vol1/vol1.htm

The following environmental compliance and permitting topics are covered in this chapter:

- California Environmental Quality Act (CEQA)/National Environmental Policy Act (NEPA) compliance
- Caltrans permits
- Non-Caltrans permits and approvals
- Stormwater Pollution Prevention Plan/Water Pollution Control Program

7.1 CEQA AND NEPA REQUIREMENTS

The California Environmental Quality Act (CEQA) defines procedures for environmental review and impact analysis of projects that need approval by local or state agencies. The National Environmental Policy Act (NEPA) does the same for projects that need approval by federal agencies. Both laws require that the potential environmental impacts of a proposed project be assessed, quantified, disclosed, minimized, and eliminated whenever possible. Stormwater monitoring projects generally do not produce such effects, though occasionally there may be exceptions.

Note that projects subject to NEPA include those that (1) are developed under the auspices of Caltrans and will receive federal funding or approval by the Federal Highway Administration and/or (2) will be issued a federal permit (e.g., Clean Water Act [CWA] Section 404 Permit). If a project appropriates federal funding, the monitoring contract agreement for the project must incorporate the necessary NEPA requirements.

CEQA and NEPA document requirements vary in complexity and may result in significant delays in scheduling. Consideration of requirements should be made during the planning phase of a project. Contact the appropriate Caltrans District and/or the Caltrans Division of Environmental Analysis early in the project planning phase to determine whether any of these requirements will apply. In many districts, the District NPDES coordinator is the appropriate person to contact; other districts may have a separate office dedicated to regulatory compliance.

A general timeframe for preparing and processing these documents is provided in Table 7.1.

Table 7-1 General Timeline for CEQA Documents

CEQA	NEPA	Average
Categorical Exemption	Categorical Exclusion	1 to 12 months
Initial Study with Negative or Mitigated Negative Declaration	Environmental Assessment with Finding of No Significant Impact	1.5 to 3 years
Environmental Impact Report	Environmental Impact Statement	3 to 6-plus years

7.2 NON-CALTRANS PERMITS AND APPROVALS

Depending on project location, affected resources, and type of construction activities, other permits and/or approvals may be required from various federal, state, and local agencies. Regulatory agencies that must be consulted for a given monitoring project should be identified by the District's Environmental Unit. Federal agencies may typically include US Army Corps of Engineers (USACE) and US Fish and Wildlife Service (USFWS). State agencies may include the State Water Resources Control Board (State Water Board), Regional Water Quality Control Board (RWQCB), and CCC. Permits that may be required for construction/installation of equipment and/or facilities associated with monitoring projects are outlined below.

7.2.1 Non-Caltrans Encroachment Permits

An encroachment permit may be required from a local public agency (e.g., city, county, flood control district) for work or activities performed in a public right-of-way (e.g., streets, storm drain easements, flood control facilities) under the jurisdiction of the local agency. Prior to implementing monitoring activities within a public right-of-way, consultation with the local agency must be scheduled through the Caltrans encroachment permit Coordinator. Consultation with the local agency is necessary to determine the need and procedures for obtaining an encroachment permit.

7.2.2 California Coastal Commission, Coastal Zone Permit

The California Coastal Commission (CCC) is the state agency that implements the California Coastal Zone Act. The CCC jointly implements the federal Coastal Zone Management Act with the San Francisco Bay Conservation and Development Commission. A coastal development permit is required for monitoring projects that entail any construction in the coastal zone (e.g., installation of monitoring equipment or other facilities). Where local governments have developed local coastal programs certified by the Coastal Commission, authority for issuing coastal zone permits is delegated to the applicable local government. For example, for monitoring projects that occur in the San Francisco Bay-Delta portion of the coastal zone, the Bay Conservation and Development Commission is responsible for issuing coastal zone permits. Chapter 18 in Volume 1 of the SER provides basic information on coastal permitting.

The Caltrans NPDES Coordinator should be contacted to determine whether it is necessary to schedule consultation with the Caltrans Coastal Commission Liaisons and for assistance in obtaining a permit if one is required.

7.2.3 Tahoe Regional Planning Authority Permit

The Tahoe Regional Planning Authority (TRPA) is charged with protecting the water quality of Lake Tahoe and issuing permits for activities that occur within its watershed.

Its policy specifically addresses activities that affect aesthetics, stream environment zones (SEZs), and associated hydrologic areas in the Lake Tahoe basin.

The Caltrans NPDES Coordinator should be contacted to determine if a permit is required and for assistance in obtaining a permit if one is required.

7.2.4 Other Non-Caltrans Approvals

Monitoring projects may require additional approvals or permits, in addition to those described above. Table 7.2 lists the non-Caltrans permits that may be required for a stormwater monitoring project. For example, monitoring projects that occur in areas that potentially contain significant important cultural resources, such as archaeological or historical sites, may require consultation with the State Historic Preservation Officer or Bureau of Indian Affairs. The Caltrans NPDES Coordinator should be contacted to determine if any other approvals are required and for assistance in obtaining any required approvals.

Table 7-2 Non-Caltrans Permit Requirements

Resource Affected	Agency	Permit
Coastal Shoreline (except San Francisco Bay area)	Coastal Commission	Coastal Development Permit
Coastal Shoreline (San Francisco Bay area)	Bay Conservation and Development Commission	Coastal Development Permit
Lake Tahoe Watershed	Tahoe Regional Planning Agency (TRPA)	TRPA Project Permit
Stream Environment Zone	Tahoe Regional Planning Agency	TRPA Project Permit
Central Valley Floodways	Reclamation Board	Encroachment Permit
Water	US Army Corps of Engineers	Section 404 Permit
Water	Regional Water Quality Control Board	Section 401 Water Quality Certification
Water	State Water Resources Control Board	NPDES Permit
Water	US Army Corps of Engineers	Rivers and Harbors Act Section 10 Permit
Groundwater	Regional Water Quality Control Board	NPDES Permit
Fish and Wildlife Habitat	CA Dept. of Fish and Wildlife	Section 1602 Streambed Alteration Agreement
Fish and Wildlife Habitat	US Fish and Wildlife	Endangered Species Act Section 7, Biological Opinion

Resource Affected	Agency	Permit
Fish and Wildlife Habitat	US Fish and Wildlife	Migratory Bird Act
Fish and Wildlife Habitat	NOAA Fisheries	Marine Mammal Protection Act
Fish and Wildlife Habitat	NOAA Fisheries	Magnuson Stevens Act: Essential fish habitat
Cultural Issues	State Historic Preservation Office	National Historic Preservation Act Section 106 Programmatic Agreement
Cultural Issues	Advisory Council on Historic Preservation	National Historic Preservation Act Section 106 Programmatic Agreement
Cultural Issues	Native American Tribes	Consultation
Geology and Soils	Local agencies	Soil Boring, Clearing and grading permits
Scenic Resources	CEQA statutes Section 21084(b), CEQA Guidelines Section 15300.2(d)	Scenic Resources Evaluation
Public Parks, Recreation Areas, Wildlife/Waterfowl Refuges, Historic Sites	Department of Transportation Act (49 USC 303) Section 4(f)	Caltrans Determination
Private Property	Property Owner	Private Property Access Permit

7.3 Construction General Permit Requirements

Construction activities associated with a monitoring project are subject to the requirements of the most recently adopted version of the Construction General Permit, NPDES General Permit for Storm Water Discharges associated with Construction and Land Disturbance Activities. Under this permit, a Storm Water Pollution Prevention Plan (SWPPP) is required for any construction activity resulting in greater than one acre (0.4 hectare) of soil disturbance or is considered part of a larger Common Plan of Development totaling one acre. Development of a Water Pollution Control Program (WPCP) is required for construction activities resulting in less than one acre of soil disturbance.

A SWPPP is rarely needed for monitoring projects; however, some monitoring projects may require preparation of a WPCP. The WPCP must comply with Section 7-1.01G (Water Quality) of the Caltrans Standard Specifications, and with any provisions specified in the contract. Guidelines, templates, and samples useful in preparation of a

Water Pollution Control Program may be found on the Division of Construction website at the following link:

https://dot.ca.gov/programs/construction/storm-water-and-water-pollution-control

The Caltrans NPDES Coordinator should be contacted during the monitoring project planning phase to determine if a SWPPP or WPCP is required, and for assistance in preparing any required documents. The SWPPP or WPCP must be certified by the consultant’s resident engineer and reviewed for acceptability by the Caltrans Construction representative. If a SWPPP is required, the consultant must also prepare a Notice of Construction, which must be submitted to the RWQCB at least 30 days prior to construction.

8 Equipment Installation and Maintenance

This chapter provides guidance for the installation and maintenance of stormwater monitoring equipment. For a discussion of the principles of operation of this equipment, see Chapter 4.

The following aspects of equipment installation and maintenance are discussed in this chapter:

- Flumes and weirs
- Flow meters
- Autosamplers
- Sampler tubing, strainer, and conduit
- Data loggers
- Rain gauges
- Telemetry
- Protective equipment enclosures
- Confined space entry
- Equipment demobilization
- Checking out/turning in equipment from/to Caltrans

8.1 General Design of a Caltrans Stormwater Monitoring Station

A typical Caltrans automated monitoring station consists of the following components:

- Flume or weir
- Flow meter
- Autosampler
- Sample collection tubing and strainer
- Composite sample container
- Data logger

- Rain gauge
- Telemetry
- Power supply
- Protective equipment enclosure

Figure 8.1 shows the components of a typical automated monitoring station. Figure 8-2 illustrates a schematic layout of an automated monitoring station that incorporates these components.

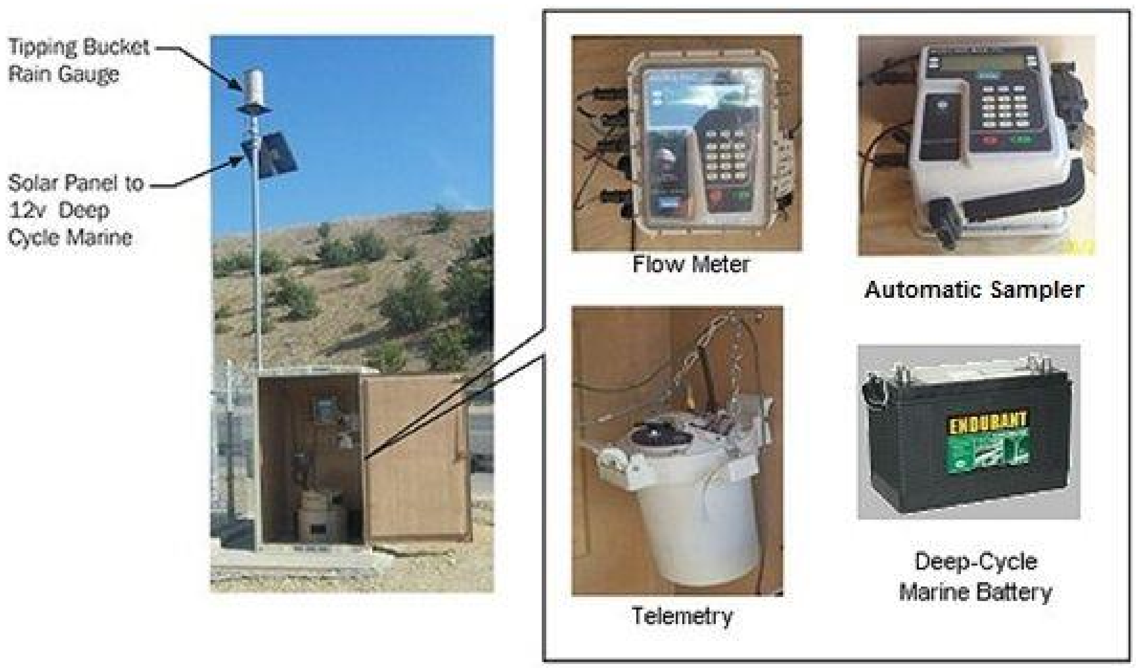


Figure 8-1 Components of a Typical Automated Monitoring Station

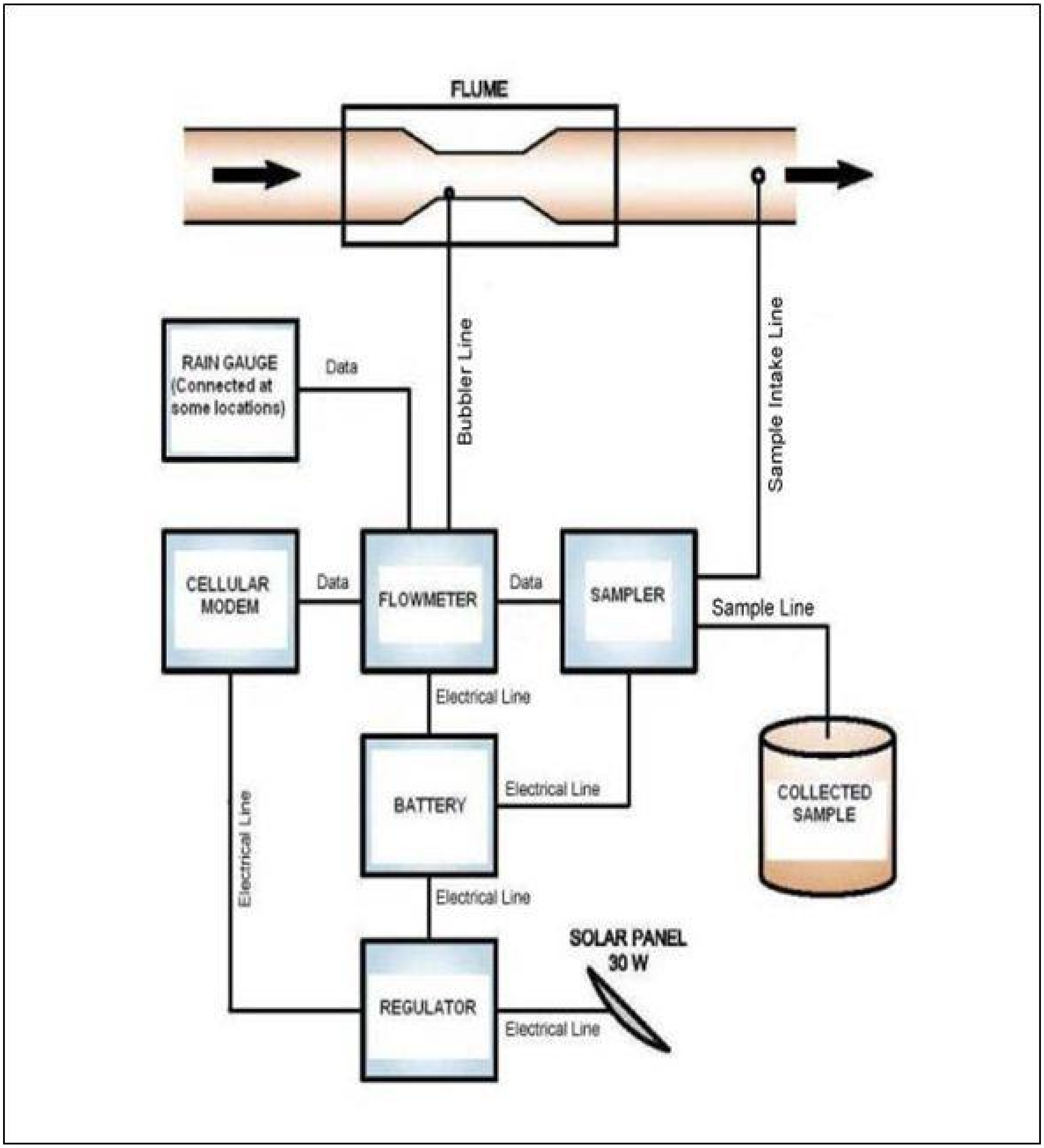


Figure 8-2 Schematic of an Automated Monitoring Station

8.2 Flumes and Weirs

As discussed in Chapter 4, the two primary flow measurement devices used by Caltrans are flumes and weirs. It is possible to measure flow volume without these devices, but much more accurate flow volume measurements can be made using a primary flow measurement device and automated flow meter together.

The most important consideration when selecting a primary device is that it be the proper size for the expected flow rates. Flumes and weirs are calibrated for a minimum and maximum flow rate, and flow rates outside these limits will not be measured accurately. Also, flumes and weirs often constrict flow, and flumes and weirs that are too small may cause flooding upstream during heavy storms.

Some minor construction is often required to install a primary device. These structures must be level and anchored to the ground securely, so they do not move over the life of the project. This is critical for accurate, consistent flow measurement. Ordinarily, this involves either partially embedding the device securely in the ground or constructing a concrete pad and anchoring the device to it.

Prefabricated flumes and weirs are certified by the manufacturer to operate accurately within a specific range of flow rates. A prefabricated primary device must be installed according to the manufacturers' specifications.

8.2.1 Flumes

Flumes may be installed in channels of small-to-moderate size. In general, the width of the entrance to the flume should equal the width of the channel being monitored. The flume crest is usually set level with or slightly higher than the bed of the approach channel. Flumes may be set in concrete or earth or bolted to companion structures. When pouring concrete, the flume should be braced internally to prevent distortion of the flume walls.

Water must enter the flume in a smooth, free-flowing manner, with minimal turbulence and uniform velocity across the width of the channel. To create these conditions there must be a section of straight length of channel upstream of the flume that is long enough to produce steady, uniform flow without standing waves. The straight length of channel required may be ten to 40 times the flume throat width, depending upon the channel geometry and flow conditions (Bos, 1989). Upstream turbulence can cause non-uniform flow in the flume itself, which can invalidate the stage-discharge relationship and result in erroneous flow measurements.

The portion of the channel directly downstream of the flume should allow water to flow freely away from the flume. A downstream channel that is restricted or undersized can cause resistance to flow, creating a backwater effect. This condition is called submerged flow, and it can cause water to back up into the flume, reducing the flow velocity and invalidating the flume's stage-discharge relationship. Different flume designs have different levels of tolerance for submerged flow. Some flumes can operate under varying degrees of submergence using a correction factor. Other flume designs cannot tolerate any submergence; for example, an H-flume requires free-fall conditions at the downstream end.

Because water accelerates through a flume, the deposition of sediment is not normally a serious problem. However, flumes can become clogged with debris. When constructing a monitoring site, consideration should be given to conditions upstream that could contribute vegetation, litter, or other materials that could get stuck while passing through a flume.

8.2.2 Weirs

Weirs can be installed in channels and pipes of a wide range of sizes. A weir must be installed such that the approaching flow has negligible velocity and is free from turbulence. To achieve these conditions, the weir should be installed in a natural channel with a long approach and with little or no slope. When possible, the approach to a weir should be a straight channel for a distance of at least 20 times the maximum expected depth of water within the pool.

Weirs must be constructed and installed to ensure water flows over the crest in free-fall, with air space between the nappe (flow over the weir) and the downstream face of the weir. A weir plate should be ⅛- to ¼-inch thick with a straight edge or a thicker plate with a downstream chamfered edge. The upstream edge of the weir must be sharp, with right angle corners. The upstream face should be smooth and perpendicular to the axis of the channel in both horizontal and vertical directions. The weir crest must be set higher than the water level downstream of the weir so water gravity-flows over the weir freely. The crest of the weir also must be exactly level to ensure a uniform depth of flow over the weir crest.

For more information about design and installation of primary flow measurement devices, see Teledyne Isco (2008) and the Caltrans Standard Operating Procedures for Stormwater Flow Measurement Verification (Caltrans 2010).

8.2.3 Calibration and Maintenance of Flumes and Weirs

Prefabricated primary flow measurement devices come calibrated from the manufacturer. Primary devices that are constructed onsite must be sized properly for the expected range of flow rates (Caltrans 2010). Primary devices do not usually need to be recalibrated unless a condition at the site changes.

Because stormwater flow usually carries sediment and debris, most primary devices require periodic cleaning of the approach channel. Regular cleaning and maintenance are recommended to assure measurement quality. Primary devices should be inspected before every storm event to make sure they are clean and do not show signs of wear or damage that could affect the measurement of flow rate.

Weirs are fairly high-maintenance primary devices. When using a weir, it is important to inspect it frequently and remove sediment/debris that has accumulated behind it. Sediment and debris accumulated behind the weir or trapped on the crest may invalidate the head-discharge relationship and prevent the weir from operating properly.

8.2.4 Use of Existing Conveyances

There are circumstances where it may not be possible to install a primary flow measurement device. In these cases, the monitoring consultant must search the study area for locations where stormwater discharge flows through a natural or artificial conveyance, with a known geometry, that can be used for flow monitoring, in conjunction with a depth measurement device or an area-velocity flow meter.

8.3 Flow Meters

Any instrument that measures the flow depth in a flume or weir may be considered a flow meter. However, in nearly all cases, Caltrans monitoring consultants use automated flow meters for this purpose.

The configuration and flow characteristics of the channel determine the best type of automated flow meter to use for accurately measuring flow.

Different flow meter sensors work on different principles, based on their mode of depth measurement, as described in Chapter 4. A meter must be selected that is appropriate for the hydraulic structure that is being used for flow measurement. The three types of depth-based flow meter sensors normally used by Caltrans are bubblers, pressure transducers, and ultrasonic sensors. A fourth kind of sensor, the area-velocity probe, is often used in situations where a primary device cannot be installed or where there are backwater effects.

The following discussion of various kinds of sensors is an overview. Flow meters should always be installed according to manufacturers' specifications. See Table 4-4 for a comparison of the advantages and disadvantages of each kind of sensor.

8.3.1 Bubbler

A bubbler-type flow meter makes use of a 1/8-inch vinyl tube that is submerged in the stormwater discharge, connected to a controller unit in the flow meter. The bubbler controller unit measures the amount of force that is required to push bubbles out of the end of the submerged tube. The amount of force required to push air out of the tube is proportional to the depth of the water.

A bubbler tube must be installed at the invert (bottom) of the primary device at the point where flow is to be measured. The bubbler tube must be anchored securely in place and should not move over the life of the project. Any change in the position of the bubbler tube can cause a loss of accuracy.

The bubbler tube should be routed so it slopes downward continuously from the flow meter to the flow stream so that any condensation that forms in the tubing will drain out of the tube. If moisture collects in a low spot in the tubing it could restrict the flow of air and cause erroneous readings. The opening of the bubbler tube must not point upstream in the pipe or channel.

The length of bubbler tubing that runs between the channel and the controller should be as short as possible. Excess tubing increases the likelihood of cuts, kinks, and problems with condensation. The tube should be a single continuous piece, with no spliced connections. Care should be used during installation not to cut or kink the tubing. If possible, the tubing should be placed in a conduit to protect it from being kinked or damaged.

8.3.2 Pressure Transducer

A pressure transducer is a submerged sensor with a pressure-sensitive diaphragm. This diaphragm is deflected proportionately as the depth of flow increases. The amount of deflection is measured and transmitted to the controller unit, where it is converted into a measurement of flow rate.

Pressure transducers must be placed at the invert of the primary device at the point where flow is to be measured. They should be placed to one side of the stream if possible so they are not in the path of silt that might build up around them. If possible, the cord that connects the sensor to the controller unit should be placed in a conduit to protect it from damage.

8.3.3 Ultrasonic Depth Sensor

An ultrasonic depth sensor is mounted above the flow at the point in the primary device where depth is to be measured. The sensor emits a high-frequency ultrasonic pulse that is reflected off the surface of the water. The time that the pulse takes to echo back to the sensor is proportional to the flow depth.

The ultrasonic sensor must be installed where there are no obstructions between it and the surface of the water. Ultrasonic pulses can reflect off any surface, such as ladder rungs or the side walls of the conveyance and create false readings.

The sensor will stop reading the level when the water reaches the sensor housing, so it must be installed higher than the highest expected water level.

8.3.4 Area-Velocity Probe

An area-velocity probe continuously measures both depth and velocity of a stormwater flow.

Depth is measured either by the bubbler technique or pressure transducer, as described above. The velocity sensor is integrated with either a bubbler tube or pressure transducer sensor. The velocity sensor emits an ultrasonic signal that measures the “Doppler” shift as reflected off particles in the moving water.

Area-velocity probes are usually installed in locations where it is not possible to install a primary flow measurement device, and where an existing channel or conveyance must be used instead. An area-velocity probe must be placed at the invert of the pipe or channel at the point where flow is to be measured. The probe should be placed in the center of the channel so the ultrasonic pulse is directed down the center of the flow; a probe placed near the side of the channel will measure velocity closer to the channel wall, where the velocity may not be representative of the entire flow. Also, placing an area-velocity probe too near the side of a channel might cause the ultrasonic signal to bounce off the channel wall, which could cause a false reading.

8.3.5 Other Considerations for Probe Installation

The cable that attaches the sensor to the flow meter must be mounted so that it prevents the cable from obstructing flow and interfering with the sensor. Because turbulence can significantly influence the sensor’s ability to take measurements in the flow stream, placement of the sensor is extremely important. Avoid installing sensors near obstructions, vertical drops, pipe bends, and elbows, which can create turbulence. The sensor's cable and conduit also must be secured in a manner that will not create turbulence.

The cable or tube that connects the sensor to the flow meter should be housed in a conduit to the point at which it enters the protective enclosure. When installed in a pipe, bubbler tubes, pressure transducers, or area-velocity sensors must be located at the bottom of the pipe and far enough into the pipe so that water turbulence is minimized.

8.4 Flow Meter Installation

The flow meter is installed inside the protective equipment enclosure. This device must be securely fastened to the inside of the enclosure so that controls, display windows, and cable connections are easily accessible. Cables entering/exiting the flow meter must be secured to the inside of the enclosure to reduce the potential for accidental disconnection or damage.

8.4.1 Flow Meter Calibration and Maintenance

The flow meter must be calibrated and maintained following the manufacturers' instructions. This must be done at the start of each monitoring season and may require additional maintenance, based on the manufacturers' recommendations. Calibration and maintenance requirements should be specified in the QAPP for the monitoring project (see Appendix A).

Electronic sensors need occasional maintenance to assure that they are performing properly. The flow meter and sensor cables must be inspected prior to each stormwater monitoring season and after significant flow events occur. Connections between flow meter and sensor must be visually inspected prior to each monitoring event.

General guidelines on the calibration and maintenance of typical sensors used in flow meter installations are presented below.

8.4.1.1 Bubbler

Bubbler level meters are relatively simple devices and are typically not affected by wind, turbulence, surface foam, floating debris, or periods of dry weather between sampling periods.

The bubbler tube should be inspected periodically for damage and the outlet of the bubbler tube should be inspected to make sure it has not become clogged with sediment or algae. Some flow meters are equipped with an automatic or programmable purge feature to periodically clear the bubbler tube with a blast of air from the pump. Clogged or fouled tubing should be cleaned, or the fouled tip can be cut off and the clean tip repositioned in the primary device, channel, or pipe. If clogging proves to be a continuing problem, the bubbler tube may be replaced with a larger inside diameter tube.

8.4.1.2 Pressure Transducer

The accuracy level of a pressure transducer is potentially affected by dry conditions between storms, contaminants in the water, debris, and freezing conditions. During higher flows, the sensor may be damaged by heavy debris bouncing along the conveyance. Frequent inspection and maintenance of these devices may be required, especially during periods of dry weather, as well as following periods of high flow.

8.4.1.3 Ultrasonic Depth Sensor

Ultrasonic depth sensors are typically mounted in a channel. The accuracy of downward-facing ultrasonic depth sensors can be affected by wind conditions, loud noises, turbulence, and foam. The minimum distance above the water necessary for installing these sensors is oftentimes not achievable in small spaces.

8.4.1.4 Area-Velocity Sensor

Area-velocity (AV) sensors can be installed in locations with a potential backwater condition, or in situations where installing a primary flow measurement device is not feasible. AV sensors can be mounted in open channels or in locations with pressurized flow and, when calibrated correctly, can be more accurate than stage-discharge-based flow measurements. However, high concentrations of suspended solids can reduce signal return, making the ultrasonic sensor used in the area-velocity probe susceptible to inaccurate measurements. In addition, ultrasonic sensors may be less accurate under low-flow conditions when the probe is only partially submerged. This type of sensor also does not perform well in flows with very low amounts of suspended solids.

As with pressure transducers, the accuracy of an AV sensor is potentially affected by dry conditions between storms, contaminants in the water, debris, and freezing conditions. During higher flows, the sensor may be damaged by heavy debris bouncing along the conveyance. Frequent inspection may be required, especially during periods of dry weather, as well as following periods of high flow.

Flow meters contain desiccant packets and moisture indicators to keep internal equipment components dry. The moisture indicators must be checked during each site visit and before each monitoring event. System malfunctions can often be attributed to high moisture levels inside the equipment. Dry desiccant is blue; when it turns pink, this indicates it is saturated and must be replaced.

Figure 8.3 shows a standard flow meter calibration form. This form can be printed for use in the field to record flow meter calibration.

FLOW METER CALIBRATION FORM
GENERAL INFORMATION

Caltrans Site ID:		
Date:	Time In:	Time Out:
Personnel:		Stormwater Consultant:
BMP Location:		

PREPARATION

1. Plug drain hole in calibration bucket. Fill bucket to 11 Inch mark on ruled scale.
2. Place calibration bucket on top of drain bucket to capture water as it drains.
3. Detach bubbler tube from brass nipple on flow meter.
4. Attach calibration bucket bubbler tube to flow meter.

CALIBRATION

1. Press green **ON** key. Press white **LEVEL ADJUST** key.
2. Enter a level of **11 Inch** and select **ACCEPT** from upper left corner of liquid crystal diode (LCD) screen.
3. Press white **MAIN MENU** key. Select **STATUS** from lower right corner of LCD screen.
4. Remove drain plug from calibration bucket. Allow the bucket to drain slowly.
5. Record flow meter **LEVEL** reading as bucket drains past the following increments:

	CAL #1	CAL #2	CAL #3
10 IN			
8 IN			
6 IN			
4 IN			
2 IN			

6. If all five level readings are within 0.15 IN of the corresponding calibration bucket levels, skip step
7. Repeat preparation and calibration procedure. If three calibrations do not yield accurate level readings, discontinue calibration. The flow meter is confirmed to be malfunctioning.
8. Remove calibration bucket bubbler tube from flow meter.
9. If flow meter level does not promptly return to **0.0**, it is confirmed to be malfunctioning.

EQUIPMENT STATUS

CALIBRATION SUCCESSFUL	FLOW METER IS FUNCTIONING PROPERLY
(CIRCLE ONE)	(CIRCLE ONE)
CALIBRATION UNSUCCESSFUL	FLOW METER NEEDS REPAIR

COMMENTS

TEAM LEADER'S SIGNATURE:

Figure 8-3 Calibration Form for an Automated Flow Meter

8.5 AUTOSAMPLER INSTALLATION

Autosamplers are installed inside a protective equipment enclosure, along with other components of the automated monitoring station such as the flow meter, the data logger, and the sample container.

The autosampler must be installed in a manner that provides easy access to controls, display windows, and cable connections. Adequate space must be available in the equipment enclosure to allow for easy removal and replacement of sample containers from the autosampler. Wiring must be well-organized and secured to the inside of the enclosure to prevent accidental disconnection or damage. The autosampler must be oriented in a way that allows the sample intake tubing to enter the sampler enclosure without bending sharply or kinking, and allows easy access for tubing replacement. A typical installation is shown in Figure 8.4.

Figure 8-4 Autosampler with Tubing

Although most autosamplers can operate independently, in Caltrans installations they are almost always actuated by a flow meter. These two pieces of equipment should be installed near each other, out of the way of other equipment such as batteries and sample carboys that are moved more frequently. The cables that connect them should be attached to the wall of the protective enclosure so they will not be snagged during routine monitoring activities.

In cases where very large sample volumes are required to meet the project objectives, two autosamplers can be connected to, and actuated by, a single flow meter. The autosamplers are connected to the flow meter by a splitter that sends the actuator signal to both autosamplers at the same time. This configuration allows a monitoring station to collect more sample volume because the two samplers collect samples simultaneously.

Figure 8-5 shows the inside of a protective equipment enclosure that has been equipped with two autosamplers that are actuated by a single flow meter.

Figure 8-5 Dual Autosampler Installation

8.5.1 AUTOSAMPLER CALIBRATION AND MAINTENANCE

An autosampler is calibrated by programming it to pump a certain water volume and then pumping water from one container into another. If the programmed volume and the actual pumped volume do not agree then the sampler is adjusted and the process is repeated until the measured volume equals the programmed volume. This procedure can vary between manufacturers and models. Required maintenance can also vary between instruments. For step-by-step instructions on calibrating and maintaining autosamplers, see the manufacturer's instructions.

At minimum, autosampler calibration must be checked prior to each stormwater monitoring season. After each stormwater monitoring event, the sample containers must be checked to verify that the programmed sample volume was delivered by the autosampler. If the volume of sample pumped into the sample containers does not agree with the recorded sample volume, then the autosampler must be recalibrated prior to the next monitoring event.

Figure 8.6 shows a standard autosampler calibration form. This form can be printed and used in the field to record autosampler calibration.

Automatic Sample Calibration			
Caltrans Site ID:			
Date:	Time In:		Time Out:
Personnel:		Stormwater Consultant:	
BMP Location:			
CALIBRATION			
1. Press green **ON** key. Press white **MANUAL MODE** key.			
2. Select **GRAB SAMPLE** from lower left corner of LCD screen.			
3. Enter a **GRAB SAMPLE VOLUME** of:	250 ml	or 500 ml	or 1,000 ml
4. Select **ACCEPT** from corner of LCD screen.			
5. Allow grab sample to pump into graduated cylinder.			
6. Record target volume:			Record actual volume:
If volume is within 15 mL of target volume, **STOP HERE**. No calibration necessary.			
7. Press white **MAIN MENU** key.			
8. Select **OPTIONS** from lower left corner of LCD screen.			
9. Select **VOLUME CALIBRATION** from upper right corner of LCD screen.			
10. Select **MANUAL CALIBRATION** from list on LCD screen.			
11. Select **START PUMPING** from upper right corner of LCD screen.			
12. Allow calibration sample to pump into graduated cylinder.			
13. Select **DONE** from upper right corner of LCD screen.			
14. Enter volume collected in graduated cylinder.			
15. Record target volume:			Record actual volume:
16. Select **ACCEPT** from upper left corner of LCD screen.			
Repeat steps 1 through 6.			
Record target volume:			Record actual volume:
Repeat calibration procedure until **GRAB SAMPLE** volume is within 15 mL of target volume. Record additional calibrations below.			
Calibration	Record target volume:		Record actual volume:
Grab Sample	Record target volume:		Record actual volume:
Calibration	Record target volume:		Record actual volume:
Grab Sample	Record target volume:		Record actual volume:
EQUIPMENT STATUS			
Choose One:			
NO CALIBRATION NECESSARY CALIBRATION DIFFICULT			CALIBRATION SUCCESSFUL CALIBRATION UNSUCCESSFUL
COMMENTS:			
TEAM LEADER'S SIGNATURE:			DATE:

Figure 8-6 Calibration Form for an Autosampler

8.6 Sampling Tubing, Strainer, and Conduit Installation

Prior to installation, all sampling equipment, including tubes and strainers, that comes into contact with a sample must be cleaned according to the procedure presented in Appendix A. After cleaning, to prevent contamination, the tubing must be sealed at both ends and double-bagged in sealable plastic bags for storage.

Two kinds of tubing are used in a standard peristaltic pump-type autosampler setup:

- Pump Tubing – A short length of flexible tubing made of a flexible, resilient material such as Tygon®.
- Sample Intake Tubing – Solid Teflon® or Teflon®-lined vinyl tubing that attaches to the pump tubing and runs from the autosampler to the sample intake location.

8.6.1 Pump Tubing

The pump tubing is installed by removing the cover of the peristaltic pump and threading the tube inside, between the pump housing and the rotors. The diameter of the pump tubing may vary according to the brand and model of the pump being installed. Pump tubing must be properly sized for the pump. Consult the manufacturers' specifications for pump tubing. The easiest way to make sure the pump tubing is sized properly is to purchase it directly from the autosampler manufacturer.

8.6.2 Sample Intake Tubing

Sample intake tubing is connected to the sampler tubing by inserting it at least ½ inch into the pump tubing and securing it with a clamp. The intake tubing must be sized so it fits snugly inside the sampler tubing, forming a tight fit that can hold a vacuum and will not leak. A standard size for intake tubing is 3/8-inch, but this may vary according to the type of sampler tubing.

Sample intake tubing runs from inside the protective equipment enclosure to the sample collection point, usually the invert of the primary device or other water conveyance. The tubing must be large enough to avoid plugging and small enough to provide sufficient sample velocity to accommodate complete transport of suspended solids without settling out.

Intake tubing must be installed so it slopes downward from the protective enclosure to the conveyance. This allows the tubing to drain naturally between sample collections. However, the sampler cannot be installed too far above the sampling point. The amount of vertical distance the water is pumped, called the vertical lift, cannot exceed 27 feet and, ideally, should not exceed about 15 feet to avoid excessive wear on the pump and pump tubing.

The sample intake tubing should be installed inside a protective metal or PVC conduit. The conduit should be secured to the protective enclosure and the primary device or conveyance. The conduit protects the sample tube from accidental damage. In cold weather environments, the intake tubing needs to be insulated to prevent samples from freezing inside the tube and consequently causing flow blockage.

Figure 8-7 Sample Intake Tubing Running from Inside a Protective Enclosure to the Invert of a Stormwater Conveyance

When installing the sampler tubing, field technicians must use the clean-hands techniques discussed in Appendix B to keep the tubing clean. The ends of the tubing should remain capped until they are fastened to the autosampler and the strainer. Tubing should be handled only with clean, powder-free nitrile gloves, and the uncapped ends must not be allowed to come into contact with any surface that might introduce contamination.

8.6.3 STRAINERS

Once the sampler tubing has been installed, a strainer must be attached to the sample-collection end of the intake tube. Again, the clean-hands technique should be used to prevent contamination. The strainer is installed to prevent sticks, trash, small aquatic organisms, and debris from being sucked into the sample intake tube and clogging the pump.

Strainers may be made of Teflon®, Kevlar®, or stainless steel that is fully coated with Teflon® or polyethylene. Strainers, like any other part of the sample collection system that comes into contact with the sample, should have no exposed metallic surfaces so trace amounts of metals cannot be introduced into the sample (a strainer is pictured in Figure 4-3).

Proper placement of the sample intake strainer helps ensure that samples collected are representative of the entire discharge. The strainer is usually placed at the invert of the primary device or conveyance so it can collect samples during low flow conditions. The strainer may be mounted slightly above the invert, on the side of the channel wall, if high solids loadings are expected and if the strainer will remain submerged during the lowest expected flows. This positioning will reduce the amount of sediment entering the strainer and help prevent clogging.

8.6.4 Tubing and Strainer Inspection and Maintenance

Sample intake tubing and pump tubing must be replaced prior to each stormwater monitoring season. Tubing can be left in place for the duration of the season unless it is damaged or becomes contaminated.

Intake tubing must be checked for kinks or cracks and to make sure it is still securely fastened to the autosampler. The strainer must be checked to make sure it is clean, not clogged, and is still fastened securely to the intake tubing. Pump tubing must be checked for wear from the peristaltic sample pump after each monitoring event. Any tubing found to be worn or damaged must be replaced before the next monitoring event.

8.7 Data Loggers

A data logger is an electronic device that integrates into an automated monitoring station and keeps a continuous record of the following site parameters:

- Flow Rate – Volume of flow passing through the monitored conveyance
- Precipitation Depth – Amount of rain measured throughout the monitoring event
- Sample History – The time each sample was taken by the autosampler
- Error History – A log of every error encountered by the rest of the automatic equipment at the monitoring station

Nearly all flow meters used for Caltrans stormwater monitoring have built-in data logging capability, so a separate data logger is not required. Third-party data logging equipment is also available, but it is not used by Caltrans for stormwater monitoring and is not covered in this manual.

Data loggers record data over the life of each monitoring event and are interrogated by field personnel following each event to download data and reset the memory. This is done either onsite or remotely via telemetry. At minimum, data loggers must be set to collect data every five minutes during storm events, and may be set to collect data more frequently, depending on the size and intensity of the storm, the memory capacity of the logger, and the requirements of the project.

The data logger is left on throughout the storm season. Continuous data records must be maintained in a format compatible with the Caltrans Hydrologic Utility (Caltrans 2011). At a minimum, the data logger must be programmed to record continuous hydrology data at 15-minute intervals during non-storm event periods. Non-storm event data are used to assess the antecedent dry period prior to monitored storms and to identify sites where dry weather flow is present.

Data loggers have a limited amount of memory, which must be considered when setting up an automated monitoring station. If data are not downloaded from the instrument in a timely manner, the data logger's memory will fill up and it will no longer collect data. Monitoring consultants should have data loggers retrofitted with extended memory if they will be installed in an area that is difficult to access.

Data logger memory may be configured to operate in either of two modes:

- Slate Mode – Data are logged until memory is full, then the logger stops recording data.
- Wrap-around Mode – When the logger fills available memory it "wraps around" to the beginning and continues to record data, overwriting the data it collected previously.

It is recommended that data loggers be set to slate memory mode and interrogated regularly to avoid losing data. The more frequently the logger is set to record data, the faster memory will fill up; field technicians must keep this in mind and ensure that downloads are frequent enough to prevent lost or overwritten data.

8.7.1 Data Logging Equipment Maintenance

Data loggers should be inspected prior to each storm event to verify they are working properly. A data logger has an internal battery, so its memory will not be erased if the unit loses power. The battery should be inspected periodically to make sure it is still holding a charge. Because Caltrans uses data loggers that are integrated with flow meters, routine maintenance of these devices is covered under flow meter maintenance.

8.8 Rain Gauges

Rainfall can be measured using any of several devices, as described in Chapter 4. Automatic tipping-bucket rain gauges are the only kind of onsite precipitation measurement device used by Caltrans for stormwater monitoring.

8.8.1 Rain Gauge Installation

A rain gauge should always be installed in an elevated position so activity on the ground (from field personnel, animals, nearby traffic) does not splash water into it. Rain gauges should be installed and maintained according to manufacturers' specifications. Following are common guidelines (National Atmospheric Deposition Program/National Trends Network [NADP/NTN], 1984–2001):

- Rain gauges must be installed securely in a location where buildings, trees, overpasses, additional solar panels mounted on adjacent poles, or other objects will not obstruct or divert rainfall from falling into the rain gauge.
- Rain gauges should be leveled when they are installed. Most rain gauges are equipped with a built-in bubble level gauge for this purpose.
- Solar panels should not be installed on the sample pole as rain gauges. The solar panels can catch wind in a storm, rocking the pole, and tipping the rain gauge.
- Rain gauges should be installed such that the openings are horizontal and level and secured so they remain level in extreme weather conditions.
- Rain gauges should be installed over undisturbed land at least three feet above the ground.
- In areas having an accumulation of over two feet of snow per year, a rain gauge should be at least 12 inches above the usual seasonal snow level. If a heated rain gauge is used to operate under freezing conditions, additional power will be needed.
- Annual vegetation around an installed rain gauge on a site should be maintained at a height of less than two feet.

Rain gauges are typically mounted on top of a rigid metal pole, as shown in Figure 8.8. The signal wire runs down through the pole and into the protective equipment enclosure, where it is connected to the data logger (in most cases, this is the flow meter). The exposed length of signal wire between the pole and the enclosure should be protected by metal or PVC conduit.

Figure 8-8 Rain Gauge Installation and Inset View

Solar panels are sometimes installed on the same pole as the rain gauge. However, in high winds, the large surface area of a solar panel can catch the wind and cause the pole to shake. This can tip the bucket in the rain gauge, causing a false reading.

When installing a rain gauge, care must be taken to install it in such a way that rain will fall directly on it without being obstructed. Because rain can fall at a significant angle during windy storms, consideration must be given to nearby high trees or structures that might interfere with falling rain before it reaches the rain gauge. An example of an incorrectly placed rain gauge is shown in Figure 8.9.

Figure 8-9 Rain Gauge Blocked by Foliage

No object or structure should project over the rain gauge with an angle greater than 45° from the horizontal (30° is considered optimal, but 45° is the highest angle acceptable; refer to Figure 8.10). To satisfy this requirement, the distance from the rain gauge to the object must be at least equal to the height of the object and preferably twice the height of the object. In addition, wind obstructions should not be closer than two to four times the obstruction height, and objects with a height of over three feet that deflect wind should not be located closer than 16.5 feet from the collector.

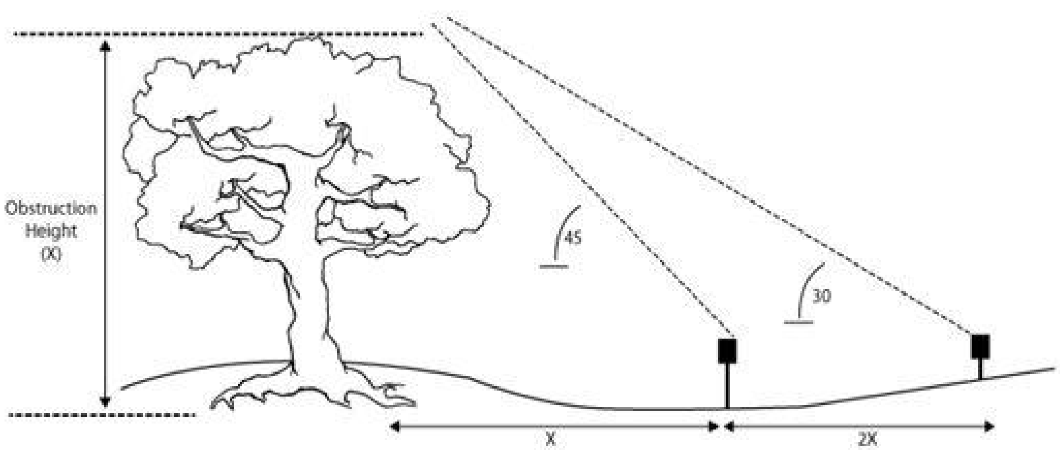


Figure 8-10 Correct Placement of a Rain Gauge

A rain gauge does not operate in freezing conditions unless it is equipped with a heating element. Heated rain gauges may be used where AC power is available. Rain gauges using antifreeze are also available but are susceptible to malfunction under high-wind conditions.

8.8.2 Rain Gauge Calibration and Maintenance

To function properly, rain gauges must be frequently maintained. The most common issue is fouling of the tipping bucket apparatus by bird droppings, leaves, or other materials. The gauge should be inspected prior to every potential monitoring event and cleaned as necessary.

At a minimum, rain gauges must be inspected, cleared of debris, and calibrated following manufacturer's directions prior to each stormwater monitoring season. The project QAPP must include equipment maintenance and calibration information. The gauge should be recalibrated following any instance of fouling from bird droppings or other materials, and at any time anomalous readings are observed.

8.9 Telemetry

Automated monitoring stations can be equipped with telemetry systems that allow field personnel to communicate with them remotely. Two-way telemetry allows field crews to download data, check the status of the station, receive error messages when equipment at the station malfunctions, and program the station from off site.

Many monitoring stations require cell phone service to establish telemetry connections. After equipment is installed, the cell phone service provider has to activate the internal modem built into telemetry equipment. Consider the following when selecting a cell phone service provider: service coverage and longevity, data download speed, and the ability to integrate with existing monitoring equipment.

Advances in communications technology can occasionally make older modes of cellular communication obsolete. For example, packet-switched cellular technology was used extensively by Caltrans for over a decade but has become almost completely superseded by faster and more reliable modes of data transmission. When selecting cellular service, the consultant must verify with the cellular provider that the equipment installed in the field can be expected to work over the life of the project.

8.9.1 Telemetry Equipment Installation

A site survey should be performed prior to installation, to assess telemetry equipment performance and determine appropriate antenna configuration. The site survey will also indicate if there is radio frequency interference from other sources that may impede the signal.

Prior to field installation, the site location, potential antenna locations, and cable routes should be identified. The distance between the antenna and the flow meter or sampler must be determined and conformity checked with the manufacturer's specifications. Telemetry equipment should be installed on a firm elevated support like a wall or a pole, which can be grounded.

The most critical part of the installation of telemetry equipment is the placement of the antenna. It is most common for cellular antennas to be placed on top of the protective equipment enclosure or in another elevated area where the signal is not obstructed.

Telemetry equipment must be installed according to the manufacturer's instructions. The telemetry unit is installed inside the equipment enclosure in an area where it will not be disturbed during normal monitoring activities, with the power and antenna cords securely fastened to the side of the enclosure.

8.9.2 Telemetry Equipment Maintenance

Telemetry equipment should be maintained according to the manufacturer's guidelines. Telemetry units are powered by internal batteries. These batteries must be checked before each monitoring event to make sure they are fully charged. Field personnel should check all connections before every storm to make sure the telemetry unit is firmly connected to the data logger, the antenna, and the battery. Connections should be checked for signs of corrosion. Telemetry units have internal desiccant packs to keep the electronics dry, and these should be inspected periodically and replaced if necessary.

8.10 Power Supply Equipment

Caltrans stormwater monitoring stations are typically powered by a combination of solar panels and deep-cycle marine batteries. While it is possible to operate this equipment using AC power, it is almost never cost-effective to run landline power to a monitoring station. The only exception is when refrigerated equipment enclosures must be used, because they cannot be operated on battery power.

8.10.1 Power Supply Equipment Installation

The power supply system of a Caltrans stormwater monitoring station typically consists of three components:

- Solar panel

- Solar panel regulator
- Deep-cycle marine battery

8.10.1.1 Solar Panel Installation

Solar panels should not be placed under trees or overpasses, or anything overhead that blocks sunlight. If the solar panel does not receive enough light, it may not be able to power the monitoring equipment. Solar panels should be mounted on tall steel poles whenever possible (the poles used for rain gauges should not be used for this purpose). This maximizes the amount of sunlight they receive, helps to keep them clean, and also helps to deter theft. The poles are normally bolted to the tops of the equipment enclosures with the bolts located on the inside; this also makes it more difficult for unauthorized individuals to remove them. Solar panels should be secured as shown in Figure 8.11.

Figure 8-11 Secure Solar Panel Installation

Power wires from the solar panels run down through the center of the pole and enter the equipment enclosure. The exposed length of cord between the pole and the enclosure should be protected by metal or PVC conduit. The power cords are connected to the solar panel regulator.

8.10.1.2 Solar Panel Regulator Installation

A solar panel regulator is installed inside the protective equipment enclosure. Power is generated by the solar panels, adjusted by the regulator if necessary, and then fed to the batteries. The regulator should be installed on the inside wall of the equipment enclosure, out of the way of field operations. Power cords should be secured to the inside wall of the enclosure, so they are not dislodged during monitoring activity.

8.10.1.3 Deep-cycle Marine Battery Installation

Batteries should be placed on the floor of the enclosure, out of the way of monitoring operations. They must be accessible to field personnel because replacement may be needed occasionally. Secondary containment for batteries should be provided so leaking acid does not cause damage to the enclosure or cause a hazard. Batteries should be covered to prevent water from splashing onto them.

8.10.1.4 Power Supply Equipment Maintenance

Immediately prior to each stormwater monitoring event, all power connections and wiring should be inspected, and all powered equipment should be checked to ensure each is receiving adequate power. Batteries must be checked during each site visit and replaced with freshly charged batteries, as necessary.

8.11 Protective Equipment Enclosures

Stormwater monitoring stations that incorporate automated monitoring equipment require a proper protective enclosure that can be locked, is resistant to vandalism and tampering, and provides protection from the elements. Protective equipment enclosures are almost always made of either steel or fiberglass. In areas where theft or vandalism are likely, protective enclosures should be made of metal and surrounded with chain-link fencing with a locked gate and razor wire along the top (Figure 8-12). The rain gauge and solar panel must be positioned central to the enclosure, or higher than the fencing and razor wire, to prevent tampering.

Equipment enclosures must be installed on secure pads that are usually constructed of wood or concrete. See Appendix N for an example of a specification for installing pads in the Caltrans right-of-way.

When installing any protective device such as barbed wire or razor wire, the monitoring consultant must receive approval from both the Caltrans District NPDES Coordinator and the local Caltrans District Traffic Operations or the Traffic Safety Staff/Supervisor. Because barbed wire and razor wire have the potential to cause injury to trespassers, use of these types of protective devices must be discussed with the Caltrans Task Order Manager before they are installed.

Figure 8-12 Monitoring Station Enclosed in a Secure Fence

Fiberglass enclosures come in various sizes, including a full-sized, walk-in style shown in Figure 8.13. This type of enclosure has the advantage of serving as a shelter from the elements where field technicians can write in their field logs and perform minor maintenance and repairs. Larger enclosures can also be used for storing equipment and supplies.

Figure 8-13 Walk-in Protective Equipment Enclosure

The protective enclosure needs to be secured to a structural pad, with wiring and tubing entering/exiting the enclosure through appropriately sized conduit. The pad may be constructed of concrete, wood, or plastic. Concrete pads offer the most secure foundation for a monitoring station, but they are also more expensive to install than wood or plastic. In addition, there may be local regulations that do not allow concrete pads. For instance, in the Lake Tahoe region, local regulators require pads be constructed of redwood or painted wood planks. Check local requirements prior to installation. Figure N-1 shows two typical monitoring platform configurations.

8.12 Confined Space Entry

The installation and maintenance of stormwater monitoring devices often require entry into confined spaces. Only confined space-certified personnel, with proper equipment, may enter a confined space. Confined spaces are locations or enclosures with immediate potential for unhealthy concentrations of oxygen, atmospheres that may be flammable or explosive, or toxic materials that could cause health impacts upon contact or inhalation. The Occupational Health and Safety Administration requires employees who enter a confined space to be instructed about the nature of the hazards involved, the necessary precautions to be taken, and the use of protective and emergency equipment required for the job. During storm conditions, or at other times when significant flows are present, monitoring personnel must not enter a confined space. Below-ground-level space requiring entry for equipment installation must be evaluated by personnel trained and certified in confined space entry.

If an accident occurs, untrained personnel must not enter the confined space and must immediately request assistance from confined space-certified personnel. Confined space entry must be discussed in the Health and Safety Plan for the project or program (see Appendix C).

A permit or permits may be required for the installation of monitoring equipment. In addition, the local Caltrans District NPDES Coordinator and Traffic Operations Safety Supervisor should also be consulted prior to construction for a discussion of the permitting process.

8.13 Theft and Vandalism

Equipment losses due to theft or vandalism must be reported to the Caltrans Task Order Manager immediately, and to the city or state police, highway patrol, or sheriff, depending on the jurisdiction in which the theft or vandalism occurred. In such cases, a police report must be filed for Caltrans to process equipment replacement requests.

8.14 Equipment Demobilization and Summer Equipment Maintenance

Caltrans requires that electronic equipment be removed from monitoring enclosures during the summer months to protect the equipment from exposure to potentially damaging high temperatures. Sampler tubing and sampler strainers must be removed from the monitoring site and replaced prior to the next wet season.

At the end of each monitoring season, all electronic equipment must be removed from the monitoring sites and stored either in the consultant's offices or at one of the two Caltrans equipment storage yards. Equipment is removed from the field to minimize exposure to the public and to protect it from high summer temperatures.

Cords and wires that connect flow meters, autosamplers, solar panels, and rain gauges must all be carefully disconnected and stored. Wires must be coiled or wrapped individually, not wound together in bundles. Wires and cords must not be cut during the demobilization process unless there is no other way to remove them.

Consumable items such as tubing and polyethylene carboys should be removed from the site and either saved for the next season or discarded. The consultant should use best judgement when considering whether consumable materials should be re-used. If plastic carboys and tubing look stained or dirty, they should probably be disposed of and replaced at the beginning of the next monitoring season. Borosilicate glass carboys should not be disposed of unless they are cracked or damaged.

Electronic devices such as flow meters and autosamplers must not remain in the locked equipment enclosures over the summer. In many areas, the temperature inside equipment enclosures can easily reach 100 degrees or more, which could cause damage to sensitive electronic equipment. This equipment must be removed and stored in a relatively climate-controlled environment between storm seasons.

Solar panels and rain gauges must be removed from their poles and stored in a secure location. Removing this equipment from the field reduces the chance it will be vandalized or stolen.

Deep cycle marine batteries must not be left at the monitoring site over the summer. They should be evaluated for functionality by the consultant at the end of the storm season. If they can be used during the next season they should be stored safely at the consultant's offices. If not, useable, batteries should be taken to an authorized e-waste recycler. Batteries are not stored at the Caltrans storage facilities.

Equipment maintenance and repair should be done during the summer whenever possible, when the equipment is not being used. Malfunctioning equipment may be repaired by the consultant if possible or sent to the factory for service. Accumulated mud and grit should be wiped off monitoring equipment before it is stored so the equipment is ready to be re-deployed for the next storm season.

9 TRAINING

All field personnel must be familiar with the requirements of the project QAPP, the project Health and Safety Plan, and this manual before they are deployed into the field. An Operations, Maintenance, and Monitoring (OM&M) Plan is sometimes used in place of a QAPP.

This chapter describes a training session that will provide stormwater monitoring team members with the knowledge and skills to safely perform their assigned duties. Because stormwater sampling events are difficult to predict and monitoring projects often run a year or longer, it is desirable that one or more members of the sampling team remain involved throughout the project to ensure monitoring is performed consistently over the life of the project. All sampling team members should receive this training even though one person may be designated the primary field technician on the project. This training should ideally be provided by stormwater professionals who have both field and laboratory experience.

Stormwater monitoring training should include these basic elements:

- Classroom training session
- Field training session
- On-the-job training
- Annual refresher training

9.1 CLASSROOM TRAINING

It is recommended that team members and alternates attend a classroom training session to review sampling methodology and QC requirements specified in the QAPP. The training session outlined here should take approximately eight hours. The names of all employees who attend training must be recorded and kept in the project file so everyone associated with the project knows which field technicians are qualified to work on the project. Ideally, the training session should occur shortly before the monitoring phase of the project begins.

The elements of the training session are as follows:

- Overview of the project
- Review of the QAPP
- Operating/programming sampling instrumentation and equipment
- Review of the Health and Safety Plan
- Open discussion/questions and answers

The following documentation should be reviewed thoroughly by training personnel when they prepare the outline for the training session:

- The project QAPP
- The Project Health and Safety Plan
- Monitoring equipment user manuals
- This Guidance Manual

All trainees should sign an acknowledgement stating they have received the QAPP and the Health and Safety Plan, and they have reviewed them. These documents should be kept in the project file.

The training session should be organized chronologically to follow the normal progression of events from pre-monitoring preparations through post-monitoring activities.

Training materials should describe team organization, site-specific responsibilities of individual team members, and standard operating procedures for the sampling equipment. In addition, any questions arising from the document review can be addressed during this session. An outline of a typical classroom training session for Caltrans stormwater monitoring is shown in Figure 9-1.

Conduct a Project Overview – 2 Hours

1.0 Project need and purpose
2.0 Project goals
3.0 Project duration
4.0 Project organization
5.0 Responsibilities of all involved with the project
6.0 Sampling site locations
7.0 Weather tracking/storm selection

Review the QAPP **- 4 Hours**

8.0 Sample container procurement and labeling
9.0 Event mobilization procedures
10.0 Station preparation and maintenance
- 10.1 Pre-storm site visits
- 10.2 Storm event site visits

11.0 Notification procedures
- 11.1 Storm action levels
- 11.2 Telephone tree

12.0 Sample collection
- 12.1 Sampling site safety
- 12.2 Traffic control
- 12.3 Clean sample handling protocols
- 12.4 Sampling instrumentation and equipment
- 12.5 Grab and composite sample collection procedures
- 12.6 QA/QC sample collection
- 12.7 Sample preservation
- 12.8 Field observations
- 12.9 Mandatory equipment checks during event

13.0 Event demobilization procedures
- 13.1 Demobilization decision
- 13.2 Station shutdown
- 13.3 Sample compositing and splitting
- 13.4 Sample delivery (including holding time issues)
- 13.5 Chain-of-custody (COC) documentation

Review the Operation of Monitoring Equipment– 1 Hour

Review the Health and Safety Plan – 1 Hour

Open Discussion/Questions and Answers – 1 Hour

Figure 9-1 Outline for a Classroom Stormwater Training Session

During the training session, training personnel should circulate copies of the QAPP, the Health and Safety Plan, and any other appropriate documentation. The following items should be available during a training session:

- Documentation (QAPP, Health and Safety Plan, equipment manuals)
- Storm kit and sampling supplies
- A live demonstration of the automated sample collection equipment that will be used
- Sample bottles and labels
- Example of a properly filled-out chain-of-custody (COC) form

9.1.1 Conduct a Project Overview

The training session should begin with a description of the project background and purpose. For example, the project may be required by the Caltrans NPDES stormwater permit, may be a BMP pilot study, or may be a receiving water quality characterization study. The project goals should be stated and discussed. Staff should understand the organization of project responsibilities, the expected project duration, and be familiar with the number and location of the monitoring stations. Brief information on sample types, sample collection methods, and project safety should also be covered and then reinforced later during the classroom and field sessions. This project overview session should take approximately two hours.

9.1.2 Review the QAPP

Training personnel should highlight key sections of the QAPP and demonstrate the use of the monitoring equipment. To emphasize the importance of minimizing sample contamination, special attention should be given to proper sample handling using clean sampling techniques as discussed in Appendix B. Ample time should be provided for answering field team member questions.

Approximately four hours should be set aside to review and discuss the elements of the QAPP. Trainers should conduct a thorough review of project operations relating to sample container procurement and labeling, event mobilization, station preparation and maintenance, notification procedures, sample collection, demobilization, and conducting field measurements for parameters such as pH and temperature.

The following elements should be discussed in detail: event criteria, sampling frequency, monitoring team responsibilities, monitoring site details, analytical constituents, field equipment installation and maintenance, monitoring preparation and logistics, sample collection, laboratory methods, QA/QC, data management, and clean sampling techniques.

9.1.3 Review the Operation of Monitoring Equipment

This section of the training class should focus on discussion and demonstration of stormwater sampling equipment and instrumentation to be used for the project. Typically, this equipment includes primary measurement devices, flow meter devices, data logging and system control equipment, an autosampler and other sampling equipment, telecommunications equipment, a rain gauge, a power supply, and site enclosures. The following guidelines should be followed:

- Use the actual equipment/instruments that will be used in the project.
- Use video, photographs, or other audio-visual media showing essential details.
- For each equipment/instrument to be used, provide an overall product description, including product accuracy, reliability, durability, and versatility.
- Explain how equipment and instruments measure flow and hydrologic/water quality parameters and collect flow-proportioned composite samples of stormwater runoff.
- Provide other general information, e.g., use of automated/remote access features.
- Explain equipment calibration, operation, and programming.

9.1.4 Review the Health and Safety Plan

A Health and Safety Plan provides guidance on the health and safety issues that relate to field work associated with the project. Monitoring consultants provide their own Health and Safety Plans; however, any Health and Safety Plan that is used as part of a Caltrans project should reference Chapter 8 of the Caltrans Maintenance Manual (Protection of Workers) (Caltrans 2014).

Attention should be paid to hazards associated with working in the Caltrans right-of-way. Monitoring in these areas can involve working near uncovered conveyances, steep slopes, and high-voltage power lines. Sample collection in the Caltrans right-of-way often requires that personnel park vehicles on the shoulder of busy freeways and work near high-speed traffic or in proximity of construction and maintenance equipment/activities. In urban areas, Caltrans right-of-way is sometimes inhabited by transients, and field crews in rural areas may encounter dangerous wildlife. The Health and Safety Plan must include information on safe procedures when working near highways and these must be discussed during the training session.

Approximately one hour of the training session should be dedicated for a review of the Health and Safety Plan. Team members should be provided with a thorough overview of the project Health and Safety Plan as well as project-specific hazards. Team members should refer to the Health and Safety Plan over the duration of the project so that they are aware of the potential hazards and know how to avoid them.

During the Health and Safety Plan review session, attention should be given to the location and directions to the nearest hospital emergency room with respect to the location of each sampling site. Team members should also be instructed to report any unsafe conditions to the field task leader or project manager. If new safety concerns are discovered in the field, the Health and Safety Plan should be updated to include them. If field personnel encounter any situation that they believe to be unsafe, they are to leave the area immediately and contact their supervisors for guidance.

9.1.5 Open Discussion/Questions and Answers

During each training session, enough time should be allowed for a question and answer period. Discussion among participants should be encouraged, and all questions must be answered thoroughly. Instructors should provide their contact information to participants in cases where the participants may have questions after a monitoring project is initiated.

9.2 Field Training Session

When the classroom training session is complete, all participants should attend a field simulation as a “dry run,” under the supervision of the project manager or sampling team leader. This field training session should take approximately four hours and begin with a brief review of the key issues discussed in the classroom session. During the dry run, sampling team members travel to their assigned monitoring locations and run through the procedures specified in the Sample Collection section of the QAPP. These procedures include:

- Site access and site parking
- Working within the Caltrans right-of-way
- Working near moving traffic
- Traffic control measures (if any)
- Calibrating field equipment
- Preparing stations for monitoring
- Documenting field measurements
- Collecting stormwater samples
- Recording field observations and completing associated forms
- Downloading data from automated equipment
- Completing sample labels and field log forms
- Packing samples
- Delivering or shipping samples to laboratory

The equipment and materials required for wet-weather sampling events should be available and used to simulate, as closely as possible, the conditions of an actual sampling event. The stormwater monitoring team members should receive hands-on training with field equipment and sample handling procedures. The trainer should re-emphasize health and safety considerations during the field sampling simulation.

9.3 On-the-Job Training

In addition to classroom and field training, inexperienced monitoring personnel must complete training for one season under supervision of a field task leader or an experienced team member before being allowed to conduct monitoring without supervision. Upon completion of on-the-job training, every field technician should be able to explain the methods and procedures associated with all aspects of sampling and monitoring.

9.4 Annual Refresher Training

For multi-year projects, an annual two-hour refresher training session should be held prior to the onset of each subsequent monitoring season. During this session, the stormwater monitoring team members and alternates should review the QAPP and the Health and Safety Plan, with emphasis on individual team member responsibilities. The project manager or sampling team leader should provide more detailed instruction for any new team members, and, at his/her discretion, repeat the classroom training session and field sampling simulation if the sampling team includes new members.

10 Pre-Storm Preparation

Pre-storm preparations are essential for successful stormwater monitoring. Prior to deployment of field crews and the initiation of stormwater monitoring, weather systems must be tracked, field personnel must prepare, and necessary equipment must be inventoried. Sample bottles should be pre-labeled if possible.

Stormwater monitoring preparation includes the following elements:

- Weather tracking
- Storm action levels
- Communications
- Sample identification
- COC form preparation and sample bottles labeling
- Field equipment preparation
- Field crew mobilization
- Automated equipment programming

In addition, proper COC procedures should be followed, as described in Section 12.5.2.

10.1 Weather Tracking

The National Weather Service (NWS) provides weather, hydrologic, and climate forecasts and warnings for the United States. Forecasts can be obtained from the NWS website (www.weather.gov), along with imagery, maps and graphical forecasts, and forecast model results. The website also provides access to radar, satellite, and land-based weather station data.

An example of a typical weather forecast printout is shown in Appendix E. To supplement forecasts from the NWS, private weather forecasting services can be contracted to provide custom forecast services for specific locations on a weekly or semiweekly basis. Private weather forecasting services are also available on an on-call basis for telephone consultations regarding impending storm events. Additionally, weather information can be obtained from weather news available on the Weather Channel and local television forecasts, as well as other sources available on the

Internet. References for California weather forecasting services are provided in Appendix E.

For time periods of up to one week prior to the arrival of a storm system, NWS model predictions and satellite imagery form the basis of the predictive information provided by NWS and private forecasters. As prospective storms approach, NWS radar observations and hourly reports from land-based NWS weather stations may be used to track and evaluate storm progress. Telephone communication with a contract forecaster is an effective way to access current information from these sources. As rainfall becomes imminent, observations from local field personnel can also be useful.

Weather forecasts provide a quantitative precipitation forecast (QPF) and the associated probability for an impending storm event. QPF is the amount of precipitation, normally provided for discrete time intervals, for the expected duration of the storm.

The QPF and probability of precipitation are used to determine if consultation with Caltrans is necessary before mobilization. If a decision is made to target the storm for monitoring, QPF is used to determine whether the storm will produce enough runoff to allow for collection of an adequate set of samples. The QPF is also used to determine sampler pacing, to ensure the required number of sample aliquots are collected at appropriate flow intervals without under-filling or overfilling the composite bottles.

If a storm event QPF is over-predicted and the actual rainfall amount falls short of the prediction, the samples collected during the monitoring event may not be adequate for the specified analyses. If the QPF under-predicts the amount of rainfall received, then the composite bottles may need to be replaced one or more times during the event. (If necessary, the sampling frequency can be reduced at the time of such a bottle change.) It is better to err on the side of an under-predicted amount of rainfall, because adding more sample bottles during a storm event is preferable to having inadequate sample available for the specified analyses.

During the wet season, when the stormwater monitoring program is in progress, the monitoring task order manager or field monitoring coordinator tracks weather conditions and potential storms. The frequency of weather tracking increases as storm arrival time gets closer.

10.2 DEFINITION OF A STORM EVENT

Caltrans defines a storm event as follows:

1. A storm with precipitation of 0.1 inches or greater that produces measurable discharge and that occurs at least 72 hours from the previously measurable (greater than 0.1-inch precipitation) storm event (USEPA 2018).
1. The storm event begins with a period of six consecutive hours with cumulative precipitation of at least 0.1 inches.
2. The storm event ends with a period of six consecutive hours, each hour with precipitation less than or equal to 0.01 inches.

When representing the storm event on a hydrograph, the start of the storm event is truncated to the first interval with precipitation of at least 0.01 inches, and the end is truncated to the first one-hour interval with precipitation less than 0.01 inches or the sixth interval with 0.01 inches if all six ending intervals have 0.01 inches.

In any case where a storm is forecast to begin before the 72-hour antecedent criterion has been met, the monitoring consultant must contact the Caltrans Task Order Manager for guidance. Caltrans may opt to waive this requirement on a case-by-case basis, depending on the nature of the project and the study requirements.

Figure 10.1 displays a graphic representation of storm definition.

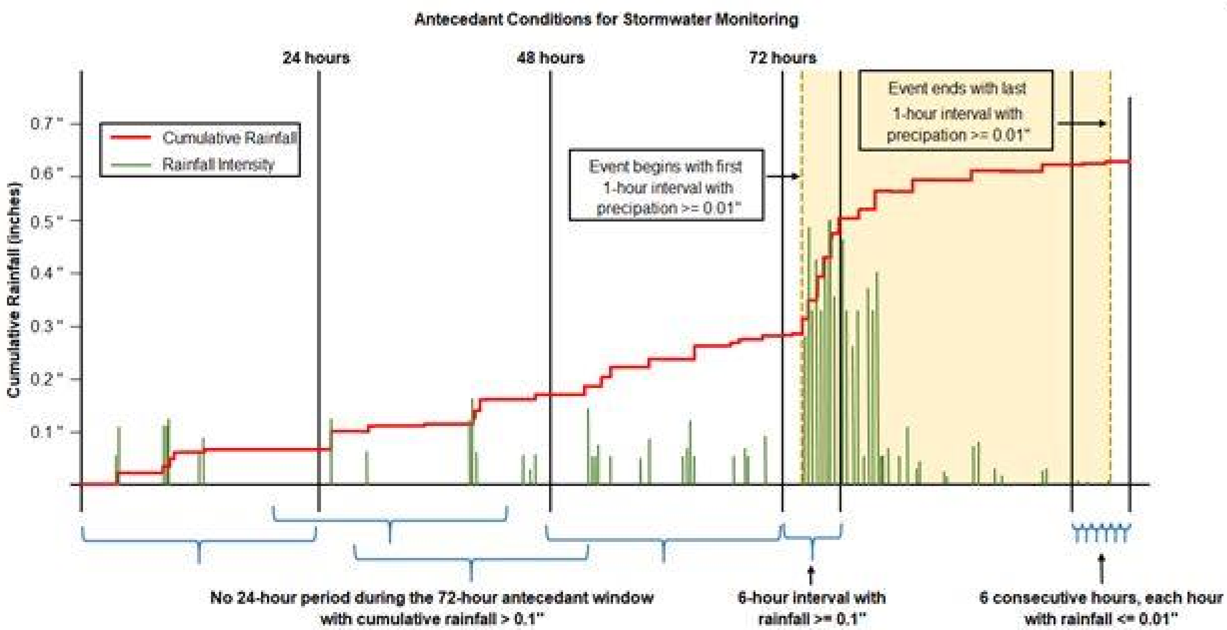


Figure 10-1 Graphic Representation of Storm Definition

10.3 Storm Action Levels

Storm action levels are necessary for efficient stormwater monitoring preparation, mobilization, and demobilization. Project-specific storm action levels and storm selection criteria must be defined in the QAPP.

For example, a project QAPP could define the following storm selection criteria to qualify a storm event for monitoring:

- Forecasted to produce at least 0.1 inch of rainfall with probability of precipitation equal to or greater than 70%.
- Preceded by at least 72 hours without a measurable storm event. A measurable storm event is defined as more than 0.1 inch of rainfall, measured in a 24-hour period, that generates runoff.

Some situations will require the project manager's best professional judgment to determine whether to qualify a storm event for monitoring. In such cases, the project manager shall provide the Task Order Manager with rainfall/runoff graphs and other factors to justify the decision.

Project managers, field crews, and laboratories are notified each time the storm action level changes. An example of typical storm action levels is shown in Table 10-1.

10.4 STORM SELECTION CRITERIA

When a storm is approaching, the monitoring consultant must make the determination whether to mobilize. The following criteria are used to qualify storm events:

1. Quantity Precipitation Forecast (QPF) – The amount of precipitation that the incoming storm is expected to produce
2. Probability of Precipitation (POP) – The percent probability that the expected storm will occur
3. Antecedent Dry Period – The time that has elapsed since the end of the previous measurable storm event

Table 10-1 shows the standard procedures for mobilization for an upcoming stormwater monitoring event.

Table 10-1 Storm Action Levels

Action Level	Task Manager Action	Field Crew Action
Non-Monitoring - Not actively seeking candidate storms	• Monitor weather reports weekly.	• None.
Standby - Evaluating developing storm systems	• Monitor weather reports semi-weekly.	• Notify project manager where crew members will be and how they can be reached if they leave the area for more than one or two days. • Arrange for substitute if needed.
Pre-Alert- Target storm expected within the next 72 hours	• Monitor weather reports every 24 hours. • Verify operation of monitoring equipment as needed. • Alert field crews regarding change in action level. • Verify availability of field crews. • Alert analytical laboratory and Caltrans.	• Remain in local area if possible. • Verify availability with project manager.
Alert - Target storm expected within the next 24 hours	• Monitor weather reports every six hours or more frequently as storm approaches. • Alert field crews regarding change in action level and probable time of storm. • If storm event is marginal, alert crews the event may be a go or no-go and continue to notify every four hours.	• Prepare monitoring equipment for sampling and/or observations. • Upload autosampler pacing specifications to remote sampling instruments. • Upload autosampler pacing specifications to remote sampling instruments. • Prepare COC forms and label sample bottles.
Go - Precipitation imminent or underway on targeted storm	• Monitor weather reports as needed. • Mobilize field crews.	• Mobilize to sample collection stations for during-storm event observations, sample bottle maintenance, grab sampling, etc.
Post-Storm	• Demobilize field crews.	• Split composite samples for field duplicates. • Label and log samples on the COC form. • Ensure timely delivery of samples to analytical laboratory. • Complete field notes. • Prepare for next storm - inventory/clean/organize/replace equipment as necessary.

10.5 COMMUNICATIONS

A telephone tree must be developed to clearly define lines of communication and notification responsibilities. The telephone tree is used for stormwater monitoring preparation activities, personnel notification of storm action level changes, communications and during stormwater monitoring and coordination of demobilization activities following a monitored storm event. The telephone tree must also include a list of laboratory telephone numbers for the purpose of after-hours sample delivery. Emergency telephone numbers must be listed, including those of hospitals nearest the monitoring stations. The telephone tree should include office, cellular, home, and other pertinent numbers for each person involved in the project. Each person listed must have access to a copy of the telephone tree during the stormwater monitoring season. An example of a telephone tree is shown in Figure 10-2.

A project-specific telephone tree must be included in the QAPP. Additionally, a pre-storm conference call or meeting is recommended to discuss the weather forecast, mobilization strategy, and field logistics.

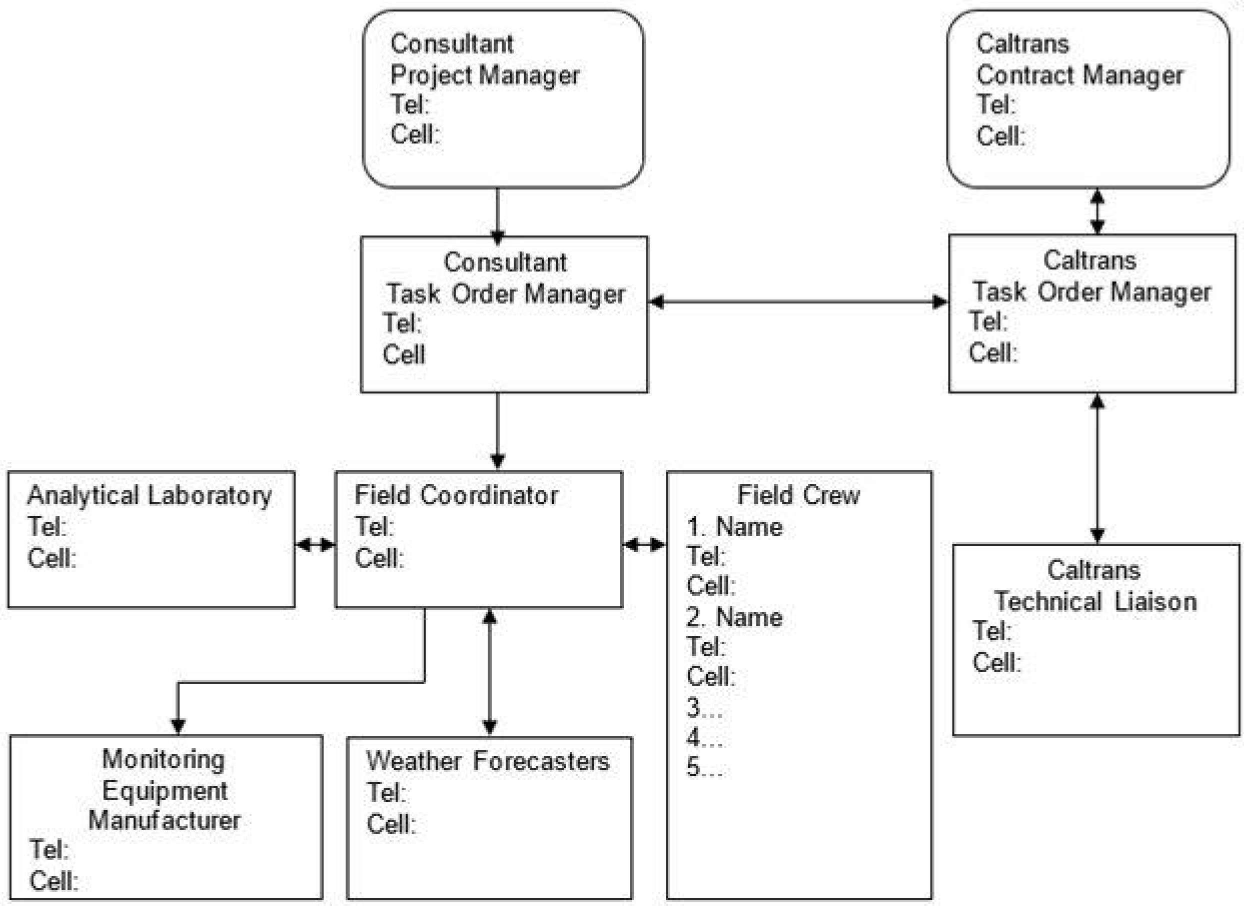


Figure 10-2 Example of a Telephone Tree

10.6 Sample Identification

Each stormwater sample collected must receive a unique sample identifier (sample ID) for tracking. A standard sample identification scheme should be used, which must include the following fields, at a minimum:

- Date of sample collection
- Time of sample collection
- Type of sample being collected (field sample, duplicate, blanks, and so on)
- Station ID

Field blanks and field duplicates should always be submitted to the laboratory as normal samples, so the lab does not know the samples are quality control samples (also known as blind samples). Sample IDs for these kinds of samples should be similar to normal field samples and must be noted in a field log so data reviewers will know which samples are QC samples and which are not.

10.7 Preparing Chain-of-Custody Forms and Labeling Sample Bottles

COCs can be prepared before a storm event to save time in the field. COCs can be fully filled out so only the field information (field technician name, sample collection dates/times, and so on) needs to be added when the samples are collected. Appendix F includes a blank COC that can be printed and used for monitoring.

Sample bottles should be pre-labeled if possible before each stormwater monitoring event. Pre-labeling sample bottles simplifies field activities, leaving only date, time, sample ID, and sampling personnel names to be filled out in the field. Preprinted waterproof bottle labels are available with space to pre-label by hand or using a printer. Custom bottle labels may be produced using blank waterproof labels and labeling software. A standardized bottle label must include the following information, with other items as appropriate:

- Project name
- Sample ID number
- Site name
- Site identification
- Date and time
- Sample matrix (e.g., aqueous)
- Sample type (grab or composite)
- Bottle _ of _ (for multiple bottle samples)
- Collector name
- Preservative
- Analyte
- Whether the sample is to be used by the lab as a matrix spike sample

Applying labels to sample bottles in a dry environment prior to field crew mobilization is preferable. Labels do not stick to wet bottles, and a loosely adhered label may fall off during sample transport. The labels must be applied to the bottles rather than to the caps. Figure 10.3 shows an example of a bottle label.

Computer labeling programs can save a great deal of time in generating bottle labels. The sites and analytical constituent information can be entered in the computer program for each monitoring program in advance and printed as needed prior to each monitoring event.

<table>
<tr><td colspan="2" rowspan="2">Project Name:

Caltrans Long-term Characterization Study</td><td colspan="2">Sample ID Number:
12-10-_ _ _ _ _ _ _ _ _ _ _ - _00</td></tr>
<tr><td>Preservative:
4°C</td><td>Bottle:
___ of ___</td></tr>
<tr><td colspan="2">Site Name:
Sand Canyon Toll Road Maintenance Station-Outlet</td><td>Site ID:
12-10</td><td>Sample Matrix:
Water</td></tr>
<tr><td colspan="4">Analyte(s): Hardness, TSS, Conductivity, pH, Turbidity, TOC, Nitrate as Nitrogen, TKN, Nitrite as Nitrogen, Total Phosphorus, Dissolved Ortho-Phosphate, Total and Dissolved Metals (Cd,Cu,Pd,Ni,Zn). Pesticides (Chlorpyrifos, Diazinon)</td></tr>
<tr><td>Date:
_ _/_ _/_ _ _ _</td><td>Time:
_ _ : _ _</td><td>Collector's Initials:
_ _ _</td><td>Sample type:
Composite</td></tr>
</table>

Figure 10-3 Example of a Bottle Label

10.8 Field Equipment Preparation

At the beginning of the season and immediately after each monitored event, field crews should restock field supplies. Field equipment should be cleaned, calibrated, and maintained as needed. A checklist of project-specific field supplies and equipment must be provided in the QAPP.

An example field supplies checklist is provided in Figure 10.4.

Storm Kit Supplies List		Storm Mobilization Supplies List	
First aid kit	☐	Storm kit	☐
Keys (to gates and to enclosures)	☐	Waterproof log books/log sheets	☐
Flashlights (2) – hand-held and head-mounted	☐	Paper towels	☐
Maps	☐	Distilled water squirt bottles	☐
Large flat screwdriver	☐	Ice scoop	☐
Small flat screwdriver	☐	COC forms	☐
Umbrella - large size	☐	Appropriate number of 20-liter composite bottles in fabricated ice chests	☐
Alkaline batteries for flashlights	☐	Appropriate number of grab sample bottles	☐
Water resistant pens; fine point (2)	☐	Cubitainers for toxicity samples	☐
Spare sample bottle labels	☐	Bottle labels	☐
Desiccant (for samplers and flow meters)	☐	Coolers and ice	☐
Diagonal cutters	☐	Grab pole	☐
Duct tape	☐	Rope	☐
Electrical tape	☐	Laboratory-provided blank water	☐
Cable ties (assorted sizes)	☐	Cellular phone	☐
Utility knife	☐	Personal extra change of clothes	☐
Re-sealable baggies (assorted sizes)	☐	Lighting	☐
Gloves: powder-free nitrile	☐	Personal rain gear	☐
Hard hats	☐	Orange safety vests	☐
Rubber bands	☐	Traffic cones/signs	☐
Quality Assurance Project Plan	☐	Health and Safety Plan	☐

Figure 10-4 Field Supplies Checklist

The following equipment preparation procedures must be conducted prior to an event for which an alert has been issued:

- Inspect pump tubing and replace if necessary
- Inspect intake tubing condition and connections
- Inspect desiccant cartridges in sampler and flow meter
- Inspect flow meter condition and connections
- Inspect rain gauge for blockage
- Check electrical connections
- Ensure batteries are charged and positioned
- Insert sample bottles into sampler
- In non-refrigerated samplers, completely surround sample bottles with ice
- Reset automatic sampler
- Calibrate portable analytical meters that will be used to make field measurements
- Check and clear sediment, vegetation, or debris that accumulated in flumes or weirs

At a minimum, the frequency and type of maintenance for field equipment must be consistent with the manufacturers' recommendations.

10.9 Mobilization of Field Crews

When an approaching storm meets selection criteria, the field crew and analytical laboratory will be alerted by the Monitoring Task Manager. Field crews will be given notice to mobilize when precipitation is imminent or has begun.

Clearly defined deployment criteria are required for the purpose of efficient field crew mobilization and demobilization. A flowchart that combines project-specific storm selection with storm action levels should be used for field crew mobilization. Figure 10-5 is an example of a deployment flowchart using project-specific precipitation levels, etc.

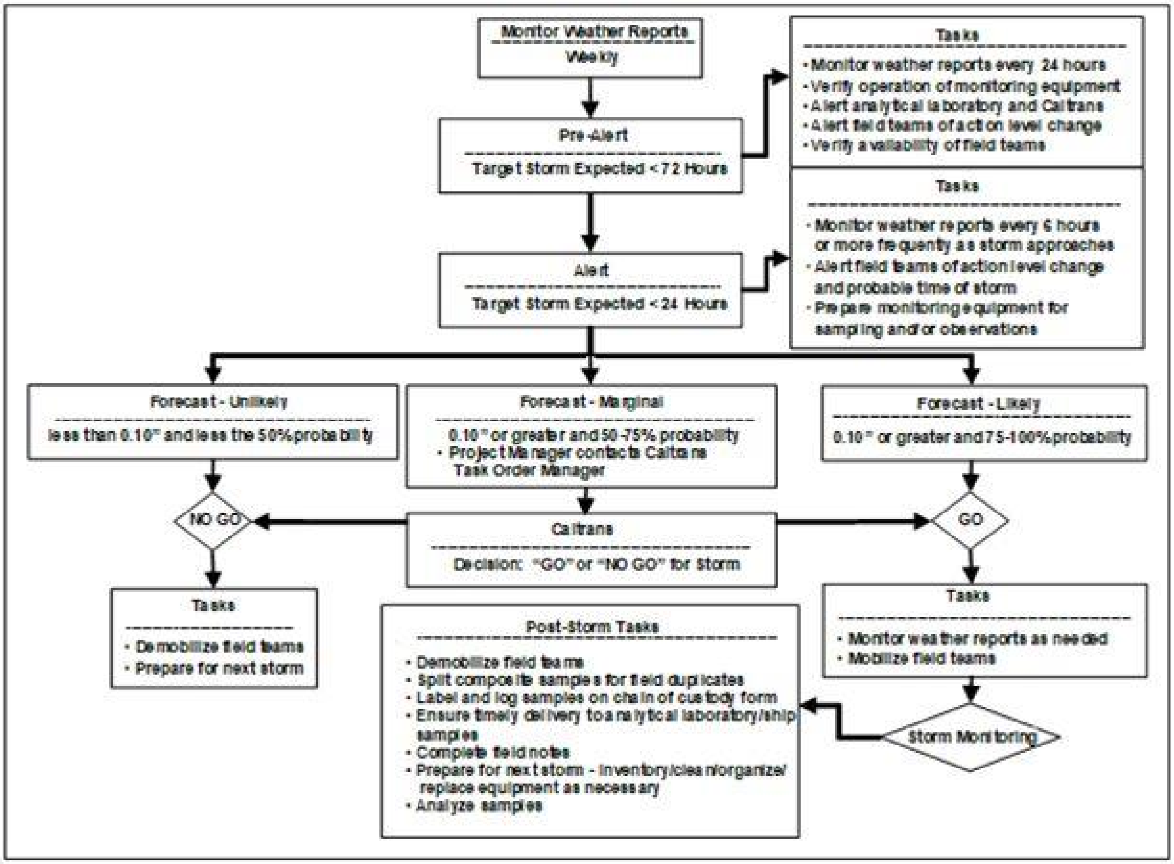


Figure 10-5 Example of a Deployment Flowchart

When a storm alert has been issued, field crew members check monitoring equipment and supplies to ensure they are ready to conduct monitoring. Once given the go-ahead by the Monitoring Task Manager, the field crew members travel to their assigned locations and conduct final preparations for monitoring. Upon arrival at the monitoring site, the field crew must:

- Check battery levels
- Check tubing and connections
- Install clean composite bottles and remove lids, as necessary (see Appendix B for detailed bottle changing procedures)
- Add ice to sampler, if necessary
- Program automatic flow meter and sampler if this procedure has not been performed remotely via telemetry
- Clean trash, vegetation, etc. that may have accumulated within flow measurement and collection system devices (Figure 10.6)

Figure 10-6 Accumulated Debris in a Stormwater Collection System

En route to monitoring sites, the field crew must procure ice for sample preservation. Composite samples must be kept cool during sample collection. Grab samples must be iced. Once samples are collected, they are placed in coolers packed with ice for transport. Keeping ice in double re-sealable bags facilitates ice handling. Re-freezable ice packets are generally not recommended because they are susceptible to leakage, thus creating a mess and introducing the potential for sample contamination.

Prior to mobilization, field personnel must be familiar with the contents of the project-specific Health and Safety Plan. Each sampling team must have a copy of the Health and Safety Plan whenever they are deployed to the field.

10.10 Programming of Automated Equipment

Automated monitoring equipment works independently in the field when field personnel are not present. This kind of equipment must be programmed by field technicians before the start of a storm event so it will respond appropriately to changing field conditions.

10.10.1 Overview of Automated Equipment Programming

The steps involved in the programming of automated equipment will vary depending upon the software programs, but typically include the following:

- Reset system counters (e.g., precipitation, runoff volume, sample count, etc.) to zero.
- Switch modes from non-storm monitoring to storm monitoring, which configures the equipment software for sample collection.

- Set thresholds for sampling locations to allow stations to enter sample collection mode. Thresholds can include the minimum precipitation amount, flow depth, or flow volume required to initiate the sample collection routine.

Most automated monitoring stations contain continuous flow measurement devices and data logging software. To collect flow-proportioned composite samples, the flow measurement device must be programmed to send a pulse to the sampler each time a specified flow volume has passed the flow sensor. The sampler, in turn, is programmed to collect a pre-determined volume of sample, called an aliquot, each time it receives a pulse. Therefore, each time the programmed sample flow volume has passed the sampling location, a composite sample aliquot is collected.

To ensure the collection of representative samples, automatic samplers must be programmed to perform a full back-purge cycle of the intake tube after each sample aliquot is collected. When multiple sample containers are used, samplers must be programmed to perform a full back-purge cycle prior to the filling of each individual container. Purging the sample intake tube prior to the collection of each aliquot or individual container sample helps to keep the line clear. Debris in the sample tubing intake may cause flow restriction, reducing velocities within the intake tube. When intake tube velocities are reduced, heavy particulates may not be correctly represented in the sample. Additionally, reduced velocities may result in sampler aliquot volume calibration problems or increased pump tubing wear. Automatic samplers may also be programmed to perform rinse cycles after the back-purge cycle and prior to the collection of sample aliquots. However, for stations that have a high sampling head height or a long intake tubing length, rinse cycles are not advised because of additional wear on the pump tubing. Worn or split pump tubing will result in missed sample aliquots.

10.10.2 ESTIMATING THE VOLUME OF RUNOFF

The following equation may be used to estimate the total runoff volume for the forecast storm event:

$$V_r \text{ (acre-feet)} = \text{QPF (inches)} * \frac{1 \text{ (foot)}}{12 \text{ (inches)}} * \text{A (acres)} * R_v$$

Where:

Vr	=	Total runoff volume for forecast storm (calculated)
QPF	=	Quantitative precipitation forecast
Area (A)	=	Drainage area (acres)
Rv	=	Catchment volumetric runoff coefficient

If the pervious and impervious areas are known in a drainage area, this equation may be modified to include separate runoff coefficients for pervious and impervious areas as follows:

$$V_r \text{ (acre-feet)} = \text{QPF (inches)} * \frac{1 \text{ (foot)}}{12 \text{ (inches)}} * [(A_{pervious} * R_{v\ pervious}) + (A_{impervious} * R_{v\ impervious})]$$

Where:

Vr	=	Total runoff volume for forecast storm (acre-feet)
QPF	=	Quantitative precipitation forecast (inches)
$A_{pervious}$	=	Pervious drainage area, acres
$A_{impervious}$	=	Impervious drainage area, acres
$Rv_{pervious}$	=	Volumetric runoff coefficient, pervious portion of catchment
$Rv_{impervious}$	=	Volumetric runoff coefficient, impervious portion of catchment

Then convert the runoff estimate to cubic feet:

$$V_r(cf) = V_r(acre\text{-}feet) * \frac{43{,}560\,(cf)}{1\,(acre\text{-}foot)}$$

Where:

V_r	=	Total runoff volume for forecast storm (calculated)

The runoff coefficient used in these equations is specific for each drainage area. It is defined as the fraction of total precipitation volume delivered to the area that ends up as stormwater runoff at the point of discharge.

An initial estimate of the runoff coefficient may be determined based on the fraction of impervious area within the drainage area. The following equation provides a simplified method of computing Rv based on the impervious area fraction, which can be used for monitoring areas with an unknown runoff coefficient (Urbonas 1999):

$$Rv = 0.858I_a^3 - 0.78I_a^2 + 0.774\ I_a + 0.04$$

Where:

Rv	=	Runoff Coefficient
I_a	=	fraction of the total drainage area covered by impervious surfaces (value must be between 0 and 1). Note that the total impervious area, not the hydraulically connected portion, is used.

As more storm events are monitored at a site, a regression curve between the actual measured rainfall and runoff volume can be constructed. The runoff volume for a forecast storm can be estimated by using such a regression curve (Figure 10.7).

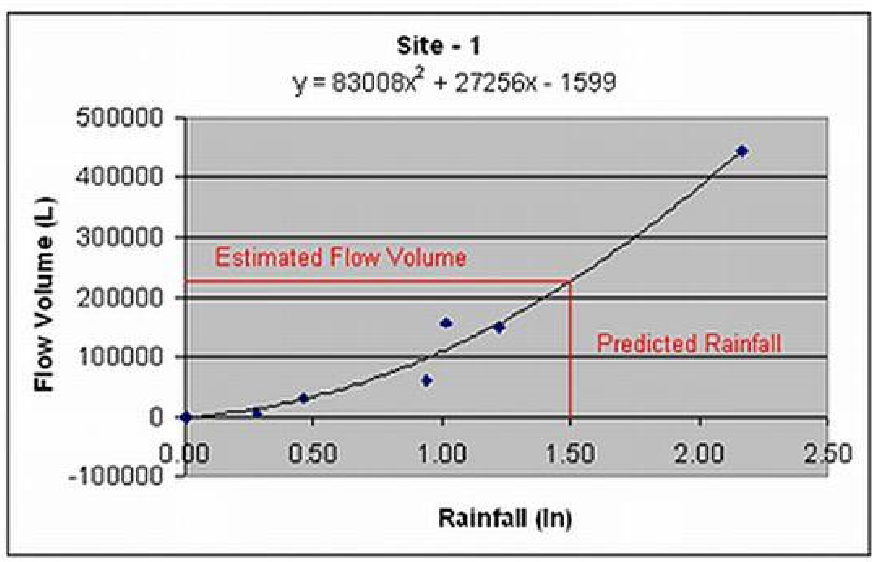


Figure 10-7 Example Vr Calculation Using Regression Curve

10.10.3 Estimating the Sample Volume, Aliquot Volume, and Number of Aliquots

A certain minimum sample volume is required by the laboratory to conduct planned analyses, including QA/QC analyses. An automated stormwater monitoring station collects an aliquot of sample every time a preprogrammed volume of flow passes through the station.

There is a trade-off between the volume of each aliquot and the number of aliquots collected during a storm event. The larger the aliquot volume, the fewer aliquots can be put into a single sample container. A certain minimum number of aliquots is required to represent a storm adequately, as shown in Table 10-2. Because an automatic sampler is triggered to collect an aliquot each time a certain volume of runoff has passed, the heavier the storm, the more frequently aliquots will be collected. An aliquot volume is selected, and the sample pacing volume is adjusted to provide the desired number of aliquots based on the expected precipitation amount and anticipated storm runoff volume. The desired sample aliquot volume must be selected and agreed upon during the development of the QAPP.

Because storms can vary widely in intensity and duration from even the best predictions, selecting the right sample aliquot volume and deriving the appropriate sample pacing volume takes a great deal of skill and experience. Predicting the correct sampler pacing for a storm is one of the most difficult parts of stormwater monitoring and should always be made by experienced project managers and field technicians.

Table 10-2 Required Number of Aliquots for Storm Representation

Total Event Precipitation	Minimum Number of Aliquots	Percent Storm Capture Requirement[1]
0–0.25″	6	85
0.25–0.5″	8	80
0.5–1″	10	80
>1″	12	75

[1] Percent storm capture is the percent of flow volume represented by a composite sample. It is calculated by dividing the flow volume that passed the sampling station during sample collection by the total flow that passed the sampling station during the entire monitoring event.

10.10.4 Flow Volume per Sample

The amount of flow that passes the sampling point between each aliquot collected must be programmed into the flow meter before the sampling event begins. Flow volume per sample is calculated as follows:

$$V_S(cf) = \frac{V_T(cf)}{CSA}$$

Where:

Vr	=	Total runoff volume for forecast storm (calculated)
Vs	=	Flow volume per sample
CSA	=	Number of composite sample aliquots required

Ideally, if the predicted precipitation is delivered by the targeted storm, the flow volume per sample should enable the automatic sampler to collect enough samples to perform the analyses specified in the QAPP, including the required QA/QC analyses. If the required analytical volume is less than the capacity of the composite bottle(s), a margin of safety can be provided by setting the sample pacing to collect the needed composite sample volume at a fraction (typically one-half to three-quarters) of the predicted rainfall amount. This setting is determined by using an appropriate fraction of the QPF in calculating the volume of runoff. If less rainfall is received than predicted by the QPF, this safety margin will ensure collection of enough sample volume.

If a storm delivers more precipitation than expected, composite bottle replacement may be required to capture runoff from the entire storm event, as noted previously. Appendix B describes composite bottle replacement procedures.

10.11 Insufficient Sample Volume

If less precipitation is received than predicted, the resulting composite sample volume may be insufficient to conduct all the required analyses. It may be possible to salvage a successful monitoring event in such cases by performing some analyses and omitting others. Depending on the project, some analyses may be more important than others. Also, some analyses, such as metals, may require a small volume of sample, whereas others, such as TSS, require a larger volume. If the sample volume is too small, the project manager should contact the Caltrans task order manager to discuss which analyses should take priority.

10.12 Verifying the Runoff Coefficient

After several storms have been captured successfully at a monitoring site, the runoff coefficient for the site should be checked to verify it is accurate. This can be done by comparing the expected runoff volume to the actual volumes measured during the storm events. The runoff coefficient can be calculated using the following equation:

$$R_{vs} = \frac{\left(\sum_{i=1}^{n}\right)\left(\frac{P_i A}{V_{ri}}\right)\left(\frac{1\ ft}{12\ in}\right)\left(\frac{43{,}560\ ft^3}{1\ ac}\right)}{n}$$

Where:

Rvs	=	Volumetric runoff coefficient for the station
Pi	=	Precipitation depth for the ith storm feet
A	=	Catchment area square feet
Vri	=	Volume of runoff for the ith storm (cubic feet)
n	=	Number of storm events

10.13 Contacting the Caltrans Task Order Manager

It is sometimes desirable or necessary for the consultant to contact the Caltrans Task Order Manager for guidance, or just to keep the TO Manager apprised of conditions in the field. Consultants must use best judgement when deciding whether to contact the TO manager. The rule is to err on the side of caution and contact Caltrans whenever it seems appropriate. Table 10-3 lists some common circumstances that required contacting the TO manager.

Table 10-3 Circumstances that Require Contacting the Caltrans TO Manager

Event	When to Notify TO Manager	Purpose of Contact
District personnel or regulatory agencies approach the consultant with information or requests that might impact stormwater monitoring	As soon as possible after contact is made with other districts or agencies	Put the Caltrans Task Order Manager in touch with the individual who initiated contact
A problem is detected with the monitoring equipment that cannot be fixed by the consultant	As soon as the problem is discovered	Obtain authorization to repair equipment or exchange it for working equipment
There is an upcoming storm event that falls short of the mobilization criteria but may still be monitorable	48 hours prior the beginning of the event	Authorization to proceed with monitoring or stand down
Monitoring event was successful; however, sample volume is too small to perform all analyses	As soon as possible after the problem is detected; must be same day	Go over sample prioritization with limited sample volume
Some problem with a completed event is observed.	As soon as possible after the event	Determine if any follow-up is required
There is some critical failure in the laboratory	As soon as contacted by the lab	Determine if any follow-up is required
A potential or actual safety violation occurs in the field	As soon as possible; never more than 24 hours after the event	Determine if any follow-up is required

11 SAMPLE COLLECTION AND HANDLING

This chapter describes the types of samples, sample collection techniques, and sample handling methods used for Caltrans stormwater monitoring projects. This chapter also discusses sample documentation and sample transport to the laboratory.

The project QAPP contains the information field crews need to collect, store, and transport samples, and to give instructions to the laboratory.

Samples must be collected in certified clean containers that are clearly labeled. Cleaned sample containers and sampling equipment such as strainers and sampler tubing may be handled only while wearing clean, powder-free nitrile gloves. Laboratory-cleaned sampling equipment and composite containers are double-bagged in clean, re-sealable plastic bags for storage or shipment, and should be stored in a clean area with lids properly secured.

The following aspects of sample collection and handling are discussed in this chapter:

- Safety
- Types of samples collected
- Field filtration
- Holding times
- QA/QC sample collection
- Documentation
- Transportation of samples to the laboratory

11.1 SAFETY

Field crews must be deployed in teams of two or more, be physically capable of performing all tasks required for sample collection and be aware of any potential hazards on the site. Before stormwater samples are collected, monitoring personnel must evaluate the safety of performing sample collection activities. The following precautions should always be taken:

- Each monitoring location must be evaluated by experienced field technicians to determine what hazards exist at each location and what steps field personnel must take to avoid them. This must be done before the monitoring phase of the project begins.

- Before entering a confined space (manhole, standpipe, vault, or chamber), field personnel must be properly trained and equipped according to the Occupational Safety and Health Administration Confined Space Entry Standard. During storm conditions, or when a significant water flow is present, field personnel must not enter a confined space.
- If personnel are exposed to traffic at a monitoring station, they must be trained to identify the need for appropriate traffic control measures, and how to implement them.

All field personnel must also be familiar with the project Health and Safety Plan. The Health and Safety Plan is a project-specific document that contains, at minimum, maps of each monitoring site, a list of potential hazards at each site with an assessment of each hazard and rules for avoiding each hazard, a list of required personal protection equipment, a list of emergency telephone numbers, and directions to the nearest hospital with an emergency room. A Health and Safety Plan should also contain general safety information such as how to recognize heat exhaustion and heat stroke, reminders to stay hydrated, information about dangerous wildlife in the area, and first aid procedures. Monitoring crews must have a copy of the project Health and Safety Plan in their possession whenever they are deployed to the field. Guidelines for developing a Health and Safety Plan are explored more fully in Appendix A.

11.2 Types of Samples

Samples collected from a stormwater runoff stream may be one of two types:

- A grab sample is a singular, instantaneous collection of a sample to characterize water quality at a single location and time. Grab samples are representative of the discharge only at the time that they are collected. The data produced from grab samples are often referred to as a “snapshot” of the runoff stream at a single point in time.
- A composite sample is comprised of multiple grab samples or sample aliquots mixed together. A composite sample can be collected over a specified period at a particular location (temporal composite), or at a particular time over a spatial range, such as a creek cross-section (spatial composite). Temporal composites generally are proportioned based on either flow (“flow-proportioned”) or time

("time-proportioned"). Data from composite samples represent the entire discharge volume of a given storm event.

While grab samples and spatial composites are typically collected manually, temporal grab and composite samples may be collected either manually or via automated means.

For most Caltrans stormwater monitoring projects, temporal variation is of primary concern. For this reason, Caltrans stormwater monitoring typically involves the use of automated equipment for collection of flow-proportioned, temporal composite samples, to characterize runoff over the life of the storm.

The advantages and disadvantages of grab and composite sampling are summarized in Table 11.1.

Table 11-1 Comparison of Grab and Composite Samples

Sample Type	Advantages	Disadvantages
Grab	• Appropriate for every constituent • Easy to collect • Requires minimal equipment • Provides a measure of an instantaneous constituent concentration • Constituent concentration spikes are not masked by dilution	• Represents the discharge at only a single point in time • Analysis of multiple grab samples for determining event mean concentrations (EMCs) are very expensive
Composite	• Sample represents the entire storm event, so spikes and troughs in constituent concentration are accounted for • Provides more representative EMCs for mass loading calculations	• Sampling equipment is more sophisticated and expensive • Not appropriate for some constituents, such as petroleum and bacteria • Constituent concentration spikes may not be detected because they may be masked by dilution

11.2.1 Grab Sample Collection

Although most Caltrans monitoring projects rely on composite samples to characterize stormwater discharges, grab samples are required by USEPA methods for certain constituents. Grab sampling is required for samples that will be analyzed for oil and grease, volatile organic compounds, low-level mercury, and bacteria.

Samples collected for microbial tests, such as coliform bacteria and Enterococcus, must be collected in sterile sample containers to avoid bacterial contamination that could interfere with the analysis.

Volatile constituents, such as ammonia, low-level mercury, and volatile organic compounds (VOC), are normally collected as grab samples because they may be lost to the atmosphere if left for an extended period in a composite sampler.

Figure 11.1 shows a sample being collected manually, both directly and with a bailer. Bailers are usually used when field technicians cannot reach a runoff stream safely.

Figure 11-1 Collection of a Grab Sample by Hand (Left) and Using a Bailer (Right)

Samples to be analyzed for petroleum products such as gasoline, diesel, and oil, must be collected as grab samples for several reasons. These samples should not be collected in automated sample collection equipment because petroleum products tend to stick to the sides of sampler tubing and unpreserved composite sample containers. Petroleum left in unpreserved sample containers is subject to degradation by bacteria. Most important, petroleum products tend to float on the surface of a runoff stream, so they will be missed by automated equipment that collects water from the middle or toward the bottom of the stream. Samples collected for petroleum products must be taken from the surface of the runoff stream at the air/water interface. Figure 11-2 shows how samples for petroleum products may be taken from the surface of the runoff stream at the air/water interface.

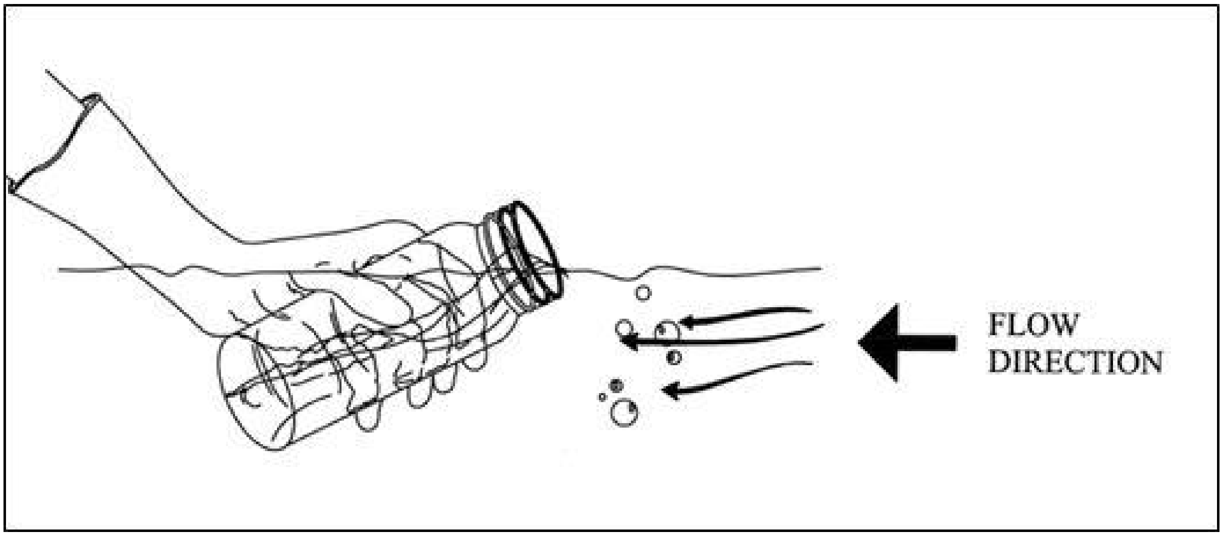


Figure 11-2 Collection of Grab Samples at the Air/Water Interface

Some samples must be preserved as soon as they are collected. The laboratory provides sample containers that have the correct preservatives in them to meet this requirement, and it is important not to rinse the preservative out of a container while filling it with the sample. Never overfill, overflow, or rinse out a pre-preserved sample container.

In addition, some constituents must be measured in the field. These include pH, dissolved oxygen, and temperature. Although conductivity and turbidity are usually tested in the laboratory, these analyses may also be performed in the field. Field tests are generally performed on a sample taken from the runoff stream at the time of analysis, so the data generated from field tests are considered "grab" data.

When grab samples are collected just once during a storm event, it is important to collect those samples under flow conditions that will provide the most representative sample possible. Usually, this is at event peak flow; however, event peak flow conditions are typically difficult to determine during a monitoring event. Field technicians must use their best professional judgment when deciding when to collect grab samples; for example, planning to collect grabs during the six-hour period with the highest QPF.

11.2.2 Grab Sampling Methods

Grab samples, as defined above, can be collected by one or more of the methods described in this subsection: direct fill, direct submersion, intermediate container, peristaltic pump, automatic equipment, sandbag, and dustpan methods. The various options are described below. For all of these methods, it is essential to use clean sampling techniques, especially to avoid touching the inside of any container, and to prevent any contaminants from entering the container.

11.2.2.1 Direct Fill Method

When there is an outfall or lip over which the sample water cascades, samples should be collected by directly filling the sample container in the sample stream. Instructions for collecting the grab sample using the direct fill method are outlined below:

1. Prepare the sample label and apply it to the bottle.
2. Remove the sample container lid and protect it from contamination.
3. Grasp the container firmly with one hand and place the container mouth into the sample stream to fill.
4. After filling the container, tightly apply cap.
5. Avoid introducing scum or debris into the bottle and avoid stirring up bottom sediments in the conveyance.

When the sample stream cannot be reached directly, bottles may be filled by affixing sample containers to the end of a grab pole and placing the sample bottle in the stream for filling as above.

11.2.2.2 Direct Submersion Method

When there is no outfall or lip over which the sample water cascades but the stream is deep enough, samples should be collected by direct submersion of the sample container in the sample stream. When possible, sample containers should be uncapped, filled, and recapped underwater. Instructions for collecting the grab sample using the direct submersion method are outlined below:

1. Prepare the sample label and apply it to the bottle.
2. Grasp the container firmly with one hand and plunge the container mouth down to a depth of six to 12 inches below the water’s surface in the horizontal and vertical center of the conveyance.
3. Remove the sample container lid and protect it from contamination.
4. Tilt the container with the mouth submerged so the opening faces upstream.
5. Tip the container slightly upwards to allow air to exit and the container to fill.
6. When the container is full, tightly apply the cap.

7. Avoid introducing scum or debris into the bottle and avoid stirring up bottom sediments in the conveyance.

11.2.2.3 Intermediate Container Method

Note: this method may not be used for collection of samples that will be analyzed for bacteria (such as coliform or Enterococcus) or petroleum hydrocarbons (including gasoline, oil, and grease). This method may otherwise be used to collect samples when sample bottles are pre-shipped with preservatives. The instructions for collecting the grab sample by intermediate container method are outlined below:

1. Prepare the sample label and apply it to the bottle.
2. Clean and decontaminate the intermediate container (e.g., bucket, bailer, etc.) using methods described in Appendix D.
3. Hold the intermediate container under the outfall of a discharge pipe or at the lip of an inlet grate or dip the intermediate container downstream of a discharge with the container opening facing upstream and allow the sample to enter the container.
4. Mix the sample to make sure it is homogenous and then immediately pour the sample into the appropriate grab sample container as shown in Figure 11.3.
5. Tightly cap the sample container.

Figure 11-3 Sample Transfer from Intermediary Container to a Sample Bottle

11.2.2.4 Peristaltic Pump Method

Note: this method may not be used for collection of samples that will be analyzed for bacteria (such as coliform or Enterococcus) or petroleum hydrocarbons (including gasoline, oil, and grease). Instructions for collecting the grab sample by a peristaltic pump are outlined below:

1. Prepare sample label and apply it to the bottle.
2. Install clean tubing into the pump.
3. Place the intake end of the tubing into the runoff stream at a point that is mid-stream and mid-depth.
4. Remove the sample container lid and protect it from contamination.
5. Place the output end of the tubing at the mouth of the sample container.
6. Turn the pump on and pump the sample into the container, ensuring the tubing does not contact the inside of the container.
7. Turn off the pump and tightly cap the container.

11.2.2.5 Automatic Equipment Method

As a variant of the peristaltic pump method, automated sampling equipment can be operated manually for grab sample collection of certain constituents. Note: this method may not be used for collection of samples that will be analyzed for bacteria (such as coliform or Enterococcus) or petroleum hydrocarbons (including gasoline, oil, and grease). For existing installed sites, automatic sampling may be paused for grab sample collection and then restarted after the grab sample has been collected.

When using this grab sample collection method with an installed autosampler, an effort must be made to collect the sample between collection of composite sample aliquots (i.e., immediately after the automated sampler has collected an aliquot). This effort will avoid or reduce disruption of composite sample aliquot collection timing. Step-by-step instructions for collecting a grab sample using automated equipment are outlined below:

1. Prepare the sample label and apply it to the bottle.
2. Place the automated sampling equipment in pause mode (see manufacturers' manual for instructions).

3. Remove the pump tubing from the composite sample container using clean, powder-free nitrile gloves; use clean handling techniques and avoid touching the end of the tubing, even while wearing gloves.
4. Remove the sample container lid and protect it from contamination.
5. Place the tubing at the mouth of the sample container(s) to be filled.
6. Place the sampling equipment in sample mode (see manufacturers' manual for instructions) and allow the sample to enter the container(s).
7. Once the sample containers are filled, tightly cap them.
8. Return the tubing to its original position in the composite sample container.
9. Re-set the sampling equipment to its original sampling sequence for the collection of the composite sample (see manufacturers' manual for instructions).

11.2.2.6 Sandbag Method

Note: This method may not be used for collection of samples to be analyzed for low-level mercury, bacteria (such as coliform or Enterococcus), or petroleum hydrocarbons (including gasoline, oil, and grease). If the sandbags are plastic, this method may not be used for samples to be analyzed for organic chemicals. If the sandbags are cloth or other non-plastic material, this method may not be used for samples to be analyzed for metals.

The sandbag method is a manual method for collecting grab samples from flows that are too shallow to submerge the container. Place full plastic sandbags in the path of the flow to create a small obstruction similar to a weir or a dam. This concentrates the flow to a larger volume that can be sampled using one of the previously discussed techniques. When using this method, do not back up runoff into the traveled way. Remove the sandbags prior to leaving the site.

11.2.2.7 Dustpan Method

Note: this method may not be used for collection of samples to be analyzed for low-level mercury, bacteria (such as coliform or Enterococcus) or petroleum hydrocarbons (including gasoline, oil, and grease). If the dustpan is plastic, it may not be used for samples to be analyzed for organic chemicals. If the dustpan is metallic, it may not be used for samples to be analyzed for metals.

The dustpan method is another manual method for collecting grab samples from flows that are too shallow to submerge the container. A dustpan can be used to collect grab samples for certain constituents. The type of dustpan selected must be based on constituents to be analyzed. If sampling for metals, use a dustpan that is composed of plastic. If sampling for organics, use a dustpan composed of metal. Like all sample collection equipment, dustpans used in this way must be cleaned in accordance with the procedures discussed in Appendix B.

11.2.3 Grab Sampling Methods for Specific Constituents

This section describes constituent-specific grab sample collection methods. These methods are used to collect bacteriology samples, volatile organic compound samples, oil and grease/petroleum hydrocarbons samples, toxicity samples, and low-level mercury samples.

11.2.3.1 Bacteriology Samples

Samples for bacteriological analysis must be collected in sterile containers. Sterile Teflon® bailers are available for this purpose; otherwise, the sample must be collected directly into a sterile bacteriological analysis bottle. Clean sampling techniques must be used when collecting bacteriological samples (see Appendix B). Keep the sample container closed until ready to be filled. When removing the cap, do not contaminate the inner surface of the cap or the neck of the container.

When the sample is collected, be sure to fill the container to the fill line, but no higher than the fill line, so the sample may be mixed by shaking prior to examination. Fill the container without rinsing, replace the cap immediately, and then chill the sample.

Sodium thiosulfate is a reducing agent that is used as a de-chlorinating agent in bacteriology sample containers and should be used only when there is a chance that the sample contains residual chlorine. Simple field test kits are available to check sample water that may contain residual chlorine (e.g., municipal wastewater treatment effluent). If the sample does not contain chlorine, the preservative should be discarded.

11.2.3.2 Volatile Organic Compounds

For the collection of volatile organic compounds (VOCs), use a 25- or 40-milliliter (mL) vial equipped with a screw cap with a hole in the center and a Teflon®-lined septum cap. Collect samples in duplicate and prepare replicate field blanks with each sample set. A sample set includes the samples collected from the same general sampling site at approximately the same time.

VOC samples must not be collected anywhere near a running vehicle, as the exhaust may contaminate the sample.

VOCs will escape from the water to the air if air is trapped in the vial. Therefore, fill the sample containers just to overflowing without passing air bubbles through the sample or trapping air bubbles in the sealed container. To ensure air bubbles are not trapped in the vial, the following procedures must be used:

1. Fill the vial until a reverse meniscus forms above the top of the vial.
2. Screw on the cap (the excess sample will overflow).
3. Invert the vial to check for the presence of air bubbles.
4. If air bubbles are observed, the vial needs to be opened, emptied, then completely refilled, and then repeat the first three actions.
5. Tightly seal the sample containers and ensure the TFE-lined side of the septum is face down.
6. After sampling, invert the vial several times to mix the contents.
7. Chill samples to approximately 4°C immediately after collection and hold at that temperature in an atmosphere free of organic solvent vapors until analysis.

11.2.3.3 Oil and Grease/Petroleum Hydrocarbons

Grab samples for oil and grease/petroleum hydrocarbons must be collected directly into the containers 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 container). These grab samples need to be collected at the air/water interface because oil and grease and other petroleum hydrocarbons tend to float (see Figure 11-2). Direct the laboratory that the sample must not be subdivided. Only glass containers may be used to collect samples for oil and grease analysis.

11.2.3.4 Toxicity Samples

Grab samples for toxicity testing can be collected directly into the container that will be used in the laboratory or by using an intermediate container (e.g., plastic Cubitainers are easily filled by collecting the samples in a glass amber container and then pouring from the container into the Cubitainer). Grab sample containers must be filled to the top, leaving no air space, to minimize the loss of toxicity due to volatilization of toxic constituents. Prior to collecting toxicity samples, each sample container must be rinsed with water from the runoff stream to be analyzed, according to the following procedure:

Rinse each sample container three times. For containers smaller than one-liter, rinse each container by filling it with the water of interest three times. For containers one-liter and larger, fill one container with the water from the runoff stream and use it to rinse other containers before filling them with the sample.

1. If samples are poured off from larger composite containers, water from the composite sample should be used for rinsing prior to filling the sample container.
2. When rinsing each container, be sure the cap is on the container so that the cap gets rinsed as well.
3. Rinse water may be poured into a separate container for field measurements such as pH and conductivity.

11.2.3.5 Low-Level Mercury Samples

Due to the ubiquitous presence of mercury in the environment, great care must be taken to avoid contamination when collecting low-level mercury samples in stormwater runoff.

Samples are collected directly into sample containers that are provided by the laboratory. The lab provides fluoropolymer containers that contain the correct preservative, and each container is double bagged in Ziploc bags. Whenever possible, samples are collected facing upstream and upwind to minimize introduction of contamination.

Samples for low-level mercury are collected as grab samples using the standard “Clean Hands – Dirty Hands” procedure. All operations involving contact with the sample bottle and transfer of the sample from the sample collection device to the sample bottle are handled by the individual designated as "clean hands." "Dirty hands" is the individual responsible for preparation of the sampler (except the sample container itself), operation of any machinery, and for all other activities that do not involve direct contact with the sample. “Clean hands” should be the only person that come into contact with the inner Ziploc bag and the sample container.

After each sample is collected, the sample number is documented and any unusual observations regarding the sample or the sampling event are documented on the field observation form.

If the sample is to be analyzed for dissolved metals, it needs to be filtered in accordance with the approved analytical method. Samples for low-level mercury must be filtered by the laboratory as soon as possible after they have been received. Low-level mercury samples are not field filtered.

Samples should be transported to the laboratory as quickly as possible after collection to minimize the possibility of contamination.

11.2.4 Sample Collection from the Ocean

Some Caltrans stormwater projects require seawater samples be collected from the surf zone on the beach. In this case, only grab samples are collected. To collect a sample from the ocean, a field technician wades knee-deep into the surf zone, submerges the sample container or intermediary container to fill it, and then comes back onto the beach. It may be necessary to do this several times to obtain enough sample volume.

If possible, samples should be collected directly into the proper laboratory sample bottles. In cases where large sample volumes are required, it may be preferable to collect the sample in a larger container such as a composite sample container.

When samples are collected from the ocean into a composite sample container, it may not be practical to carry the composite container into the surf zone; in this case, an intermediary container must be used. A clean sample bottle or bucket may be used for this purpose. Composite sample containers and intermediary containers should either be certified clean by the manufacturer or pre-cleaned by the laboratory before use. A separate intermediary container must be used for each sample collected. If a single intermediary container is used to collect multiple samples, there is a risk of cross-contamination.

When the project constituent list includes metals, intermediary containers must not be made of metal. Caltrans tests seawater samples for metals at very low detection limits, and a metal intermediary container may introduce contamination into the samples.

Collecting samples in the surf zone introduces safety concerns, particularly during stormy weather. Whenever a field technician enters the surf zone, he or she must wear a floatation device such as a life preserver. A rope must be tied around the technician's waist; the other end of the rope must be held by a second field technician who is standing on the beach, well out of the surf zone. The second technician must be physically strong enough to pull the person in the surf zone out of the water if there is any trouble.

For safety reasons, ocean samples may only be collected during daylight hours, never at night.

11.2.5 Sampling Snowmelt Runoff

Samples to be collected daily for the first three days of the snowmelt period. If ambient air temperatures remain above freezing after three days have passed, snowmelt sampling will then be performed once a week for the following three weeks or until the snowmelt period ceases. Snowmelt cessation will be determined by one of the following:

1. Ambient air temperatures drop below freezing during most of the day; or
2. A storm/rain precipitation event occurs after the snowmelt event was initiated.

Beginning March 15th of each year, snowmelt flows will most likely be continuous since ambient air temperatures will usually remain above freezing. From March 15th through May 31 of each year, snowmelt sampling events will be conducted daily for the first two days of a snowmelt event and then once a week thereafter until the spring runoff period has ended or the tributary station location shows no signs of daily flows for one week. Flow status will be evaluated in the afternoon, when ambient air temperatures are highest and flow potential is greatest.

11.2.6 Grab Sample Preservation

For certain analytes, chemical preservatives (e.g., hydrochloric, nitric, phosphoric, and sulfuric acids; sodium hydroxide; sodium thiosulfate; and zinc acetate) are added to prolong the stability of the constituents during storage. For grab samples, the laboratory will prepare the sample containers with sufficient preservative prior to sampling to preserve the sample at the required or project-specified pH. Alternatively, the preservative will be added to the sample after submittal to the analytical laboratory. The person ordering the sample containers should specify whether the preservative is to be added prior to sampling or after collection at the analytical laboratory. If preservatives are added after sample collection, it should be done immediately after collection.

Stormwater runoff samples are kept on ice or refrigerated to 4°C (0° to 6°C is the acceptable range) from the time of sample collection until delivery to the analytical laboratory. In addition to keeping stormwater samples cool, it is important to minimize the exposure of the samples to direct sunlight. Sunlight may cause a biochemical or photochemical transformation of the sample, resulting in unreliable analytical results.

Samples must be covered or placed in an ice chest immediately following collection or removal from the automatic sampler enclosure.

11.2.7 Composite Sample Collection

Most stormwater runoff monitoring involves collection of samples that are composited over time. There are two general types of temporal composite samples:

- Time-proportioned – A composite sample produced from aliquots taken at regular time intervals; each aliquot is of equal volume. A time-proportioned composite sample represents every portion of the storm hydrograph equally, regardless of changes in flow rate.
- Flow-proportioned – A composite sample that is produced from aliquots that are taken in proportion to the rate or volume of flow. The resulting composite sample is more representative of the entire discharge volume than either a grab sample or a time-proportioned composite sample, because each portion of the hydrograph is represented proportional to flow volume.

Because concentrations of water quality constituents can vary quite widely over the life of a storm, and because water quality may vary with flow rate, flow-proportioned composite sampling is the standard composite sample collection method used by Caltrans. Composite sample aliquots are collected more frequently from the runoff stream during periods of heavy discharge, and aliquots are collected less frequently during periods of lower flow.

Composite samples are typically collected using automated sampling equipment but can also be collected manually. Alternatives may be used to collect composite samples when either automated sampling or flow monitoring is not feasible (see Appendix L).

Normally, the first composite sample aliquot is taken at or shortly after runoff begins, and additional aliquots are collected throughout the storm until runoff ends; so the final composite sample represents runoff from the entire storm. It is also possible to characterize a specific, isolated part of a stormwater discharge by collecting aliquots only during that part of the runoff.

11.2.8 Composite Sampling Methods

This section describes the specifications for flow-proportioned composite sampling and time-proportioned composite sampling utilizing both automatic and manual methods.

11.2.8.1 Flow-Proportioned Composite Sampling

Caltrans stormwater monitoring projects typically utilize the varying time/constant volume flow-proportioned sampling scheme, which involves collecting sample aliquots of equal volume to represent intervals of equal flow volume throughout a storm event.

There are two principal advantages of flow-proportioned composites over time-proportioned composites or grab samples: (1) they are not biased by over- or under-sampling on any part of the hydrograph; and (2) they allow direct estimation of event mean concentration (EMC) from analysis of the composite sample, and calculation of event mass load (EML) as the product of the composite sample concentration and the total event runoff volume, without making assumptions about the shape of the hydrograph or the relationship between pollutant concentrations and flow rates.

Flow (i.e., volumetric flow rate) is defined as the volume of water per unit of time that is transported through a designated cross-sectional area. In the context of stormwater monitoring, flow rate is typically measured as the volume of water that passes through a channel or conveyance in gallons per second. Measuring flow accurately is necessary to collect flow-proportioned composites.

Flow-proportioned composite sampling requires an estimate of several key parameters, including:

- Storm event quantity precipitation forecast (QPF) (from forecast information)
- Expected runoff volume (determined from the QPF and watershed characteristics)
- Expected storm duration (for even-time-interval methods)
- Minimum required composite sample volume for planned analyses and toxicity tests, including a toxicity identification evaluation (TIE), if applicable
- Minimum acceptable number of sample aliquots (Table 10-3)
- Sample aliquot size (varies proportionally to measured flow throughout the event for equal-time-interval methods; set to a single volume per event for equal-flow-volume methods)

11.2.8.1.1 Automatic Flow-Proportioned Composite Sampling

Automated flow-proportioned composite sampling for Caltrans projects is typically done on an equal-flow-volume-per-aliquot basis, in which aliquots of equal volume are collected every time a pre-selected flow volume passes by the flow sensor.

The “flow volume per sample” is determined based on the QPF and the required composite sample volume, with consideration of the minimum required number of sample aliquots for the storm event. At automated monitoring stations, sample collection is programmed to begin automatically once the programmed thresholds (triggers) have been met.

Automatic sampling stations must be checked periodically throughout a monitored storm event to make sure the station is functioning properly. If the composite sample container (or containers, in the case of multi-container composite sample collection) fills more rapidly than expected, field personnel must be mobilized to conduct a container change. If the required sample volume exceeds the capacity of one container, a container change is also required. If the composite sample collection period exceeds 24 hours, then the composite sample container(s) must be replaced with a clean container(s) at or prior to the end of each 24-hour period. For constituents with short holding times, such as 48 hours or less, the required sample volume for those tests must be removed from each 24-hour composite for analysis, as necessary, to comply with holding time requirements.

After the storm event has ended, field personnel retrieve the filled composite sample container(s) and demobilize the sampling equipment. Sample splitting and delivery to the laboratory are described later in this chapter.

11.2.8.1.2 Manual Flow-Proportioned Composite Sampling

Composite sample collection may be done manually at monitoring sites that are not equipped with automatic equipment. This is similar to automatic flow-proportioned composite sampling, but samples are collected manually, either by directly dipping a sample container or bailer into the runoff stream or by using a peristaltic pump to pump water out of the runoff stream and directly into a sample container. Manual flow-proportioned composite sampling can be performed using one of the techniques described in Appendix L.

11.2.8.1.3 Precipitation-Based Flow-Proportioned Composite Sampling

Use of precipitation measurements to trigger flow-proportioned sampling is not recommended. However, for sites where flow measurement is not feasible or is very unreliable, such as sites where sheet flow is prevalent, flow-proportioned samples may be collected using precipitation measurements as an analog for runoff flow. The assumption is made that runoff volume is directly proportional to event precipitation. So, instead of calculating flow volume per sample, rainfall depth per sample is determined. A sample aliquot is then collected each time the selected precipitation increment has fallen. Therefore, for this approach, an on-site rain gauge is required for precipitation measurement (Chapter 4). To determine appropriate rainfall amount per aliquot for a target storm event, simply divide the event QPF by the number of sample aliquots required. This is determined by the total composite volume required and the desired sample aliquot volume, subject to the minimum numbers of sample aliquots per event.

11.2.9 Flow Measurement

Because flow-proportioned composites are created based on the volume of flow that passes through the monitoring station, accurate flow measurements are necessary to produce flow-proportioned composite samples.

Flow measurements must be performed utilizing one of the methods discussed in Chapter 4. When using manual methods, field crews must begin taking flow measurements as soon as possible after stormwater runoff begins (concurrently with sample collection). If automated sampling equipment is utilized, the equipment must be programmed to obtain the desired aliquot volume every time a specified flow volume is recorded, based on the predicted rainfall amount.

If multiple containers are used for composite sample collection, or if more flow volume is delivered than expected during a storm event (requiring one or more composite container changes per monitoring station), it is necessary to combine the multiple composite containers to produce a single flow-proportioned composite sample. To do this, it is normally necessary to use the collected flow data to determine the amount of sample from each composite container to be used to form the final composite. When using automated equipment, the field crew will typically download data from the flow meter or data logger to determine the flow volume represented by each composite container. The sample volumes to be used out of each composite container can be calculated by the monitoring crew, and the completed composite scheme faxed or otherwise delivered to the analytical laboratory. The methods for calculating appropriate sample volumes from each container are described in Section 10.10.2.

It is important to ensure that flow and rainfall data are collected at one- to five-minute intervals during storm events, so rapid fluctuations in the hydrograph are captured. This is especially important for small drainage areas such as those typically monitored for Caltrans.

11.2.9.1 Time-Proportioned Composite Sampling

A time-proportioned composite sample can be prepared either manually or with automatic sampling equipment. For the collection of a time-proportioned composite sample, the sampler collects fixed-volume sample aliquots at constant time intervals and combines them in a composite sample container. Such sampling is appropriate for locations with a sample stream that is not flow dependent or for locations where flow measurement is not feasible. Information on the collection of a time-proportioned composite sample using manual methods or automatic sampling equipment is presented below.

11.2.9.1.1 Automatic Time-Proportioned Composite Sampling

A time-proportioned composite sample may be collected using an automated sampler programmed to collect sample aliquots at fixed time intervals. The aliquot volume and number of composite sample aliquots collected during the stormwater monitoring event will vary based on the total volume of sample required for the planned analysis. Therefore, the laboratory conducting the analyses must be contacted prior to the sampling event to determine how much sample volume is required.

At the end of the storm event, the composite sample is evaluated to determine if the required sample volume was collected. The sample is then labeled, a chain-of-custody form is developed, and the composite sample is submitted to the laboratory for analysis.

11.2.9.1.2 Manual Time-Proportioned Composite Sampling

For the manual collection of a time-proportioned composite sample, aliquots collected from the stormwater discharge should be separated by at least 15 minutes with a minimum of three aliquots taken each hour. Sampling should start as soon as possible but no longer than 30 minutes after the start of the rising hydrograph for the discharge.

Sample aliquots are collected manually and immediately transferred into a composite sample container (carboy), which is stored on ice. At the end of the monitoring event, the carboy is submitted to the laboratory for analysis.

11.2.10 Changing Composite Containers

When an automated monitoring station is used to collect composite samples, a container change may become necessary if the composite container becomes full prior to the end of sample collection. Use the following procedure to change composite containers:

1. Place automated sampling equipment in pause mode prior to the initiation of the composite container change. This action is accomplished in the field or by remote monitoring personnel if the monitoring station is equipped with telemetry.
2. Wear clean, powder-free nitrile gloves and practice clean sampling techniques.
3. Remove the end of the pump tubing from the full sample container; remove the full container from the sampler and cap it with a clean lid; place a clean container in the sampler; and place the tubing into the clean container. Do not allow the exposed tubing end to contact hands or other surfaces.
4. After the sample container has been changed, close the sampler. Using the sampler keypad, place the sampler in sampling mode. Notify the field supervisor or remote operation personnel as soon as the container change is complete.
5. If requested by the field supervisor or remote operation personnel, change the sampling interval to prevent the sample container from filling again. Record the change in the field log.
6. Complete the appropriate information on the label of the collected composite sample container(s).
7. Pack the collected composite container(s) in ice and secure it inside a vehicle for transport.
8. Verify that the automatic sampler has been placed in sampling mode if sampling is to continue. Visually inspect sampler components for possible damage or clogging to ensure the system will be ready to continue sampling or is ready to sample the next storm.

When conducting monitoring to determine compliance with water quality objectives or receiving water impacts, the more rigorous composite container changing protocols must be followed.

11.2.11 Splitting Composite Samples

The sampling team or analytical laboratory pours composite samples collected in a single composite sample container into individual sample containers for analysis. To limit contamination, splitting should be conducted by the laboratory.

If a composite sample duplicate is required, the sampling team should split the composite sample into two composite containers to generate a sub-sampling duplicate (replicate samples generated from a single composite sample container). As with field duplicate samples (replicate samples collected simultaneously in the field), sub-sampling duplicates should be submitted to the analytical laboratory "blind," labeled as an ordinary field sample so the laboratory does not know it is a duplicate sample.

When toxicity testing is planned in conjunction with general stormwater monitoring, it can be viewed by the sampling crew as an additional constituent for analysis. Therefore, samples for toxicity testing need to be poured off into the appropriate sample containers in the same manner as samples for other analyses. When pouring off samples for toxicity testing, fill sample containers completely, leaving no space at the top.

Three sample splitting methods are described below.

11.2.11.1 Peristaltic Pump Method

The peristaltic pump method utilizes manual agitation to thoroughly mix the sample before splitting it by using a peristaltic pump. The following procedure is recommended:

1. Label the containers for drawing individual samples per required analyses.
2. Wear clean, powder-free nitrile gloves for handling containers and lids.
3. Clean items that will contact the sample using protocols presented in Appendix E.
4. Manually agitate the sample continuously and draw samples into individual sample containers using a portable peristaltic pump and clean tubing. The volume of sample drawn in various containers should be in accordance with laboratory-recommended sample volumes for relevant constituents.
5. Manually shake the composite sample container during sample transfer to ensure the individual samples are homogeneous and particulate matter in the original composite sample is drawn equally into the individual containers.

6. Clean and replace peristaltic pump tubing following protocols presented in Appendix D prior to splitting another composite sample into individual sample containers.

Performing sample splitting by agitation and peristaltic pump can be accomplished by both crews in the field and the analytical laboratory.

11.2.11.2 United States Geological Survey (USGS) Method

This method utilizes manual agitation to thoroughly mix the sample before splitting it by using a funnel splitter (Figure 11-5). The following procedure is recommended:

1. Label the containers for drawing individual samples per required analyses.
2. Wear clean, powder-free nitrile gloves for handling containers and lids.
3. Shake the composite container thoroughly, with lid in place, until the sample is well mixed.
4. Immediately after mixing, pour the composite sample into a pre-cleaned Teflon® funnel/splitter with clean tubes leading to individual sample containers. The volume of sample poured into the containers should be in accordance with laboratory-recommended sample volumes for relevant constituents.
5. Clean the funnel/splitter and tubing using protocols presented in Appendix D prior to splitting another composite sample into individual composite samples.

Performing sample splitting by funnel/splitter can be costly and may cause logistical problems because the splitting equipment must be cleaned after every use. It is recommended when a single composite sample must be split into multiple samples. This method can be used either in the field or in the laboratory, but it is often more practical for use in the lab because of the cleaning requirements.

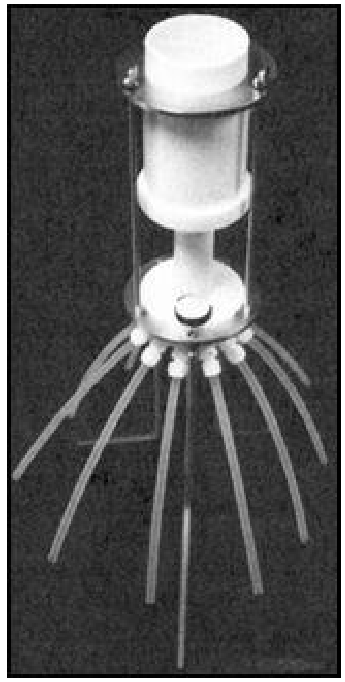


Figure 11-4 USGS Sample Splitting Method – Teflon® Funnel/Splitter

11.2.11.3 MANUAL POURING METHOD

This method utilizes manual agitation to thoroughly mix the sample before splitting it by pouring into separate containers. The following procedure is recommended:

1. Label the containers for drawing individual samples per required analyses.
2. Wear clean, powder-free nitrile gloves for handling containers and lids.
3. Shake the composite container thoroughly, with lid in place, until the sample is well-mixed. For large composite containers, the use of a swiveling mechanical container holding/mixing/pouring device is recommended.
4. Immediately after mixing, pour the composite sample into individual sample storage containers. The volume of sample poured into various containers should be in accordance with laboratory-recommended sample volumes for relevant constituents.
5. Cap the containers.
6. Repeat Step 3 immediately prior to filling each sample storage container.

Performing sample splitting by the agitation and pour method is recommended for crews in the field because no added equipment is necessary except a mechanical holder/decanter, which does not contact the sample water. Also, large numbers of composite samples can be split into multiple sample containers without performing the necessary cleaning protocols required for the previous three methods.

11.2.12 Multi-Container Compositing

When multiple composite sample containers are filled at a single site during a single storm monitoring event, the sample containers are typically composited together to produce a single composite sample representing the entire monitoring event. Each sample container must be well-agitated prior to pouring the sample into another composite container. The sample is mixed thoroughly by shaking or otherwise agitating the composite container to prevent sediment from remaining on the bottom of the container; various methods for doing this are described below. Throughout the sample compositing procedures, clean, powder-free nitrile gloves are used for container and lid handling. This process can be done by analytical laboratory personnel or by field sampling personnel in a clean, dry setting.

To combine multiple sample containers and generate a single composite sample for the entire storm event, two items must be determined: (1) the percentage of the sampling event flow represented by each individual sample container; and (2) which of the sample container(s), if any, will limit the compositing of samples. Because individual sample containers will likely contain different volumes, one container will likely dictate the total sample volume available for compositing. Individual sample containers may contain different sample volumes for several reasons. For example, the number of aliquots may differ in each container if runoff ceased before triggering all programmed sample aliquots or if a composite bottle was changed prior to filling completely. Composite container volumes may also differ slightly due to unequal aliquot volumes caused by pump tubing blockages or wear.

The sample in each individual composite container is considered representative of the volume of stormwater runoff that passed the sampling point during the filling of that container. The volume drawn from each container should be in proportion to the portion of the total volume that passed the sampling point during the storm event. Therefore, to properly combine multiple composite samples, the following must be known:

- Individual sample volumes in each composite sample container
- Total flow volume that passed during the collection of the total sample volume in each individual composite sample container
- Total runoff volume for the monitoring event

Multi-container composite samples should be combined by first calculating the proportion of the runoff event represented by each composite container. The calculated proportions are then used to compute the volumes that should be drawn from each container using the equations presented below.

First, calculate the total sampled flow represented by a given sample container:

$$P_n = V_n/V_t \times 100$$

Where:

P_n = Percent of the total sampled flow represented by sample n
V_n = Volume of flow that passed during the collection of sample n
V_t = Total volume of flow that passed during the sample collection event

Next, calculate the exact volume of sample to be drawn from the container:

$$S_n = S_t \times P_n$$

Where:

S_n = Volume to be contributed from sample n to the composite sample
S_t = Volume needed for doing all sample analyses (normally about 20 L)
P_n = Percent of the total sampled flow represented by sample n

These calculations are repeated for all sample containers collected during the storm event. If the calculated contribution from any composite container exceeds the volume present in that container, then that container is the volume limited container. The total volume of the final composite is then calculated as Sn/Pn where Sn is the volume collected in the volume limited container and Pn is the percent of the storm event represented by that container.

11.2.13 Composite Sample Preservation

Preservatives are not added to the composite container when composite sampling procedures are used because no single chemical preservative is generally suitable for all of the constituents to be analyzed. Upon sample receipt, the laboratory must first divide the composite sample into the appropriate container for each analysis and then add chemical preservatives, as appropriate.

Stormwater runoff samples are kept on ice or refrigerated to between 0° and 6°C from the time of sample collection until delivery to the analytical laboratory. Refrigerated automatic samplers are ideal for keeping composite samples cool during sample collection. Where refrigerated automatic samplers are not used, composite samples must be kept on ice from the time sampling is initiated until delivery to the lab. The ice must be checked regularly to ensure the sample is kept cool.

In addition to keeping stormwater samples cool, it is important to minimize the exposure of the samples to direct sunlight. Sunlight may cause biochemical or photochemical transformation of the sample, resulting in unreliable analytical results. Samples must be covered or placed in an ice chest with a closed lid immediately following removal from the automatic sampler enclosure.

11.2.14 EVALUATING SAMPLE REPRESENTATIVENESS

As soon as the samples have been collected, the hydrologic data from the event must be evaluated to make sure the monitored event met the minimum storm capture requirements for the project (Table 10-3).

Percent storm capture is the percentage of the total event flow that passes the sampling station during which sample collection occurred (i.e., the portion of the runoff represented by the composite sample). This is calculated simply by dividing the flow volume that passed the sampling station during sample collection by the total flow that passed the sampling station during the entire monitoring event. Percent storm capture can be checked by analyzing flow data from the data logger using the Caltrans Hydrologic Utility (Caltrans 2011). The Hydrologic Utility takes time-series data from the data logger and creates a complete hydrograph of the event. Field technicians can quickly determine what percentage of the storm was successfully captured and review the rest of the hydrograph for problems or anomalies.

The minimum acceptable number of sample aliquots and minimum acceptable storm percent capture depend on the total event precipitation, as shown in Table 10-3. The specified minimum number of sample aliquots is intended to ensure adequate representativeness of the composite sample throughout the monitoring event. Higher numbers of sample aliquots are desirable whenever possible, subject to the practical limitations of sample collection.

If storm capture criteria are met, then the samples are sent to the laboratory. If the requirement for storm capture is not met or if there are other problems with the hydrograph that might result in the storm event being rejected, the monitoring team must contact the Caltrans Task Order Manager immediately and explain the situation.

The Task Order Manager will either authorize the team to send the samples to the laboratory or direct them to dispose of the samples.

11.3 Field Filtration for Dissolved Metals

For samples to be analyzed for dissolved metals, sample filtration is required within 15 minutes of completion of sample collection. If filtration can be done in the field in such a way as to minimize the possibility of contamination, and if the analytical laboratory is a substantial distance from the monitoring location, field filtration should be performed to meet USEPA requirements.

Several devices are available for filtering samples in the field. The most used field-filtration setup used by Caltrans consists of a disposable 100 mL plastic syringe and a 0.45-micron Luer lock filter attached to the syringe intake port. Field technicians remove the plunger, fill the syringe with sample water, and manually force the water through the filter directly into a laboratory sample bottle. Regardless of what techniques and devices are used, samples collected for dissolved metals must be passed through a 0.45-micron filter before being preserved.

When filtering samples in the field, it often happens that the filters clog so quickly that is difficult or even impossible to obtain enough filtered sample to analyze. This problem is usually solved by using multiple filters; as one filter clogs, the field technician replaces it with a fresh filter and continues to filter the sample. If four or five filters have clogged and the minimum volume required for the analysis (typically 100 mL for metals analyses) cannot be obtained, the field technician must use best professional judgement to decide whether it will be practical to field-filter the sample. If the sample cannot be field filtered, the field technician will note this in the field log and send the required volume of unfiltered sample to the laboratory for filtration.

Filters purchased for field-filtration of metals samples must be purchased certified-clean from a scientific supply company.

At the beginning of every season, field crews should perform a test of the filtration equipment and their field-filter technique by field-filtering blank water obtained from the laboratory and sending it to the lab for analysis. This test will verify that the filters are clean and that the filtering technique is not adding contamination to the samples.

In any case where samples are to be filtered by the laboratory, it is important that the samples be transported to the laboratory promptly and filtered immediately upon receipt.

The laboratory must be notified in advance that samples will be delivered and immediate filtration for dissolved metals analysis will be required.

In cases where it is not logistically possible to filter the sample within 15 minutes of collection (for example, when composite samples are collected at an automated monitoring station, and field personnel are not present at the end of the monitoring event), field technicians will make every effort to filter samples as soon after collection as possible. The date and time that the samples were filtered will be recorded in the field log.

11.4 Holding Time

Regulatory holding times are specified by analytical methods (Table 5-1). For the purpose of this manual, the holding time starts when sample collection is complete and is counted until extraction/preparation or analysis of the sample. The time of collection of the final sample aliquot is considered the sample collection time for determining sample holding time for composite samples that represent less than 24 hours of flow. If the composite sample collection period exceeds 24 hours, the composite sample container(s) must be replaced at, or prior to, the end of each 24-hour period. For constituents with short holding times, such as 48 hours or less, the composite sample volume must be removed from each 24-hour composite for analysis, as necessary, to comply with holding time requirements. Each short-hold analysis is reported as a discrete data point. Figure 11-6 shows an example procedure for combining composite samples for a three-day monitoring event with multiple sample bottles so hold times are not exceeded.

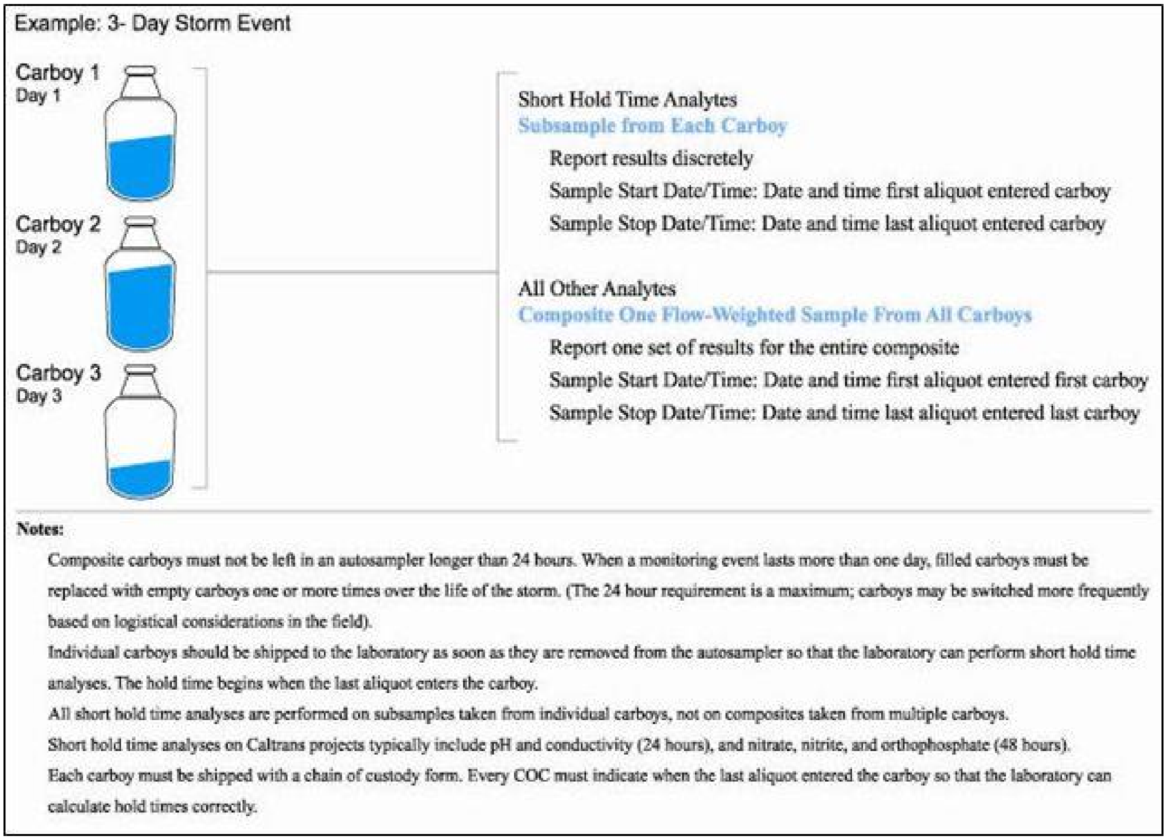


Figure 11-5 Procedure for a Three-Day Event with Multiple Sample Bottles

It is important that field and laboratory personnel work together to meet specified holding times. The lab must make every effort to prepare and analyze the samples as soon as possible after they are received. Prompt analysis also allows the laboratory time to review the data and, if analytical problems are found, reanalyze the affected samples.

Some holding times are short and will require the laboratory to immediately analyze the sample upon receipt. Holding times may influence allowable sampling windows if the laboratory has not agreed to work evenings or weekends. To minimize the risk of exceeding the holding times, stormwater samples must be transferred to the analytical laboratory as soon as possible after sampling is complete. Moreover, the laboratory needs to be notified before sampling begins so it is prepared to analyze the samples immediately upon receipt. Samples should be frozen to extend holding time unless it is prohibited by project specification or a regulatory agency. USEPA and State Water Board guidance must be obtained in such cases.

11.5 QA/QC Sample Collection

The collection of QA/QC samples is an important part of the sample collection activities during a storm event. As explained in Chapter 12, a QC sample schedule must be developed and followed throughout the monitoring season. The following QC samples are normally collected:

- Equipment blanks
- Field blanks
- Trip blanks (VOA samples only)
- Field duplicates

In addition, enough volume should be collected for performing matrix spike/matrix spike duplicate (MS/MSD) and laboratory replicate analyses. The field technician must identify the MS/MSD and laboratory replicate samples on the COC form.

Each of these types of samples and the collection procedures are described in Chapter 12. See Table 12-3 for recommended minimum frequencies for collecting QC samples.

11.6 Documentation

A sample activity log and COC form are used to document sampling collection activities during the sample collection process and prior to receipt of the sample by the laboratory.

11.6.1 Sampling Activity Logs

Caltrans requires field crews to keep a field log for each sampling event. The following items must be recorded for each sampling event:

- Time of sample collection
- Sample ID numbers, including unique IDs for replicate or blank samples
- The results of field measurements (temperature, dissolved oxygen, pH, conductivity, and turbidity) and the time these measurements were taken
- Results of field calibrations (e.g. for primary or secondary devices)
- Qualitative descriptions of relevant water conditions (e.g., color, flow, level, and clarity) or weather (e.g., wind or rain) documented at the time of the site visit

- A description of unusual occurrences associated with the sampling event, particularly those that may affect sample or data quality

A sampling activity log (Figure 11-6) should be used to record data consistently. Detailed field observations must also be recorded. An example of a detailed field observation form is provided in Appendix F.

SAMPLING ACTIVITY LOG				
Project Name:				
Caltrans Contract No.:				
Contractor:				
Sampler's Name:				
Signature:				
Date of Sampling:				
Season: (Check Applicable)	☐ Wet ☐ Dry			
	Storm Start Date & Time	Date : time	Storm Duration	hrs
	Time elapsed since last storm (Circle Applicable Units)	Min. Hr. Days	Approximate Rainfall Amount	mm
	Flow rate	cfs	Total flow	cf
	Velocity	fps	Number of successful samples	#
	Flow meter, sampler, telemetry battery voltages	v	Number of missed samples	#

SAMPLE LOG		
Sample Identification	Sample Location	Sample Collection Date and Time

SAMPLING INTERVAL CHANGE
☐ Yes ☐ No (if Yes note the prior and changed values here)
FIELD ANALYSIS
☐ Yes ☐ No

VISUAL OBSERVATIONS: flow, trash etc.		
Sample Identification	**Test**	**Result**
	pH	
	EC	
	Hardness	
	Other tests as specified (Temperature, DO)	

Figure 11-6 Sampling Activity Log Form

11.6.2 Chain-of-Custody Forms

Chain-of-custody (COC) forms must be completed by the sampling team for samples submitted to the analytical laboratory. The purpose of COC forms is to keep a record of the transfer of sample custody, samples submitted to the laboratory, and requested analyses. The COC forms include the following information:

- Sampling date and time
- Laboratory delivery date and time
- Sampling location
- Sampler's name and contact information
- Sample type (grab or composite)
- Sampling technique (manual or automatic)
- Sample volume, container type, and preservation
- List of the assigned analyses
- Detailed description of the unusual events associated with the sampling event, sample handling, or sample transport
- Special instructions for the laboratory (e.g., filtration for dissolved metals)
- Sample temperature and condition

Customized project specific COC forms that include standard information (e.g., contact information, constituents and methods, and special notes) are recommended.

Copies of COC forms are kept with field notes in a field logbook. COC forms must be checked by the field task leader to ensure the analyses specified by the sampling plan are included. Review of the COC forms immediately following a storm event gives the data reviewer a chance to review the field crews' requests and then to notify the laboratory of the need for additional analyses or clarifications. Additional analyses or limiting analyses (for composite samples without enough volume to test a full suite) must be approved by the project manager. Appendix G shows a sample COC form that can be printed and used in the field.

11.6.3 Field Measurements and Documentation

The use of field instruments for stormwater analysis and documentation of post-storm activities is discussed in Appendix I.

11.7 Transporting Samples to the Laboratory

Composite and grab samples must be kept on ice or refrigerated nominally at 4°C (0° to 6°C or 30° to 42.8°F is the acceptable range) from the time of sample collection to the time of receipt by laboratory personnel. Sample containers being delivered to the laboratory must be: (1) well-packaged with bubble wrap, foam, etc.; and (2) kept inside coolers with double-bagged ice (wet ice is preferable to gel ice). The drain plugs on the coolers must be sealed and the lids must be secured with packaging tape. Overnight services may not deliver leaky coolers or shipping containers.

It is imperative that samples are delivered to the analytical laboratory soon enough so analysis begins within the maximum holding times specified by laboratory analytical methods (Table 5-1). For example, if the fecal coliform test is required, analysis must be started within eight hours of sample collection (the analytical method allows six hours for transportation to the laboratory and two hours to begin analysis). Similarly, soluble reactive phosphorus (orthophosphate) or nitrite analyses must be performed within 48 hours after sample collection. For composite samples, this 48-hour period starts based on the last sample aliquot rather than the first sample aliquot.

Toxicity samples need to be delivered to the toxicity laboratory within 24 hours and toxicity tests initiated within 36 hours. Although this is the acceptable holding time for freshwater acute and chronic toxicity tests, there may be situations where it is logistically impossible to submit samples to the toxicity laboratory within 24 hours. For composite samples, this 36-hour period starts based on the last sample aliquot rather than the first sample aliquot.

Analytical results reported for samples that were analyzed outside of the allowable hold time must be reported as qualified data and should be considered estimated.

12 Quality Assurance / Quality Control

The set of measures designed to ensure the integrity of a project's water quality data are collectively referred to as Quality Assurance/Quality Control (QA/QC) procedures. Data quality objectives (DQOs) for precision, accuracy, contamination, completeness, and representativeness are established for each project, as outlined in Chapter 2. The DQOs provide specific means of assessing the effectiveness of the project's QA/QC procedures.

This chapter describes QA/QC practices for water chemistry, toxicity, microbiology, and gross solids monitoring, as well as other miscellaneous quality considerations.

The following aspects of QA/QC sample methodology are discussed in this chapter:

- Standard QA/QC for water analyses
- Standard QA/QC for field analyses
- Standard QA/QC for microbiological analyses
- QA/QC scheduling
- Additional measures for field procedures

12.1 QA/QC for Water Chemistry Analysis

The quality of water chemistry data is usually expressed in terms of precision, accuracy, contamination, interference, and completeness. These parameters can be applied to both lab and field QA/QC as further described below.

Laboratories use numeric limits for precision and accuracy, called control limits, to accept or reject analytical data. Control limits are established for all water chemistry, microbiology, and toxicity methods. Some control limits are determined by each laboratory individually and can vary considerably from one lab to another for some analyses. For example, control limits for some semi-volatile organics may vary by 100% or more among different labs. Control limits for other analyses, for example trace metals, are specified in the analytical method and are normally uniform among labs. This factor should be kept in mind when reviewing data. It is common for metals, nutrients, and physical constituents to have acceptance criteria that are almost universal; other analyte groups such as pesticides, PCBs, and other organic compounds often have acceptance criteria that vary widely between labs.

Environmental laboratories analyze multiple samples at once, in a group called a batch. One full set of quality control samples (described below) is analyzed with every batch, so a batch is also frequently called a QC batch. Every water chemistry result has an associated set of batch QC associated with it. A QC batch is almost always a group of either ten or 20 environmental samples plus one full set of QC samples.

Table 12.1 presents a summary of the quality control sample types that must be analyzed to assess these parameters.

Table 12-1 Summary of QC Sample Types and Their Uses

QC Sample Type	Tests For	Source	Submitted Blind
Field Duplicate	Precision	Field	Yes
Laboratory Duplicate	Precision	Lab	N/A
Blank Spike (LCS)	Accuracy	Lab	N/A
Blank Spike Duplicate	Precision, Accuracy	Lab	N/A
Matrix Spike	Interference, Accuracy	Field	No
Matrix Spike Duplicate	Interference, Precision, Accuracy	Field	No
Field Blank	Contamination	Field[1]	Yes
Method Blank	Contamination	Lab	N/A
Equipment Blank	Contamination	Field[1]	Yes
Trip (Travel) Blank	Contamination	Field[1]	No
Bottle Blank	Contamination	Lab	N/A

[1] Clean water supplied by the laboratory

12.1.1 Precision

Precision is the degree to which repeated measurements agree with each other under unchanged conditions. This is also referred to as repeatability or reproducibility. When analyzing stormwater samples, a laboratory demonstrates a high degree of precision by analyzing the same sample repeatedly and obtaining identical or very close results each time. If the analytical results agree to within the lab's control limits for that method, the method is said to have acceptable precision. Samples analyzed multiple times to demonstrate precision are called duplicate (or replicate) samples.

Precision is expressed as a percent difference between duplicate results. Relative percent difference (RPD) is the difference between two analytical results divided by their average, and is determined using the following formula:

$$RPD = \frac{R^1 - R^2}{(R^1 + R^2) / 2} \quad X\ 100$$

Where:

RPD	=	Relative Percent Difference
R1	=	Result of first analysis
R2	=	Result of duplicate analysis

Duplicate samples are produced both in the field and in the laboratory.

Field Duplicates: A sample that is split into two fractions in the field and sent to the laboratory for analysis is called a field duplicate. Field duplicates are submitted to the laboratory with different sample IDs, so the laboratory does not know they are duplicates (this is referred to as submitting the samples blind to the laboratory). The results are compared by Caltrans to evaluate the laboratory's precision. The analysis of field duplicates is a way to measure both the precision of the field sampling protocols and the laboratory's analytical procedures. It is expected that the field duplicate results would exhibit greater variability than the laboratory replicate results.

Field technicians must take care to ensure that field duplicates are identical. This is done by collecting a single sample and mixing it thoroughly, then pouring it into two sample containers. The best way to make a set of field duplicates is to take a single sample, pour half of it into a second container, and then pour it back and forth several times to mix it. This will result in two identical samples. Field personnel should not collect one sample from a runoff stream and then a second sample from the runoff stream to use as field duplicates, because slight variations in the stream between collections could cause differences in the contents of the two containers.

Subsampling duplicates are two unique, ostensibly identical samples taken from one composite bottle. Subsampling duplicates are used as a substitute for field duplicates in some situations and are also an indicator of the variability introduced by the splitting process.

Lab Duplicates: Sometimes called lab replicates, these are created by the laboratory to test precision. Laboratory duplicates are split from a single sample by the laboratory. Each half of the split sample is then analyzed and reported by the laboratory.

Laboratory duplicate results provide information regarding the variability inherent in the analytical process and the reproducibility of analytical results.

Because a lab analyzes a duplicate with every QC batch, every piece of analytical data has an associated precision check, whether it is ordered or not. For this reason, field duplicates are not required every time samples are submitted to the laboratory. The two advantages of field duplicates are (1) they are submitted blind, so the laboratory does not know they are duplicates, and (2) they are a check of the analytical method in the actual study matrix, rather than a randomly selected sample that may or may not be representative of the study matrix.

12.1.2 Accuracy

Accuracy is the degree to which measurements agree with the true value. When analyzing stormwater samples, the laboratory demonstrates a high degree of accuracy when it reports a constituent concentration that is identical or very close to the actual concentration of that constituent in the sample.

Analytical accuracy is demonstrated by analyzing spikes (sometimes also referred to as fortified samples). Spikes are produced by introducing a known amount of target analyte into a sample or blank, which results in a sample with a known concentration of target analyte. The sample is analyzed, and the result is compared to the known concentration. If the observed concentration agrees with the known concentration to within the method control limits, then the method is said to have acceptable accuracy.

Accuracy is expressed as percent recovery, the percent of the known, true concentration that was obtained by the analysis. When spiking a sample that is known to be free of the target analyte (for example, when spiking clean DI water), accuracy is determined using the following formula:

$$\text{Recovery (\%)} = \frac{C}{S} \times 100$$

Where:

% R	=	Percent Recovery
C	=	Concentration obtained from the analysis
S	=	Spike concentration of target analyte added to sample

When spiking a sample that has a native concentration of the target analyte (usually an environmental sample, discussed below), the formula is a bit more complex. To express accuracy, it is necessary to consider not only the amount of target analyte that was added, but also the amount that was native to the sample to begin with. In this case, accuracy is determined using this modified formula:

$$\text{Recovery (\%)} = \frac{C_s - C_{us}}{S} \text{ X } 100$$

Where:

C_s	=	Concentration obtained from the analysis of spiked sample
C_{us}	=	Concentration obtained from the analysis of un-spiked sample
S	=	Spike concentration of target analyte added to sample

Note that in this case, the laboratory must analyze the sample both before and after it is spiked so the un-spiked concentration can be subtracted from the spiked concentration.

Samples used to demonstrate accuracy come both from the field and from the lab.

Matrix spikes are environmental samples that are spiked by the laboratory to demonstrate accuracy. The purpose of using matrix spikes is to demonstrate that the laboratory produces accurate results when analyzing environmental samples that might contain interfering substances. Interference is discussed in Section 12.1.4.

When sending a sample to the laboratory for a matrix spike analysis, the sample cannot be submitted blind, as field duplicates are, because the laboratory must know which sample is to be spiked.

Matrix spikes are nearly always performed in duplicate to provide a second check of precision. For this reason, when submitting a sample to the laboratory to be used as a matrix spike, three times the normal sample volume must be submitted; the first volume to be analyzed as a normal environmental sample, the second to be analyzed as a spiked sample, and the third to be analyzed as a duplicate spiked sample.

In addition to spiking environmental samples, laboratories also spike reagent-grade deionized water with a known concentration of target analyte and process them in the same way that matrix spikes are processed. These blank spikes, also called laboratory control spikes (LCS), are used to demonstrate method accuracy if there is a problem with the matrix spikes, such as contamination or the presence of an interfering substance.

12.1.3 Contamination

Contamination is the presence of a substance in a sample that was not originally native to the sample. Samples can be contaminated when they are collected, when they are being handled by field personnel, during transport, in storage, or by the laboratory. In practice, trace contaminants are introduced into virtually any stormwater sample before it is analyzed. Contamination is only a problem if it consists of a detectable level of the target analyte (the analyte that the analysis is designed to measure), or if it consists of another substance that interferes with the analysis.

In order to demonstrate that samples have not been contaminated, it is necessary to analyze blanks. Blank samples are analyzed as part of every QC batch. If no target analyte is detected above the reporting limit then the batch is considered to be uncontaminated. Samples used to check for contamination come both from the field and from the laboratory.

Field blanks are produced by pouring water (obtained from the lab) that is known to be free of target analytes into clean sample containers. This is done in the field, and the blanks are processed, transported, stored, and delivered to the laboratory in exactly the way the environmental samples are. It is assumed that any contamination that enters the samples during this process will also enter the blanks, and will be detected during analysis. As with field duplicates, field blanks should be submitted blind to the laboratory.

Trip (or travel) blanks are a particular kind of field blank that is used when monitoring for volatile analytes such as gasoline, volatile organic compounds, and low-level mercury. The laboratory prepares trip blanks by pouring clean water into sample containers. The blanks accompany the clean sample containers that the laboratory delivers to the monitoring consultant, and travel through the entire sample collection process, then back to the laboratory. Trip blanks remain sealed during the entire trip. Any volatile contamination introduced to the samples is assumed to also be introduced to the trip blanks.

Trip blanks are not usually analyzed unless unexpected compounds are detected in the samples.

Equipment blanks are also produced in the field. Before the beginning of a new monitoring season, sampler tubing and strainers are cleaned by the laboratory. When equipment has been installed at monitoring stations, field technicians obtain clean water from the laboratory and pump it through the system as if it were an environmental sample. These samples are then submitted blind to the laboratory for analysis, in order to make sure the cleaning has been performed properly.

Laboratories clean this equipment in batches, and only one set per batch needs to be tested to accept the entire batch. For example, if six sets of tubing and strainers are cleaned in one batch and then installed in the field, then only one equipment blank should be tested for all six sites. If the equipment blank is clean, it can be assumed that all of the equipment cleaned in that batch was cleaned properly.

Laboratory Blanks: Laboratories analyze a method blank as part of every QC batch. A method blank is a sample composed of reagent-grade deionized water that is known to be free of target analyte. The blank is processed through all steps of an analysis just as environmental samples are. Any contamination introduced by the lab is assumed to also be introduced into the method blank, where it will be detected during analysis.

Bottle blanks are also produced by the laboratory. Bottle blanks are produced by filling an unused sample bottle with clean water and then analyzing the water for contaminants. If bottle blanks are analyzed, this is ordinarily done every time a new lot of sample containers are received from the vendor.

However, it has become most common in recent years for vendors to supply labs with certified clean containers, which eliminates the need to test bottle blanks. Currently, it is uncommon for laboratories to test bottle blanks as part of their standard QA/QC program.

12.1.4 Interference

Interference is a chemical in or a property of the sample that affects the result of the analysis in a detectable way. An interfering substance is ordinarily a high concentration of a non-target substance in the sample that interacts with the chemistry of the analytical method and changes the result. Although interference can cause serious difficulties in some applications, it is rarely a problem in stormwater monitoring.

There are both positive interferences, which raise the analytical result, and negative interferences, which lower the analytical result. There are many substances found in environmental samples that can cause interference. High concentrations of non-target metals may make it impossible for an analytical instrument to detect lower concentrations of target metals. Moderate concentrations of oil may physically coat an electrode and cause it to malfunction or cause emulsions during the extraction process. When the laboratory suspects that some component of a sample may be interfering with the analysis, the sample is usually diluted and analyzed a second time. The purpose of diluting the sample is to dilute out the interference; however, because this also dilutes the target analyte, this process raises the detection limit.

12.1.5 Completeness

Completeness is the percentage of samples that are collected during a monitoring project that produce valid, usable data. This is usually calculated either at the end of a project, or during some natural breakpoint in the project, i.e. between monitoring seasons.

If every sample collected is properly processed and analyzed and if no data are rejected, then the completeness for the data set is 100%. In reality, some monitoring data usually need to be qualified or rejected, and this can happen for a variety of reasons. This reduces the completeness of the data set.

Note that completeness is calculated for each analyte in a study. For example, if ten samples are collected for analysis of copper and lead, and if the laboratory produces ten usable results for copper but must reject two lead results, the completeness for copper would be 100% and the completeness for lead would be 80%.

Table 12-2 presents a summary of the quality control sample types that are typically analyzed to assess these parameters.

12.2 QA/QC for Field-Measured Parameters

For field measurements, QA/QC measures pertaining to field testing should include the following:

- Daily calibration of field meters prior to use during each monitoring event
- Maintenance of field meters—especially probes
- Thorough rinsing of probes with deionized water between measurements
- Field duplicates of field measurements

Daily calibration of field meters (prior to any monitoring event) is an essential part of QA/QC for field measurements. Manufacturers' specifications should be followed for calibration. Proper maintenance of field equipment—particularly probes—is also essential. Manufacturers' specifications should be followed for maintenance; replace probes as needed. The field meter probes must be thoroughly rinsed in the field after each measurement, using laboratory-supplied, reagent grade, deionized water. Deionized water can be carried into the field and applied using a plastic squirt bottle dedicated to the purpose.

Duplicate Field Measurements. To verify the precision of field measurements, duplicate measurements must be conducted in the field on at least one in every ten samples. The duplicate measurements should be performed in rapid succession in the field, from duplicate samples collected side-by-side or in rapid succession from the same location. If the measurement is made by inserting the probe into the discharge flow, the duplicate measurements should be made in rapid succession. After recording the initial result, withdraw the probe following the first measurement, and then immediately reinsert the probe into the same spot for the duplicate measurement. In contrast to field duplicate samples collected for laboratory analysis, which must be sent to the laboratory "blind" (i.e., both labeled as regular samples), both replicates for field measurements can be done by the same person, and are generally not done as a "blind" test (i.e., the same personnel may perform and observe both measurements). The RPD between each pair of duplicate measurements must then be calculated as defined above for Water Chemistry Analysis, and compared to the project's data quality objectives.

12.3 QA/QC for Microbiological Analysis

Fundamental concepts of quality control discussed above apply generally to microbiological analyses, but specifics are often different. Microbiological testing is also performed using living test organisms; in this case, culturing them for a certain period under controlled conditions in order to quantify them.

Precision is demonstrated by performing replicate analyses. One environmental sample per QC batch is usually tested in duplicate and the results compared. A relative percent difference within laboratory control limits demonstrates acceptable precision. Monitoring consultants can also submit field duplicates to the laboratory in order to check the lab's precision.

To demonstrate accuracy, certified laboratories participate several times a year in blind checks conducted by state regulatory agencies. Artificial samples are created with relatively predictable populations of organisms, and are submitted blind to participating labs for analysis. If a laboratory reports levels of organisms that are within the acceptance criteria, the method is considered to be within limits of accuracy.

To assess the possibility of contamination during field procedures, field blanks are collected by pouring clean deionized water into sterile containers in the field. When analyzed, these samples should show very little or no microbiological growth.

Substances in water that are harmful to microorganisms may interfere with an analysis. By far, the most common and predictable substance that causes interference with microbial tests is chlorine. If a sample is chlorinated, the organisms may be damaged or destroyed during sample transport. For this reason, sterile sample containers provided by the laboratory contain a de-chlorinating agent that neutralizes any residual chlorine when a sample is collected.

Completeness is defined and calculated for microbiological testing in exactly the same way it is defined and calculated for water chemistry analyses, as discussed in Section 12.1.5.

12.4 QC Sample Schedule

Table 12.2 lists recommended frequencies for collection of field QC samples.

Table 12-2 Recommended Frequencies for Collecting QC Samples

Field Blank	Field Duplicate	Matrix Spike/Dup	Equipment Blank	Travel Blank
One per every 20 samples collected per project	One per every 20 samples collected per project	One per every 20 samples collected per project	One per each batch of equipment cleaned by the laboratory, or when new equipment is deployed	One per event at each station where samples are collected for volatile organic compounds or low-level metals. Travel blanks should be held by the laboratory and not analyzed unless directed to do so by the consultant.

A QC sample schedule, showing the types of QC samples scheduled for each planned event, must be developed and followed throughout the monitoring season. Table 12.3 shows an example QC sample schedule.

Table 12-3 Example Field QC Sample Schedule

Site	Pre-Season	Event #1	Event #2	Event #3	Event #4
1	None	MS/MSD		Field duplicate	Field blank
2	Equipment blank[1]	Field blank	MS/MSD	Field duplicate	Lab duplicate
3	None	Field duplicate	Field blank	MS/MSD	None

[1] A single equipment blank assumes the equipment at all four stations was cleaned by the lab in the same cleaning batch.

12.5 Additional Measures for Field Procedures

Certain QA/QC protocols do not involve the laboratory and do not directly involve the samples, but should be included in the stormwater monitoring QAPP.

12.5.1 Pre- and Post-Event Checks

The QAPP must include a list of checks that field personnel must perform before each storm event to ensure the automated monitoring equipment is functioning properly, it is clean, the power supply and telemetry are working, and it is programmed correctly for the impending monitoring event.

The QAPP must also include a checklist of items that must be verified after the storm to confirm the samples should be sent to the lab for analysis. This post-event checklist should include such tasks as visually inspecting the composite sample container to verify the volume seems correct based on the number of aliquots taken, and it did not overflow during the monitoring event. Another task to include on the checklist is processing the time series data through the Caltrans Hydrologic Utility to make sure the percent capture of the storm is adequate.

After every monitored event, field personnel must check the drainage area to record any confounding effects such as sediment run-on over asphalt concrete dikes, leaking irrigation systems, etc.

12.5.2 Chain-of-Custody and Sample Delivery

Samples are in someone’s custody from the time they are collected until the time they are analyzed by the laboratory. Field personnel collect the samples and release them to whomever transports them from the field; the samples may then be delivered directly to the lab(s), transferred to the monitoring consultant’s office for storage, or given to a third-party courier for transport to the lab(s). At each step along the way, the samples must be maintained at the proper temperature and delivered within required holding times.

Upon delivery to the laboratory the samples are released to the lab's Sample Control Department. Each person receiving the samples must sign for them and record the date and time they were received. A COC is used for this purpose.

12.5.3 Equipment Calibration and Maintenance

The project QAPP should have a complete checklist of all routine maintenance required for the monitoring equipment, as well as a list of things that may indicate a piece of equipment needs attention. A schedule for periodic maintenance and calibration checks for field equipment should appear in the QAPP.

12.6 Other Considerations for a QA/QC Program

In some cases, QC samples at one site may be applied to another site if site conditions and monitoring requirements are similar. For example, if the same equipment and monitoring methods are used at two locations, quality control samples for contamination checks at one site can be used for the other site. Similarly, if the sample matrix at the two sites is very similar then the MS/MSD results from one site may be used for the other site. This is a good way to save analytical costs. However, the decision to use a single set of QC samples for multiple sampling locations must be made before the monitoring phase of the project begins.

There is no universal constituent list for blank testing that would apply to all Caltrans projects. Equipment and field blanks should usually be tested for all constituents on the project constituent list, with the following exceptions:

- Constituents such as turbidity, TSS, and hardness that are unlikely to remain after bottles have been rinsed.
- Dissolved constituents. The dissolved fraction of a constituent will be detected in the total fraction. For example, any dissolved copper that was not removed by the cleaning procedure would be detected in the analysis for total copper.

Because of unforeseen storm characteristics or equipment malfunctions, adequate volume to perform QC sample analyses may not be available for each monitoring event. In this case, MS/MSD analysis must be prioritized ahead of other QC samples requiring environmental sample volume. If there is inadequate volume to do a complete MS/MSD analysis, duplicate analysis must be performed first. Variations from the sampling plan need to be documented and the monitoring program schedule must then be adjusted to ensure the minimum number of QC samples is collected and analyzed during the project.

13 Laboratory Reports and Data Review

Laboratories submit standardized reports to the monitoring consultant after all analytical work is completed. As soon as they are received, lab reports must be reviewed for errors, omissions, and unusual or suspect results. This is important because errors or other problems that are caught immediately are often relatively easy to correct, but problems that are caught weeks or months after a storm event can be difficult or impossible to fix.

- This chapter is divided into four parts:
- The organization of laboratory reports
- Data review
- Data validation
- Final data submittal

13.1 Laboratory Reports

Laboratories usually report data in three formats:

- Hard copy (paper) reports
- Electronic (PDF) reports
- Electronic data deliverables (EDDs)

Electronic reports are PDF versions of the hard-copy (paper) lab reports. PDF reports are preferred by Caltrans because they are easier to submit, store, and search than paper reports. If the PDF copy is complete, Caltrans does not require the laboratory to submit paper reports.

13.1.1 Components of a Hard Copy/PDF Report

A hard copy laboratory report must include the following elements:

- Analytical data
- Quality control data
- Narrative
- Completed chain-of-custody form

- Signature

In addition, every lab report should include the laboratory name, address, contact information, and ELAP/NELAP accreditation numbers. These items may appear anywhere in the report but are usually found on either the narrative page or cover page.

13.1.1.1 Analytical Data

Analytical test results are usually organized by constituent type; for example, metals results grouped together, nutrients grouped together, and so on. The following information must be reported for each analysis result:

- Field sample ID
- Laboratory sample ID
- Constituent name
- Analytical method
- Sample preparation dates, if applicable
- Analysis date
- Quality control batch ID
- Laboratory batch quality control data
- Analytical result
- Reporting limit

These report components are standard in the environmental laboratory industry, and there should not be a problem or an extra charge for Caltrans laboratories to provide this information. At the beginning of the project, the consultant must verify that the project laboratory includes all of these elements in a standard report.

13.1.1.2 Quality Control Data

Quality control data are produced by laboratories to verify the lab is performing analytical methods correctly and the data are reliable. A full set of QC data must be included for every analytical result in the report. QC data are usually reported in a separate section of a lab report, after the sample data section.

See Chapter 12 for a full discussion of the types of quality control data Caltrans requires for all stormwater monitoring projects.

13.1.1.3 NARRATIVE

When the laboratory encounters a problem or unusual occurrence while analyzing samples, this must be noted in a narrative. The narrative should also discuss any corrective action that was taken, and any other pertinent information that might help a data reviewer interpret the data. A good example is matrix interference; if an analyst noticed that quality control results for accuracy were out of range, this would be narrated so the data reviewer could give extra attention to all analytical results for that sample.

13.1.1.4 COMPLETED CHAIN-OF-CUSTODY FORM

The chain-of-custody form (COC) is initiated in the field, travels with the samples until they reach the laboratory, and provides specific instructions for the lab.

The COC bears a record of everything that happened to the samples from the moment they are collected to the time they are relinquished to the laboratory, including the following:

- The date and time the samples were collected
- The location from which the samples were collected
- Sample names/IDs
- Names and signatures of the field personnel who collected the samples
- Names and signatures of everyone who took custody of the samples, when they received the samples, and when they relinquished them
- The types of bottles used to store the samples
- Any preservatives added to the sample bottles
- A record of any other sample processing, such as sample filtration, that was performed in the field
- The list of analyses required for each sample
- The required turnaround time for analyses
- Any special instructions to the laboratory

It is not possible to overstate the importance of a properly completed COC. Not only is the COC a critical part of the communication between the monitoring consultant and the lab, it is also required for the final report to be legally defensible and usable for regulatory purposes. It is sometimes not possible to interpret lab data correctly without a properly filled-out COC. Field personnel must be thoroughly trained in chain-of-custody protocol to make sure the document is filled out correctly.

Appendix F contains a generic chain-of-custody form that can be printed and used for Caltrans stormwater monitoring.

13.1.1.5 Signature

Every laboratory report must be reviewed in the laboratory before it is issued, and the reviewer must sign the report to certify it has been checked. Usually, the reviewer is the laboratory project manager, but it may also be the laboratory director or quality control officer, or a senior chemist with the authority to certify reports. The reviewer's signature usually appears on a report cover page.

13.1.2 Electronic Data Deliverables

In addition to paper reports, the laboratory issues reports in a machine-readable electronic format called an electronic data deliverable (EDD). Caltrans keeps an electronic archive of all data produced by the stormwater monitoring program, and EDDs are used to upload new data to the archive.

Caltrans stormwater monitoring data is submitted to the California Environmental Data Exchange Network (CEDEN). Laboratories submit their electronic data files in standard CEDEN-compatible format. Preformatted Microsoft Excel templates in standard CEDEN format are available for download from CEDEN.org. There are three templates used to report stormwater monitoring data for Caltrans:

- Water Chemistry Data Template
- Toxicity Data Template
- Field Data Template

The water chemistry and toxicity data files originate in the laboratory. The lab fills in the laboratory portions of the EDD templates and then submits them via email to the monitoring consultant, who then adds field data and any appropriate notes or other field information.

When an EDD is complete, the consultant uses an online CEDEN data checker to validate the file. When the file passes the checker with no errors, it is ready to submit to Caltrans. Online checkers are available from several Regional Data Centers (RDCs) located around the state. Consultants must use only the version of the checker that is used by the CEDEN.org website, which is the version that is hosted by most RDCs.

EDDs are due to Caltrans 30 calendar days after the end of every monitoring event. Laboratory data must be received by the consultant in a timely manner so data can be delivered to Caltrans on time. The consultant must make binding arrangements with contract laboratories to avoid late data submittals.

If a data deliverable is expected to be submitted late to Caltrans for any reason, the consultant contacts the Caltrans Task Order Manager with a description of the problem and an estimate of when the data may be expected. If a data submittal is expected to be late because of a failure of the laboratory to deliver data on time, the consultant must contact the laboratory via email to determine the reason for late submittal and expected delivery date. The Caltrans Task Order Manager should be copied on all email correspondence.

In cases where data are received on time from some laboratories and received late from others, the consultant submits the EDD without the late data and delivers the rest of the data separately as they are available. When submitting late data, the consultant must submit only the late data and not any previously-submitted data.

13.2 Reviewing Laboratory Reports

Laboratory reports must be reviewed thoroughly as soon as they are received. Any problems must be brought to the lab's attention as soon as possible so corrective action can be taken quickly. Data should only be passed on to Caltrans after all problems have been resolved and any problems that cannot be resolved have been narrated.

There are three steps to the report review process:

- Review lab reports for content
- Review lab reports against the chain-of-custody form
- Review lab reports against the QAPP

After the reports have been reviewed, the data are ready for the more detailed process of data validation, discussed in Section 13.3.

13.2.1 Review for Content

Laboratory reports must be checked to make sure they are complete and correctly assembled. Reports must include all the elements listed in Section 13.1.1 and must be legible. The entire report should be checked for typographical errors and other anomalies. The narrative must be checked to make sure the laboratory did not encounter any problems that require immediate attention.

Reports should be checked thoroughly by the data reviewer as soon as they are received from the lab. Field data should match the COC, and any errors, problems, or anomalies should be discussed in the report narrative. When reviewing toxicity reports, the reviewer should keep in mind that the acceptability of toxicity data depends on internal laboratory factors such as the pH, temperature, and dissolved oxygen in the test water during the analysis, as well as the behavior of control organisms. This determination normally relies on the best professional judgment of the laboratory analysts.

13.2.2 Review Lab Reports against the Chain-of-Custody

The COC is the official, legal set of instructions to the laboratory from the monitoring consultant. Every laboratory report should be checked to make sure all of the analyses on the COC were performed and no additional tests were performed. Sample IDs, sample collection dates and times, and other field information in the report must match the information on the COC.

Occasionally a laboratory may inadvertently perform an analysis that was not ordered on the COC. If this happens, the data must still be reported to Caltrans. Under no circumstances should data be rejected by the monitoring consultant and not reported. The consultant should let the Caltrans Task Order Manager know to expect additional data for that storm event and contact the laboratory to inform them of their error and to make sure Caltrans is not billed for such analyses.

Figure 13-1 is a checklist that can be used when reviewing laboratory reports. It contains all elements of a report that should be checked to make sure it is complete and consistent with the QAPP and the COC.

13.2.3 Review Lab Reports against the Quality Assurance Project Plan

Laboratory data must be checked for conformance with the QAPP Every report must be checked manually to make sure all of the tests called for in the QAPP were performed, no additional tests were performed, and the correct analytical methods were used.

As discussed in Chapter 2, every Caltrans monitoring project includes a set of data quality objectives (DQOs) specified in the QAPP. DQOs are requirements that analytical data must meet to satisfy the study objective. When reviewing lab reports against the QAPP, the reviewer must check to make sure all project DQOs have been satisfied.

Laboratory Report Checklist

Report Content Checked	Yes	No	Notes/Comments
Analytical data?	☐	☐	________
Quality control data?	☐	☐	________
Narrative?	☐	☐	________
Chain of custody?	☐	☐	________
Report signed?	☐	☐	________
Report complete?	☐	☐	________
Report checked for typographical errors and legibility?	☐	☐	________
Analytical results checked for unusual or suspicious values?	☐	☐	________
Analytical results reported down to the method detection limit?	☐	☐	________
Narrative checked?	☐	☐	________
Report Conforms with the Quality Assurance Project Plan			________
All analyses performed?	☐	☐	________
Unwanted analysis performed?	☐	☐	________
Correct analytical methods used?	☐	☐	________
Project-specific reporting limits met (if applicable)?	☐	☐	________
Project-specific quality control requirements met (if applicable)?	☐	☐	________
Report Conforms with the Chain-of-Custody			________
Client and project information correct?	☐	☐	________
Sample IDs correct?	☐	☐	________
Sample collection dates/times correct?	☐	☐	________
Date/time samples were received by the lab correct?	☐	☐	________
Analyses performed according to COC?	☐	☐	________
Turnaround time met?	☐	☐	________
All the directions on the COC adhered to?	☐	☐	

Figure 13-1 Checklist for Manual Review of Laboratory Reports

13.3 Data Validation

In addition to the data review process discussed in Section 13.2, the contents of lab reports should also be checked for data quality. This process is referred to as data validation. Data validation is a general term referring to the process of evaluating every analytical result against a set of rules. The purpose of data validation is to make sure that a data set is of acceptable quality and that questionable or indefensible data are qualified or rejected.

Data validation is performed manually by individuals who are experienced with the appropriate laboratory procedures and who understand laboratory data. Data validation must be performed as soon as a report is received from the laboratory so any problems discovered can be addressed immediately.

13.3.1 Data Validation Terminology

There are a few terms that the data reviewer should be familiar with before performing data validation. These are explained below.

13.3.1.1 Quality Control Batch

Environmental laboratories analyze multiple samples at once, in a group called a batch. One full set of quality control samples is analyzed with every batch, so a batch is usually called a QC batch. Every water chemistry result produced by a laboratory is part of a QC batch and is validated based on the results of the QC samples analyzed as part of that batch.

A QC batch is usually a group of either ten or 20 environmental samples, or all samples analyzed by that method in a day, whichever is more frequent.

13.3.1.2 Control Limits

Every quality control sample that a laboratory analyzes has numeric limits for precision, accuracy, and contamination. These are called control limits. Control limits for some analyses are specified by the analytical method, while others are determined statistically by each lab. When all QC sample results fall within their specified control limits, the laboratory is said to be running in control for that method. A large part of data validation consists of checking each data point against the lab's control limits for that analysis.

Table 13-1 lists typical laboratory control limits for analytes that are common in Caltrans stormwater monitoring projects. The laboratory checks for contamination by comparing the reported constituent concentration to the reporting limit established for each analytical method.

Table 13-1 Examples of Precision and Accuracy Control Limits

Analyte	Precision Relative Percent Difference	Accuracy Percent Recovery Lower Limit	Accuracy Percent Recovery Upper Limit
Conventional			
Hardness	20	80	120
pH	20	NA	NA
TSS	20	80	120
Turbidity	20	NA	NA
Nutrients			
Ammonia-N	20	80	120
Nitrate-N	20	80	120
Phosphorus	20	80	120
Orthophosphate	20	80	120
Metals			
Cd	20	75	125
Cr	20	75	125
Cu	20	75	125
Hg	21	79	121
Ni	20	75	125
Pb	20	75	125
Zn	20	75	125
Total Petroleum			
TPH (gasoline)	21	45	129
TPH (diesel)	21	45	129
TPH (motor oil)	21	45	129
Oil and Grease	18	79	114
Pesticides and Herbicides			
Glyphosate	30	70	130
OP Pesticides	25	Lab	Lab
OC Pesticides	25	Lab	Lab
Chlorinated Herbicides	25	Lab	Lab
Carbamate Pesticides	25	Lab	Lab
Miscellaneous Organic Constituents			
Semivolatile Organics	30 to 50	Lab	Lab
PAHs	30 to 50	Lab	Lab
Volatile Organics	20	Lab	Lab

Lab – Limits established by individual laboratories

13.3.1.3 QUANTITATION LIMITS

The concept of quantitation limits is covered fully in Chapter 5, but it is useful to mention them here briefly:

Method Detection Limit (MDL): The MDL is defined as the minimum concentration of analyte that can be identified, measured, and reported with 99% confidence, that the analyte concentration is greater than zero. MDLs must be calculated separately for each constituent and for each analytical instrument used to perform the analysis. For instance, if a lab uses two instruments to analyze samples for trace metals, then MDLs for each element would have to be established for both instruments. If both instruments analyze samples for copper and lead, then separate MDLs are required for both elements on both instruments.

Reporting Limit: For most constituents, laboratories establish reporting limits (RLs) to report analytical results. A reporting limit is the minimum concentration of an analyte that can be measured within specified limits of precision and accuracy. If the concentration of a target analyte is measured at or above the RL, then it is reported at that concentration; if it is detected below that value, then it is reported as “less than” the RL. Caltrans requires that all data be reported down to the MDL; values reported between the MDL and the RL should be considered estimated.

13.3.1.4 DATA QUALIFIERS

Data qualifiers are added to PDF and EDD reports by the laboratory. Qualifiers are used to indicate details of the sample result that may be important for proper interpretation of the data. Sometimes a data point can be qualified for a relatively minor reason and still be useable. Or a data point may be qualified because of a critical failure and must be rejected.

Table 13-2 lists a selection of common data qualifiers and their meanings. This list is only a partial summary of data qualifiers that may be used to qualify environmental data.

Table 13-2 Data Qualifiers

Qualifier	Definition
U	Target analyte was not detected in the sample.
J	Result is an estimated value. All values reported between the MDL and RL should be qualified as estimated.
B	Target analyte found in method blank at concentration greater than the reporting limit.
E	Concentration outside instrument calibration range.
N	Insufficient sample volume to perform the analysis.
SL	Relative percent difference cannot be calculated for duplicate analyses because one or both sample results are below the detection limit.
NH	Sample was not homogenous; reported result may not be representative of the entire sample.
M	Analytical result was affected by matrix interference.
R	Rejected. Data should not be used.

Qualified data should be summarized in project reports, and should always be reported in tabular form, not as a narrative. A summary of qualified sample results allows reviewers to get an idea of how much project data was qualified and for what reasons.

Table 13.3 shows an example of a summary table for qualified data.

Table 13-3 Summary Table for Qualified Data

Station ID	Sample Date/Time	Field Sample ID	Qualifier	Notes
1-101	1/1/2014 15:51	1-101-01011-SAUIN-01	J	LCS out of range high
1-101	2/12/2014 18:01	1-101-021214-MED01-03	J	Result between MDL and RL
1-101	3/19/2014 4:13	1-101-031914-DA-FAL-D	R	Rejected - analyzed > 2x allowable hold time, result ND

13.3.2 Elements of Data Validation

The following quality control elements are checked as part of the data validation process:

- Reporting limits
- Holding times
- Contamination (blanks)

- Precision (duplicate samples)
- Accuracy (spiked samples)

13.3.2.1 Reporting Limits

Reporting limits are checked to make sure they are low enough to meet the project requirements, as specified in the project DQOs. RLs that are lower than those specified in the DQOs are not a problem, but they should not be higher.

The reported value for each analysis should also be compared to both the RL and the MDL. This is necessary because Caltrans requires all results detected between the MDL and the RL be reported.

13.3.2.2 Holding Times

A holding time is the time elapsed between sample collection and analysis. When collecting composite samples, the holding time begins when the last aliquot enters the sample bottle. Holding times are discussed more fully in Chapter 5.

Nearly all analytical methods used by Caltrans have established maximum allowable holding times, and if a sample is analyzed past this maximum holding time then the data must be qualified or rejected. How the data are qualified depends on how long past the holding time the analysis was performed and whether or not the target constituent was detected. The validation scheme for holding times is shown in Figure 13.2.

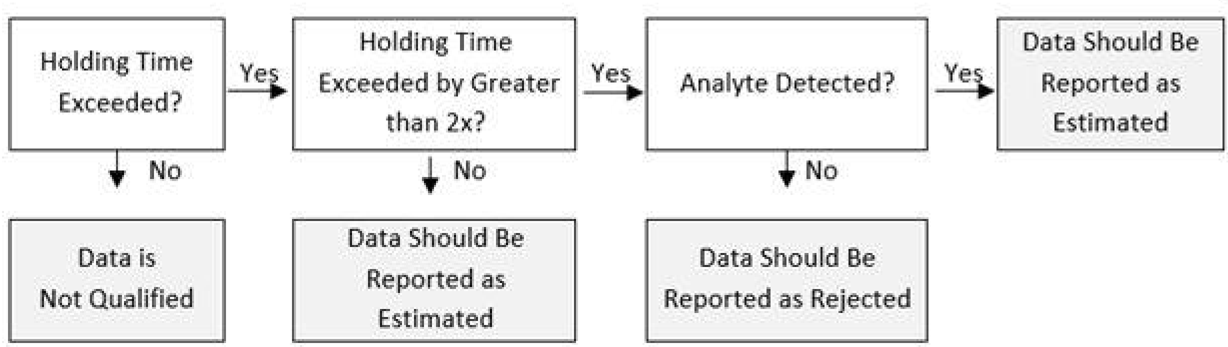


Figure 13-2 Validation Scheme for Holding Time (USEPA 2010a)

13.3.2.3 Contamination (Blank Samples)

Contamination is any substance that enters a sample after it has been collected that might interfere with a laboratory analysis. Samples can be contaminated in the field, while they are being transported, or in the lab. Blank samples are used to check for contamination; if the blanks do not contain detectable levels of target analytes or interfering substances, it is assumed the samples have not been contaminated.

As mentioned earlier, Caltrans requires analytical results between the MDL and the RL be reported. A blank is only said to be contaminated if target analytes are detected at a concentration greater than the RL. Laboratories frequently detect trace amounts of target analytes in the range between the MDL and the RL, and this does not mean the batch is contaminated.

The various kinds of samples used to check for contamination are discussed in Section 12.1.

When contamination is detected in field or equipment blanks, it should be reported to the project manager so appropriate corrective action can be taken. When contamination is detected in the other kinds of blanks, the values of associated environmental samples should be adjusted depending on the concentrations of target analytes in the samples. The validation scheme for blanks is shown in Figure 13.3.

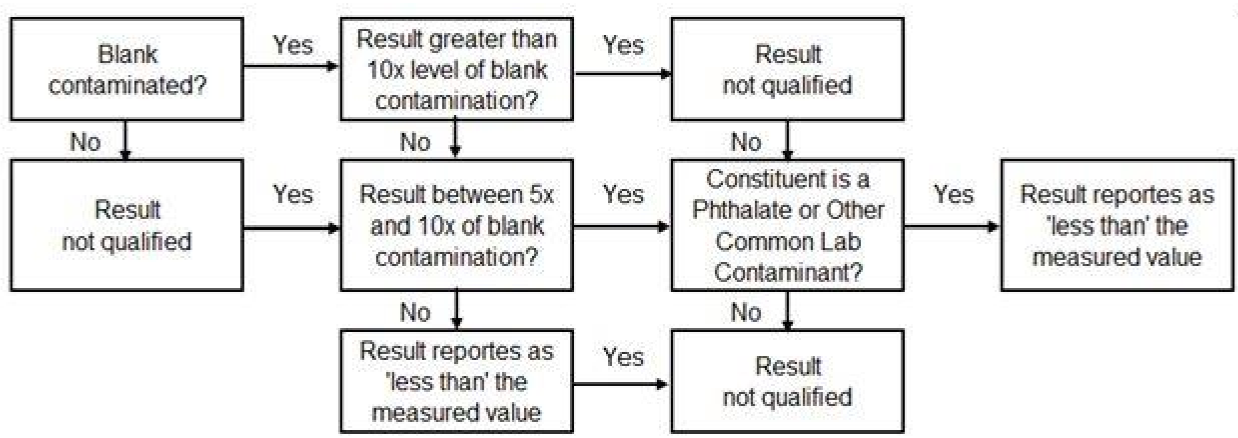


Figure 13-3 Validation Scheme for Blank Contamination (USEPA 2010a)

Table 13-4 shows the USEPA guideline for adjustment of sample data based on blank contamination.

Table 13-4 USEPA Guidelines for Data Evaluation

Environmental Sample	Phthalates and Other Common Contaminants[1]	Other Organics	Metals
Sample > 10X blank concentration	No action.	No action.	No action.
Sample < 10X blank concentration	Report associated environmental results as “non-detect” at the reported environmental concentration.	No action.	Results considered an “upper limit” of the true concentration (note the contamination in data quality evaluation narrative).
Sample < 5X blank concentration	Report associated environmental results as “non-detect” at the reported environmental concentration.	Report associated environmental results as “non-detect” at the reported environmental concentration.	Report associated environmental results as “non-detect” at the reported environmental concentration.

(USEPA 2008; USEPA 2010a)

[1]On the current Caltrans analyte list, “common laboratory contaminants” include bis(2-ethylhexyl) phthalate, di-n-butyl phthalate, 2-butanone (methyl ethyl ketone), acetone, methanol, toluene, and methylene chloride. For GC/MS analyses, this also applies to tentatively identified compounds.

13.3.2.4 Precision (Duplicate Samples)

Precision is the degree to which repeated measurements agree with each other under unchanged conditions; in other words, it is a measure of the reproducibility of an analytical method. Precision is expressed as the relative percent difference between multiple values. The concept and calculation of analytical precision are discussed more fully in Chapter 12.

Duplicate samples are used to check precision. The laboratory analyzes both duplicate samples and calculates the relative percent difference between the two results.

The kinds of duplicate samples used to evaluate precision are discussed in Section 12.1.

A field duplicate is submitted to the lab as just another sample, not as a duplicate. Because the lab does not know which samples are duplicates, it cannot compare the results of field duplicates for precision. This association must be made by the monitoring consultant during data validation. However, laboratories do check the relative percent differences of lab duplicates as part of their internal QC process.

If a duplicate sample is out of range, the analytical result does not receive a qualifier, but the violation appears on the validation report. If a laboratory duplicate is out of the accepted range, it should be noted in the lab report narrative along with a summary of what corrective action was taken. (If this or any other error is not narrated in the laboratory report, the consultant should contact the lab for clarification.) If a field duplicate is outside the accepted relative percent difference range, the consultant project manager should be notified so appropriate corrective action can be initiated.

13.3.2.5 Accuracy (Spiked Samples)

Accuracy is the degree to which measurements agree with the true value. Accuracy is usually expressed as percent recovery. The concept and calculation of analytical accuracy are discussed more fully in Chapter 12.

Spiked samples are used to check accuracy. A sample is spiked with a known concentration of the target analyte and then analyzed. The analytical result is compared to the known concentration to check the accuracy of the method. Matrix spikes are nearly always prepared in duplicate. This is done in case the sample matrix interferes with the analysis; if the analysis fails on two spiked samples, there is a strong indication that the matrix is the problem, and not some other factor. Analyzing duplicate spikes and comparing the results also provides a second check of analytical precision. Unlike field and laboratory duplicates, qualifiers may be assigned to sample results if their associated spike/spike duplicate results have a relative percent difference that is greater than the allowable limit.

The kinds of samples used to evaluate accuracy are discussed in Section 12.1.

Spiked samples are only used to check some chemistry methods. They are not used for microbiology, toxicity, or gross solids methods.

As described previously, every sample is analyzed as part of a QC batch. All data in a QC batch are qualified based on the performance of the QC samples in the batch.

13.3.3 Technical Checks

In addition to QC checks for analytical and reporting errors, the data validation team should check that the data are consistent and realistic. Table 13-5 lists the technical checks that should be performed during data review.

Table 13-5 Technical Checks Performed During Data Validation

Data Check	Acceptable Values/Validation Rules
Valid pH Result	Values are expected to be between one and 13.
Total vs. Dissolved Fractions	If both total and dissolved fractions of a constituent are analyzed in the same sample, the total fraction is expected to be present in greater concentration than the dissolved fraction.
COD vs. TOC	If both chemical oxygen demand and total organic carbon are measured in the same sample, TOC is expected to be present in concentrations equal to or greater than COD, although this may not always be the case. Chemicals used in the COD analysis may also oxidize inorganic constituents.
Ammonia vs. TKN	If both total ammonia and total Kjeldahl nitrogen are measured in the same sample, TKN is expected to be present in concentrations equal to or greater than ammonia.
Total Phosphorus vs. Orthophosphate	If both total phosphorus and orthophosphate are measured in the same sample, total phosphorus is expected to be present in concentrations equal to or greater than orthophosphate.
TDS vs. Conductivity	If both total dissolved solids and conductivity are measured in the same sample, the two are expected to be roughly correlated in the following relationship: TDS (mg/L) = Conductivity (uS/cm) * 0.67.
Correct Fraction	Analytes that have been filtered prior to analysis should be reported with a fraction “Dissolved.” Results obtained from the analysis of unfiltered samples should be reported with a fraction “Total.” Some analytes such as pH and temperature, to not have meaningful values for the Fraction parameter, and are often reported with the value “N/A.”

13.3.4 Field Data

Some data are produced in the field. For example, pH and temperature must be measured on site by field technicians, and sometimes conductivity and turbidity are measured in the field as well.

All field tests should be performed in duplicate to check for precision. Field technicians should also perform conductivity tests (and turbidity, if required) on blank samples at least once per day to check for contamination. The results of all field analyses are recorded in field logs, and these must be entered into the EDD so the data can be validated.

13.3.5 Toxicity Test Results

The analytical methodology for toxicity testing (Chapter 17) is quite different from the methods for water quality methods discussed in this chapter, and toxicity laboratory reports are different from water quality lab reports. The EDD used by the lab to submit toxicity data is also different from the EDD format used for water quality data. Toxicity data should be thoroughly validated to ensure results are based on specified protocols and those protocols were properly followed.

Toxicity EDDs include results for the water quality tests, such as pH, temperature, dissolved oxygen, and conductivity that are performed concurrently with toxicity tests. These data should be reviewed to make sure they were performed regularly and that the results look reasonable.

Data must also be reviewed to verify they are reported in the correct units; for example, data that will be used for compliance with the Caltrans NPDES permit must be reported as pass/fail. Any laboratory data this reported with other units must be sent back to the laboratory to be corrected.

Laboratories perform internal quality control checks using reference toxicants (Section 17.3). Reference toxicant data should be checked to verify that labs are operating within control limits.

13.4 Final Data Submittal

When the data have been reviewed and any problems have been resolved to the satisfaction of the project manager, the final data package is then submitted to the Caltrans task order manager. The final data package is a compressed (zipped) file in Microsoft Windows-compatible format, and must include all of the following components:

- Final CEDEN data files after passing error check
- Field data in the proper CEDEN format (if applicable)
- The hydrograph files produced by the Caltrans Hydrologic Utility (if applicable)
- The original time series files from the data logger used to make the hydrograph (if applicable)
- PDF copies of all laboratory reports
- Scanned PDF copies of all field logs

Copy of the email is sent automatically whenever an EDD successfully passes the RDC checker. This should be converted to PDF format for inclusion in the zip file. EDDs are due to Caltrans 30 calendar days after the end of every monitoring event. Laboratory data must be received by the consultant in a timely manner so data can be delivered to Caltrans on time. The consultant must make binding arrangements with contract laboratories to avoid late data submittals.

If a data deliverable is expected to be submitted late to Caltrans for any reason, the consultant must contact the Caltrans Task Order Manager with a description of the problem and an estimate of when the data may be expected. If a data submittal is expected to be late because of a failure of the laboratory to deliver data on time, the consultant must contact the laboratory via email to determine the reason for late submittal and expected delivery date. The Caltrans Task Order Manager should be copied on all email traffic.

The consultant shall submit all electronic data to the Caltrans Task Order Manager via email. Consultants are not expected to submit any data directly to any state agency unless directed to do so by the Caltrans Task Order Manager.

14 REPORTING

Monitoring consultants submit several kinds of reports to Caltrans over the life of a project. This chapter provides guidelines for composing three of the most common kinds of reports:

- Post-Storm Technical Memoranda
- Interim Project Reports
- Final Project Reports

Post-Storm Technical Memoranda (PSTMs) are submitted to the Caltrans Task Order Manager after every monitored storm event. PSTMs provide Caltrans with a quick summary of the monitoring event, including a narrative of any problems, anomalies, or other unusual occurrences that arose during the event.

Interim Project Reports are submitted to Caltrans at the end of every wet season. These reports summarize all monitoring activities that were carried out over the season, as well as year-end data summaries and evaluation.

Final Project Reports are submitted to Caltrans after the project is complete, and provide a complete, detailed overview of the entire project from the planning phase to completion. This report also includes a full treatment of all project data and the final conclusions of the project in the context of the original study questions. The final report includes additional information that is not contained in the Interim Report, such as the cost summary and detailed statistical analysis.

In some cases, the last interim report can be used as the Final Project Report if the objectives of the project have been achieved and no additional data analysis needs to be performed.

This chapter discusses three aspects of stormwater reports:

- General format of reports
- Content of PSTMs
- Format if interim and final project reports

14.1 Format of Report Deliverables

Reports are submitted to the Caltrans Task Order Manager in hard copy and in both Microsoft Word and PDF formats. These electronic copies must be submitted on a CD or DVD, along with any other computer files that pertain to the project. Materials on the CD or DVD should be organized into the following folder structure:

- Electronic data deliverables
- Graphics/pictures/ photographs
- DGN and CAD
- Report in PDF and Microsoft Word formats
- Laboratory reports in PDF format
- Spreadsheets

The following information must be displayed on the CD or DVD-R label:

- Caltrans logo
- Title of report
- Report date
- Report number

It is preferable to provide all files on a single CD or DVD. A sample generic disc label is shown in Figure 14-1. An example project CD/DVD label is shown on Figure 14-2.

Figure 14-1 Sample CD/DVD-R Label (Generic)

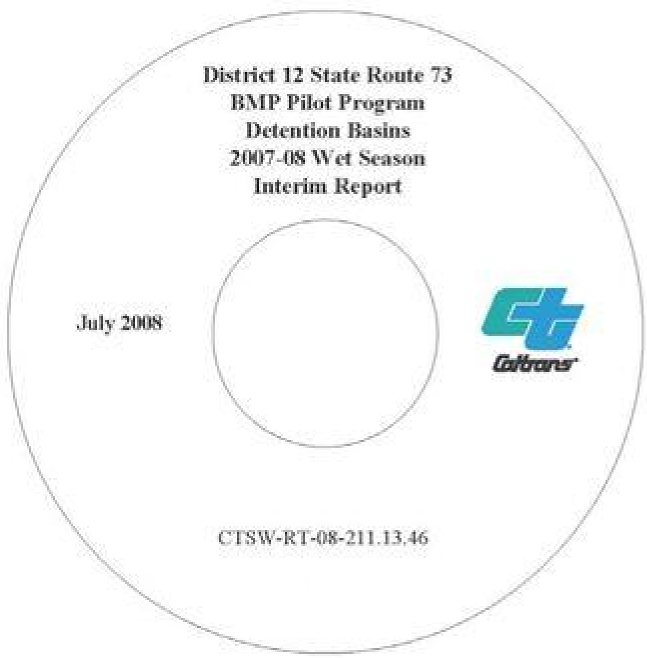


Figure 14-2 Sample CD/DVD-R Label (Example)

14.1.1 NOMENCLATURE FOR ELECTRONIC DELIVERABLES

The disc deliverable must contain both the Microsoft Word version of the document (the original working file) and a final PDF version of the document. It may be inefficient to add items such as field logs, scanned documents in the Word version and these may be submitted as separate files. However, the PDF version must include the whole document including scans, logs, appendices, data etc. This PDF will be used to produce printed copies of the document in its entirety.

The contents of a deliverable on disc should be organized in folders according to content, and have a readme.txt file in the root directory that provides a table of contents for the disc, including a brief summary of each item/folder on the disc. A typical disc would contain the following folders:

1. Document – final document in PDF and MS Word format (including all appendices in Word format, if they are not included as part of the main Word file; the PDF file must be the complete, entire document ready for printing).
2. Pictures and Figures – a folder containing all of the pictures and illustrations that went into the document.
3. Supporting Material – a folder that contains any supporting material, such as maps, charts, graphs, spreadsheets, etc.) that are associated with the project.
4. Comments – material such as emails or comments matrices, that contain comments or suggestions that have been incorporated into the document.
5. Other – a folder that contains any other materials that the author believes may be necessary or useful.

An example of the correct the folder structure for electronic deliverables is shown in Figure 14.3.

Figure 14-3 Folder Structure for Electronic Deliverables

Electronic Data Deliverable files (EDDs) should be named using the following four-part nomenclature scheme:

<Part 1>_<Part 2>_<Part 3>_<Part 4>

1. An abbreviation of the project name (for example, TMDL, Area of Special Biological Significance [ASBS]) and the district number. For example, a submittal from Caltrans District 7 for a TMDL monitoring site would begin with “TMDL07-.”

   In most cases, the Caltrans District number should be used in conjunction with the project name. However, when monitoring in ASBSs, the ASBS number should be used instead.

2. The Event Start Date listed in the PSTM for that storm event with the format: YYYYMMDD

3. The type of analysis performed:

   a) Field (field data)

   b) Tox-LabName (toxicity – where LabName is the name of the laboratory performing the analysis [e.g., Tox-Nautilus])

   c) Chem-LabName (chemistry – where LabName is the name of the laboratory performing the analysis [e.g., Chem-Physis])

4. The submittal (version) number for that EDD with the format: v#, where # is 1 for the first submittal of that EDD; 2 is the second (i.e., revised) submittal of the original document, etc.

Naming examples:

TMDL03_20151208_Field_v1

TMDL10_20151128_Chem-Physis_v1

ASBS24_20151031_Tox-Nautilus_v1

ASBS33_20151204_Tox-Nautilus_v2

Other generated electronic files (hydrographs, images, videos, etc.) should be named using the same naming convention that is used for EDDs:

1. Project name abbreviation and two-digit number corresponding to the Caltrans district where the sites are located

2. YYYYMMDD : Event Date
3. Abbreviation of the document type. Use a three- or four-letter descriptive designation as appropriate, for example, HGRAPH for hydrographs, IMG for pictures, MAP for site maps.
4. v#: Version number for the document

Naming examples:

TMDL03_20151208_HGRAPH_v1.xlsm

ASBS33_20151128_IMG_v1.jpg

TMDL07_20151031_HGRAPH_v2.xlsm

14.2 Post-Storm Technical Memoranda

It is important to review data collected during a storm soon after the event to determine if the sampling effort successfully met the study objectives; including the storm representativeness criteria. For each monitored storm event, a PSTM is submitted that provides a summary of the event. The PSTM includes precipitation forecast information, actual rainfall, storm capture information, a description of sample collection activities, and preliminary water quality data for each monitoring station.

Every field measurement taken during a storm event must be recorded in the PSTM. Standard field analyses such as pH, temperature, and turbidity should be reported in tabular format. Any other observations, such as water levels or manual flow measurements, should be reported either in tables or in a graphic format.

In addition to describing standard monitoring activities, the PSTM must be used to narrate any other work performed during a monitoring event, and describe any unusual or unexpected incidents that occur during the event. For example, any work performed by field crews, such as recording water levels, cleaning water conveyances, or performing equipment maintenance and repair, must be described in the PSTM. Anything out of the ordinary that happens onsite during a monitoring event that might impact data quality, such as clogging of conveyances or equipment malfunctions, should also be reported.

PSTMs are a valuable tool allowing Caltrans and consultants to evaluate the monitoring phase of the project in real time. Any systematic monitoring or laboratory problems can be identified mid-season and corrected.

PSTMs are submitted in two forms, draft and final. Draft PSTMs must be submitted to the Caltrans Task Order Manager three to five days after the end of a monitoring event, and should contain a summary of pre-storm and sample collection activities. The final PSTM is submitted within five days after receipt of the comments. Final PSTMs include all material in the draft PSTM with all comments addressed.

A final PSTM consists of four parts:

- General Information – Summary of the monitoring effort
- Hydrograph produced by the Caltrans Hydrologic Utility (if hydrologic data were collected)
- Analytical stormwater quality results summarized in a table
- Notes – Miscellaneous information summarizing the sampling event

14.2.1 The PSTM Utility

To facilitate production of PSTMs and to help ensure they are prepared in a uniform way, Caltrans has developed a utility called the Caltrans Post-Storm Technical Memorandum Generation Utility (PSTM Utility). This is a Microsoft Excel-based electronic utility designed to be run under the Windows operating system. A screenshot of the PSTM Utility is shown in Figure 14.4.

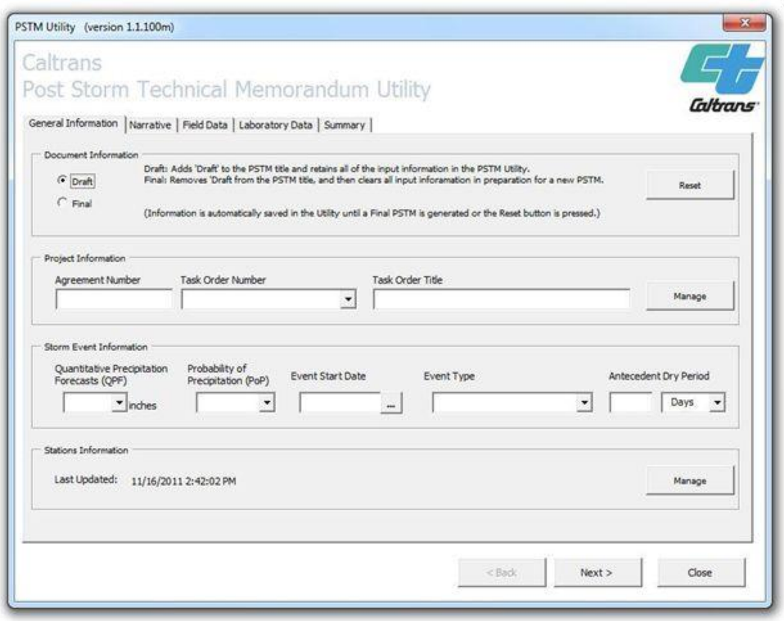


Figure 14-4 Main Screen of the PSTM Utility

The PSTM Utility accepts four kinds of input:

- User input directly into the utility
- Hydrographs produced by the Caltrans Hydrologic Utility
- Event narrative in Microsoft Word format
- Laboratory EDDs

First, the user enters storm and pre-storm information into the appropriate fields. Pull-down menus for many of these fields provide allowable values for this information.

Then the user imports one or more hydrographs. These are the output from the Caltrans Hydrologic Utility (Caltrans 2011). The button to import hydrographs is located on the Field Data tab of the utility.

Next, the user adds a written narrative summarizing the event. This can be done either by importing a Microsoft Word file or by typing a narrative directly onto the space provided on the Summary tab.

When the laboratory data are submitted by the lab, the final PSTM is produced by performing the steps described above again, and then importing the analytical data from the lab EDD. This is done from the Laboratory Data tab.

For full instructions on the use of the PSTM utility, see the user manual that ships with the software.

14.3 Final (End-of-Project) Reports

The remainder of this chapter covers the various components of interim and final reports, but it is important to remember that these are only guidelines. The material presented in this section is intended only to suggest how information should be laid out. Every monitoring project is unique, and the way reports are constructed and what they contain will depend on the requirements of the project.

This section discusses a standard organization for a final report. Final reports are normally issued at the end of a project. The organization of interim reports (reports issued throughout the project, usually at the end of each monitoring season) are discussed in the next section.

The following suggested report components are discussed in this section:

- Report numbering convention
- Deliverable page, ADA compliance, and disclaimer
- Table of contents
- Executive summary
- Introduction
- Monitoring project plan
- Site characteristics and project design
- Monitoring project design features
- Monitoring methodology
- Monitoring results and data analysis
- Analytical data
- Quality assurance/quality control
- Statistical methods
- Summary statistics
- Objectives and findings
- Lessons learned
- Conclusions
- Recommendations

References

Appendices

14.3.1 Report Cover

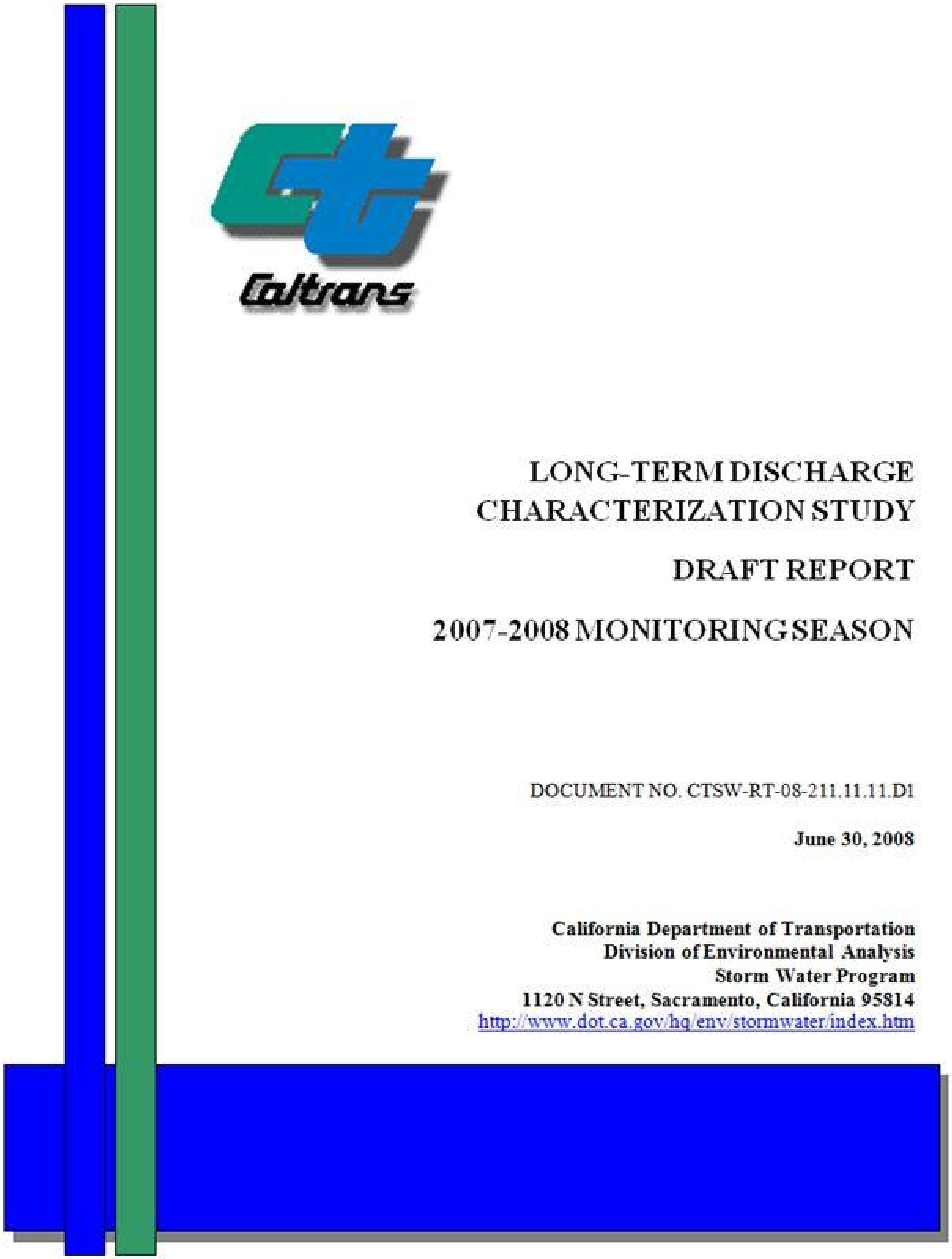
The following information must be included on the document cover:

- Caltrans logo
- Title of report
- Report date
- Report number

- Address:

  California Department of Transportation
  Division of Environmental Analysis
  Stormwater Program
  1120 N Street, Sacramento, California 94814
  http://www.dot.ca.gov/hq/env/stormwater/index.htm

A sample report cover is shown in Figure 14-5.



Caltrans

LONG-TERM DISCHARGE CHARACTERIZATION STUDY

DRAFT REPORT

2007-2008 MONITORING SEASON

DOCUMENT NO. CTSW-RT-08-211.11.11.D1

June 30, 2008

California Department of Transportation
Division of Environmental Analysis
Storm Water Program
1120 N Street, Sacramento, California 95814
http://www.dot.ca.gov/hq/env/stormwater/index.htm

Figure 14-5 Sample Report Cover

14.3.2 Report Numbering Convention

A Caltrans report number, also called a document control number, is constructed in the format CTSW-WW-YY-XXX.ZZ.NUM, where:

- "CTSW" stands for Caltrans Stormwater
- "WW" indicates the type of document. This will be one of the following values, depending on the type of document being produced:
    - RT (Report): Documents such as annual reports and final monitoring project reports
    - OT (Other): Caltrans documents such as EDDs, training manuals, or other documents and CDs
    - PL (Plans): Caltrans internal document; usually not distributed to the public or placed on the website. Items include Plans, Specifications, and Estimates; Operations, Maintenance, and Monitoring (OM&M) Plans; Monitoring and Operations Plans; other Plans
    - SA (Software Application): Caltrans internal document – software developed for Caltrans Stormwater use
    - TM (Technical Memorandum): Caltrans internal document such as an Interim Report, data summary, or issue paper
- "YY" is the two-digit calendar year of the report
- "XXX" is the last three digits of the contract number under which the document was produced
- "ZZ" is the task order number under which the document was produced
- "NUM" sequential report number issued by the specific task order. A "D" after this digit indicates a draft version

For example, the document control number CTSW-RT-03-125.05.3D means the document is a report, prepared in 2003 under Contract 43A0125 and Task Order 5, and it is the third document of this type written under this contract and task order during 2003. The D at the end indicates the report is a draft.

14.3.3 Statements for Legal Compliance

Starting June 30 of 2019 every Caltrans document must be ADA compliant. All documents must be checked using ADA compliance software tools. Every Caltrans document must include an ADA Statement of Compliance, a technical documentation page, an Acknowledgement Page, and a Legal Disclaimer. The Technical Documentation Page must be placed after the ADA Statement of Compliance, and all boxes should be correctly filled in.

The standard Caltrans ADA Compliance Page language is shown in Figure 14.6. A blank Technical Documentation Page is shown in Figure 14-7. The standard Caltrans Disclaimer Page is shown in Figure 14-8. The standard Caltrans Acknowledgements Page is shown in Figure 14-9.

"For individuals with sensory disabilities, this document is available in alternate formats upon request.

Please call or write to:
Stormwater Liaison,
Caltrans Division of Environmental Analysis, MS 27,
P.O. Box 942874,
Sacramento, CA 94274-0001,

(916) 653-8896 Voice or dial 711 to use a relay service."

Figure 14-6 Caltrans ADA Compliance Language

<table>
<tr><td>1. Report No.
CTSW-RT-1X-XXX.XX.X</td><td>2. Type of Report
Report</td><td colspan="2">3. Report Phase and Edition
Final</td></tr>
<tr><td colspan="2">4. Title and Subtitle</td><td colspan="2">5. Report Date</td></tr>
<tr><td colspan="2">6. Copyright Owner
California Department of Transportation</td><td colspan="2">7. Caltrans Project Coordinator</td></tr>
<tr><td colspan="2" rowspan="2">8. Performing Organization Names and Addresses

Consultant Organization name and address

NOTE: NO INDIVIDUAL NAMES</td><td colspan="2">9. Task Order No.
XX
Amendment No.
0X</td></tr>
<tr><td colspan="2">10. Contract No.
43A0XXX</td></tr>
<tr><td colspan="2">11. Sponsoring Agency Name and Address
California Department of Transportation
Sacramento, CA 95814</td><td colspan="2">12. Caltrans Functional Reviewers:
Design:
Construction:
DEA:</td></tr>
<tr><td colspan="2">13. Supplementary Notes
Project conducted in cooperation with XXX</td><td colspan="2">14. External Reviewers
Only for reviewers not on the contract or task order</td></tr>
<tr><td colspan="4">15. Abstract</td></tr>
<tr><td>16. Key Words</td><td colspan="2">17. Distribution Statement</td><td>18. No. of pages</td></tr>
</table>

Figure 14-7 Technical Documentation Page

DISCLAIMER

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Copyright (year) California Department of Transportation

All Rights Reserved

Figure 14-8 Standard Caltrans Legal Disclaimer Page

ACKNOWLEDGMENTS

The following individuals are acknowledged for their contribution towards this project:

Insert names of externals and consultants who worked on the project. No affiliations, only names.

Figure 14-9 Example Acknowledgements Page

14.3.4 Executive Summary

The executive summary must provide the reader with a concise overview of the monitoring project. The executive summary should be limited to one page or less. It should contain enough information for the readers to become acquainted with the scope of the project without further reading. Suggested length: one page.

The executive summary for monitoring projects should include the following elements:

- Problem statement
- Project background
- Monitoring activities
- Summary of results
- Summary of statistical analyses results (Final Report only)
- Major conclusions
- Major recommendations

14.3.5 Introduction

The introduction to the report should include enough background information to familiarize the reader with the intent and scope of the project. Suggested length: one to two pages.

The following elements should be covered in the report introduction:

- Purpose of the report
- Overview of the scope of planned monitoring activities: location, number of sites, number of events, etc.
- Description the organization of the report

14.3.6 Monitoring Project Plan

This section of the report should cover how the study question was addressed during the planning phase of the project. Suggested length: five pages or less.

This section may include the following elements:

- Discussion of the development of data quality objectives (DQOs)
- List of monitoring constituents and description of how they were selected
- Description of the Monitoring Plan

14.3.7 Site Characteristics and Project Design

This section should describe the monitoring sites in enough detail so the reader can understand how they were selected and how they were represented by the monitoring data. Elements of this section might include:

- Monitoring site selection and characteristics (this section can be replaced with a Site Reconnaissance Memo included as an appendix, if this memo exists).

If a site recon technical memorandum exists for the project monitoring sites, this section may be omitted, and the site recon memo can be included in the document as an appendix.

14.3.8 Monitoring Methodology

This section must include the following items:

- Flow and precipitation measurement
- Sampling methods
- Analytical methods

14.3.9 Monitoring Results and Data Analysis

The monitoring results and data analysis sections should cover the following report elements:

- Description of each storm event monitored during the study, including evolution of the storm event as it was tracked
- Flow and precipitation monitoring results
- Rainfall and flow monitoring results summarized in tabular form

- Hydrographs/hyetographs included as an appendix
- Operational monitoring results

Include an assessment of actual equipment maintenance and/or calibration requirements. Any proposed changes/enhancements to equipment maintenance or calibration during the project should also be included.

14.3.10 Analytical Data

Summarize in tabular form the analytical results obtained for each storm event. These data must be included as an appendix to the final report and should be consistent with the electronic data deliverable (EDD) submittal.

14.3.11 Quality Assurance/Quality Control

Discuss the QA/QC results. In particular, discuss evaluation of accuracy, precision, representativeness of monitoring data.

14.3.12 Statistical Methods

Discuss statistical methods used for data analysis and the justification for using them.

14.3.13 Summary Statistics

Present results of the statistical analysis in summary form. Summarize the statistical results in narrative, tabular, and/or graphical form, as appropriate. Detailed statistical results must be presented as appendices.

14.3.14 Objectives and Findings

Provide a section for each study objective and discuss the project results relative to each.

14.3.15 Lessons Learned

Discuss lessons learned throughout the siting, design, and implementation phases of the monitoring project. The purpose of this section is to provide a record of the positive and negative experience gained and to disseminate that experience to others who may benefit from it. The section must draw on both positive and negative experiences. For clarity, the lessons learned section may be organized into subsections such as equipment installation, flow monitoring, laboratory communications, analytical results, and instrumentation.

General questions to consider when developing the lessons learned section should include the following:

- What went right?
- What went wrong?
- What unexpected events occurred?
- What could be done differently in the future to save time, reduce costs, improve performance, or avoid problems?
- What should be done differently in the future to avoid delays, cost escalations, or performance problems?
- Where were significant resources focused ineffectively?
- What areas/tasks received more attention than necessary?
- What areas/tasks need more attention in the future?

14.3.16 Conclusions

The conclusions section should contain a discussion of the significance and meaning of the results of the monitoring program and what conclusions can be drawn from the results based on the collected data. The following questions should be answered in the conclusion:

- Was the monitoring project successful in collecting sufficient data to meet the project objectives?
- What conclusions can be drawn relative to each project objective?
- What are the limitations inherent in the data analysis, if any?
- Were there any problems with data quality?

Note any limitations of the field, analytical, and statistical methods used in interpreting the data.

14.3.17 Recommendations

A summary of the recommendations for future work, if applicable, should be presented and must be included in the final report. At minimum, this section must include a discussion of the following items:

- Any new questions requiring further action or analysis

- Suggested improvements for future studies

Depending on the nature of the project, the recommendations section might also include the following:

- Suggested changes to inspection, calibration, and maintenance procedures for monitoring equipment
- Recommendations for inspection, calibration, and maintenance frequency, thresholds, and activities
- Recommendations for changes to siting and design criteria for future monitoring projects
- Recommendations for additional monitoring
- Discussion of the need for further monitoring at project sites
- Next steps, if any

14.3.18 References

This section is included to acknowledge the originator of borrowed material and to direct the reader to further information. The list should include all sources used in the course of the study. When citing sources within the text, include the source name and the date within parentheses. The source name should be the last name of the author. If the author is an organization, then an appropriate abbreviation should be used. There should be no comma between the source name and the year; for example: (Caltrans 2008).

References should be listed in alphabetical order by in-text citation name. Here is an example of the contents of a short Reference section:

Caltrans 2000c. District 7 Litter Management Pilot Study (LMPS), Final Report. CTSW-RT-00-013.

Caltrans 2003a. Caltrans Comprehensive Protocols Guidance Manual. CTSW-RT-03-105.51.42.

14.3.19 Appendices

Appendices are intended to capture the raw data and supporting documents developed during the monitoring study. The following list presents a sample of the appendices that may be included with the Final Report:

- Monitoring plan technical memorandum
- Site selection technical memorandum
- Data evaluation and statistical analysis
- Post-storm technical memorandum
- Monitoring data
- Data validation results
- Interim reports
- Monitoring project lessons learned
- Electronic data deliverable
- Quality assurance project plan, if applicable

14.4 Interim (End-of-Season) Reports

Interim reports are produced periodically throughout a project in order to keep Caltrans informed about how the project is proceeding. It is important that Caltrans receives this feedback so they can evaluate the progress of the project and make corrections if necessary. Interim reports are most commonly delivered at the end of each storm season.

Interim reports normally have the same general layout as final project reports, discussed in Section 14.3. The descriptions of general formatting discussed in Section 14.3 can be applied to interim reports as well. The difference between the two types of reports is content. While final reports usually contain a detailed presentation of the project, interim reports are intended to summarize monitoring activities for a shorter time interval, usually a monitoring season.

This section describes the standard contents of a Caltrans interim report:

14.4.1 Introduction and Objectives

The report should include a short introduction, one to two pages, that describes the monitoring effort over the previous monitoring season. This section should not duplicate material that is in the QAPP or other project planning documents. The focus is on the previous season, not on the entire project.

14.4.2 Overview of the Monitoring Season (Limit to Two to Three Pages)

The report should include a general monitoring approach, in one or two pages, that describes, in general terms, the monitoring approach taken during the previous season. This section should discuss the type of monitoring performed (characterization, compliance, BMP effectiveness); types of samples collected (grab, composite); and the types of analyses performed (chemistry, toxicity, trash).

This section should also contain a brief discussion of the sites at which monitoring occurred and a general description of the areas that were monitored (highways, BMPs, receiving waters, and so on).

A table should be included in this section that lists all the analytical constituents (chemistry, toxicity, field measurements) that were monitored during the season. This table does not have to list constituents by site or by monitoring area; this information is specified in the project QAPP. This should be a simple table showing all analytical analyses performed during the season.

14.4.3 Summary of Monitoring Events by Station

The report should include a summary, in tabular format, showing all monitoring events performed during the season by station and by event date. Table 14.1 shows an example of monitoring events table.

Table 14-1 Monitoring Event Summary

Monitoring Station	Event Dates					
3-301	11/3/2017	11/30/2017	1/30/2018			
3-303	10/28/2017	11/29/2017	12/18/2017	2/5/2018	3/14/2018	4/28/2018
7-318	11/18/2017					
.	.					
.	.					

14.4.4 List of Any Stations Added or That Underwent Significant Changes

The report shall include a summary, in tabular format, listing all of the changes to monitoring sites that occurred over the previous storm season. This summary should include changes to monitoring sites such as the installation of new conveyances, road construction at the site, or changes to drainage areas that might influence the way samples are collected or the way data is interpreted.

If new stations were added during the season, they should be included in this section, along with a brief (one- to two-sentence) site description.

An example of this table appears in Table 14.2.

Table 14-2 Summary of Changes to Monitoring Sites

Monitoring Station	Description of Change
12-340	Caltrans Maintenance removed the pipe where the intake strainer was located. Sampling point was moved approximately 4 feet, from the pipe to a point along the curb on the freeway shoulder. Small curb added to the new sampling point to pool water deeply enough to collect samples.
3-303	Installed flume for more accurate flow measurement. During previous seasons, flow has been estimated at this site in an open channel using Manning's Equation.
7-321	Long-term construction at the site began during the summer prior to this monitoring season. A detour was routed near the monitoring site that drew traffic very close to the existing site. It was determined that the proximity of high-speed traffic posed a safety hazard for field crews. The old sample point (Caltrans station ID 8-506) was abandoned. A replacement sampling station was developed to replace it (Caltrans station ID 5-509). The new sampling station is on the same stretch of freeway, approximately 100 feet east of the old site.
.	.
.	.

14.4.5 List of any monitoring constituents added or that changed significantly

The report should include a summary, in tabular format, listing any changes to monitoring constituents that occurred over the storm season. This includes analytical constituents that may be added or removed from the project constituent list or changes in required analytical methods. An example of this table appears in Table 14.3.

Table 14-3 Changes to Analytical Constituents

Monitoring Station	Description of Change
11-360, 11-361, 11-362	Removed dissolved metals to constituent list, per direction from Caltrans. From now on, only total metals will be analyzed at this site.
12-288	Added nutrients (Ammonia, Nitrate, ammonia, nitrate, orthophosphate) to comply with most recent TMDL.
12-308	Laboratory has discontinued Method EPA 9221 for E. coli. Method switched to 9223 B-2004 Colilert.
.	.
.	.

14.4.6 Errors or Problems Encountered by Field Crews and Corrective Action Taken

The report should include a summary, in tabular format, listing all significant problems encountered by field personnel during monitoring events. This may include things like problems with malfunctioning or faulty equipment, theft or vandalism encountered on monitoring sites, or damage to equipment as a result of traffic accidents or natural causes such as flooding or landslides.

An example of this table appears in Table 14.4.

Table 14-4 Changes to Analytical Constituents

Monitoring Station	Event Date	Description of Problem	Corrective Action
3-303	11/3/2017	Field personnel misread the site map and collected samples at the wrong location. Samples were collected downstream of a municipal storm outlet. Per direction from Caltrans, samples were discarded before analysis.	Field lead has reviewed QAPP with field crews and verified that they now understand where samples are to be collected.
7-318	11/18/2017	During a heavy precipitation event, a field technician backed a truck into an equipment enclosure. The monitoring equipment was damaged so that it was not possible to collect composite samples. Per direction from Caltrans, grab samples only were collected at this site for this event.	Equipment at the site has been replaced and the site is now operational. Field lead has conducted a safety briefing with all field crews about driving vehicles under low-visibility conditions.
.	.	.	.
.	.	.	.

14.4.7 List of Laboratory Errors or Problems and Any Corrective Action Taken

The report should include a summary, in tabular format, listing all significant problems encountered by field personnel during monitoring events. Examples are problems with malfunctioning or faulty equipment, theft or vandalism encountered on monitoring sites, or damage to equipment as a result of traffic accidents or natural causes such as flooding or landslides.

An example of this table appears in Table 14-5.

Table 14-5 List of Laboratory Issues/Problems

Monitoring Station	Event Date	Description of Problem	Corrective Action
3-301,3-302, 3-303	11/3/2017	Laboratory courier did not arrive when scheduled. Samples were taken back to the office and transported to the lab on the following day. Several hold times were	Laboratory management contacted about this failure. The lab assures us that corrective action will be taken on their end.
7-318	11/18/2017	Laboratory dropped and broke glass composite carboy. All composite sample lost. Analyses performed on grab samples only.	None.
-	-	-	-
-	-	-	-

14.4.8 Summary Statistics for Monitoring Data

The data summary section will normally comprise the main part of the document. In this section, analytical data, hydrologic data, and field measurements for the entire season should be presented in summary format. In most cases, only data collected during the previous monitoring season will be presented in this section; however, depending on the nature of the project, it may also be necessary to summarize all data collected to date.

The presentation and statistical treatment of data in this section will depend on the study questions and the kind of data being summarized. For simple data collection projects such as discharge characterization and permit compliance, a simple graphical representation of the data may suffice. For more involved projects such as BMP effectiveness studies, more complicated treatments of the data may be required in order to help Caltrans answer the study questions.

The requirements for this section must be developed during the project planning phase so every interim report provides the same treatment of seasonal data. This is necessary so the data is treated the same way each season over the life of the project.

14.4.9 Quality Control

This section of the report should include a brief discussion of any laboratory or field quality control problems that occurred during the previous storm season, and that might be significant when the data is interpreted. These may include failures in the laboratory such as systematic contamination or death of control organisms. They may also include QA/QC failures in the field; for example, improperly trained field technicians might cause systematic data quality problems by collecting samples incorrectly.

This section should not include the minor exceedances in laboratory control limits, such as matrix spikes that are outside the acceptable range or blank samples that contain target analytes slightly above the reporting limit, that are often encountered in a large set of laboratory data. While all QA/QC exceedances should be evaluated by the laboratory, most of these kinds of issues do not affect the quality of the data directly. However, any QA/QC failure that results in an analytical result being rejected should be discussed briefly in this section.

14.4.10 Appendix with Post-Storm Technical Memoranda (PSTMs)

After each stormwater monitoring event the monitoring consultant submits a PSTM describing the monitoring event and summarizing the data obtained. At the end of each monitoring season, these memoranda should be organized by monitoring station and event date and included in the interim report as an appendix.

15 GROSS SOLIDS MONITORING

The purpose of this chapter is to provide guidelines for planning, implementing, and reporting stormwater gross solids monitoring. Gross solids are another stormwater quality constituent for the purpose of monitoring. Gross solids monitoring has assumed importance because of various TMDL requirements to quantify and reduce or eliminate trash loads. The methods for gross solids monitoring and analysis presented here are based on the Caltrans Litter Management Pilot Study (LMPS), conducted during the 1998-1999 and 1999-2000 rainy seasons, as well as supplementary information from other sources.

The following aspects of gross solids monitoring are discussed in this chapter:

- Definition of gross solids
- Sediment and vegetation in gross solids monitoring
- Planning a study/project objectives
- Non-storm event variables
- Constituent selection
- Monitoring methods and equipment
- Laboratory selection, contracting, and chain-of-custody
- Site selection
- Equipment installation
- Quality assurance/quality control
- Laboratory coordination
- Training
- Pre- and post- storm activities
- Data validation
- Reporting

15.1 Introduction

While numerous characterization studies have been conducted on the chemical stormwater quality constituents (such as nutrients, metals, oil and grease), very few measurements have been reported on the amount and characteristics of gross solids in stormwater. Measurement of both quantity and quality of gross solids is essential to better understand gross solids sources and transport mechanisms, and to develop techniques for their removal. The variable nature of stormwater gross solids makes them difficult to capture and sample in a comparable manner. The objective of these monitoring guidelines is to ensure consistent use of gross solids monitoring and analytical methods, so data are comparable among different studies.

15.2 Definition of Stormwater Gross Solids

Stormwater gross solids include litter and other particles of relatively large size (Caltrans 2005a). Caltrans defines litter in stormwater as manufactured items made from paper, plastic, cardboard, glass, metal, etc. that can be retained by five-mm mesh. This definition of litter excludes materials that are of natural origin such as sand, soil, or gravel. In practice, these naturally occurring materials are part of normal gross solids discharges in stormwater, so it may be necessary for field technicians to manually separate the two kinds of gross solids before weight and volume measurements are performed. Stormwater gross solids are quantified by wet (as collected) volume and weight or as 24-hour air-dried volume and weight.

15.3 Sediment and Vegetation in Stormwater Gross Solids

Sediment and vegetation are also collected in stormwater monitoring devices along with litter and other particles. It is very difficult to separate litter from sediments and vegetation in sampling systems.

15.4 Planning a Gross Solids Monitoring Study

Planning for monitoring gross solids in stormwater involves steps that are similar to stormwater monitoring, as described in Chapter 2, with additional consideration for the unique variables already mentioned:

- Describe the problem or requirement and identify the study goal
- Identify the study questions and objectives

- Define boundaries and constraints
- Identify monitoring data and information
- Develop the data analysis approach
- Specify the data quality objectives
- Develop and optimize the study plan
- Prepare technical memorandum to document the study plan

However, gross solids monitoring is unique when compared to stormwater monitoring, as constituents include litter, vegetation, and sediment rather than the chemical and physical properties. Specific guidance related to various aspects of gross solids monitoring is presented in the following sections.

15.5 Monitoring Goals and Objectives

The goal of gross solids monitoring projects may be determined by regulations, TMDLs, or other specific requirements. Stormwater gross solids may be monitored to achieve one or more of the following objectives:

- Monitor baseline gross solids patterns and loads
- Determine the source and characteristics of gross solids
- Assess the effectiveness of a best management practice (BMP) designed to reduce gross solids
- Determine the magnitude of water quality improvement resulting from capture of gross solids

Gross solids baseline monitoring studies are useful for understanding the variation in gross solids loads for different drainage areas as well as the relationship between stormwater gross solids and factors such as rainfall and drainage area characteristics. Determining the source and characteristics of gross solids may assist in developing programs to reduce them. Gross solids may contain or trap other constituents of concern, such as copper, zinc, etc., that affect water quality.

15.6 Non-Storm Event Variables

Non-storm event variables may influence the results of gross solids monitoring. These must be identified during the planning stage. Factors that could influence the amount of gross solids reaching the drainage network must be identified and, if necessary, investigated.

Potential factors may include:

- Surrounding land-use characteristics (residential, commercial, industrial, transfer station, or landfill operation)
- Population density
- Traffic patterns and composition
- Wind directions and intensity
- Roadway configuration (slope, surface characteristics, sound walls)
- Roadway management practices (sweeping, Adopt-A-Highway)
- Size and geometry of the drainage network
- Construction activities
- Dry-weather flow/irrigation system
- Vehicular accidents

15.7 Selection of Gross Solids Monitoring Constituents

The selection of gross solids constituents is dependent upon the monitoring study objectives. Some monitoring studies are aimed at quantifying only the litter fraction. Others may require quantifying the portion of vegetation or sediment captured by the device or measuring the total sample (litter, sediment, and vegetation). Because gross solids monitoring devices capture litter, sediment, and vegetation, it may be necessary to sort the sample to obtain the fraction of interest.

Table 15-1 provides a suggested hierarchy of constituents for gross solids monitoring. The selection of physical and chemical stormwater quality constituents should be based on the list of common water quality constituents listed in Table 3-1.

Table 15-1 Gross Solids Sampling and Monitoring – Constituent Selection

Level of Investigation	Minimum to Consider	Desirable	Most Detail
A) Gross Solids Load Monitoring	• Ongoing local rainfall data and measured flow data, enough to estimate rainfall/runoff relationships • Total sample (litter, sediment, and vegetation) • 24-hour air-dried gross solids (weight and volume)	• Site-specific rainfall and flow measurements for each event	• Stormwater quality samples for chemical or biological constituents[1]
B) Structural BMP Assessment	• Rainfall and flow measurements (inflow, outflow, and bypass discharges) • Gross solids for sample analysis (see below) downstream and from the BMP • Continuous water levels in and around the BMP • Adequate data points for statistical analysis of BMP effectiveness[2] • Construction, operation, and maintenance costs	• Composition of the total sample • Dry-weather gross solids accumulation	• Low-flow upstream and downstream water samples • Water samples[1] from upstream and downstream of the BMP
C) Gross Solids Fractions	• Litter versus vegetation • Gross solids weight and volume • Air-dried weight and volume	• Onsite weight and volume	• Stormwater quality samples for chemical or biological constituents
(Applicable to A or B above)	• Note sediment fraction		• biological constituents[1]

[1]See Table 5.1.

15.8 Gross Solids Monitoring Methods and Equipment

Gross solids monitoring poses unique challenges regarding monitoring methods and equipment. Runoff patterns from small freeway catchments, typical of Caltrans drainage areas, have short periods of concentration and are not typical of larger, more attenuated watersheds. The distribution of gross solids in Caltrans stormwater is variable and is an important consideration in the selection of monitoring methods and equipment.

Equipment sizing should be based on the volume and size of gross solids expected to be generated in the drainage area. Housekeeping BMPs, as well as the expected quantity of vegetation, should be considered when selecting mesh-bag, linear radial screen, or inclined screen gross solids removal devices (GSRD) for monitoring gross solids. This section outlines various options for sample collection methods and equipment.

15.8.1 Sample Collection Strategies

Gross solids samples should be collected downstream of water quality samples for chemical analyses. However, if a GSRD is in use at a monitoring location, then chemical sampling may also be performed at the GSRD outlet, depending on the design of the device and the objectives of the study.

Sample collection strategies that may be adopted as appropriate for the project include the following:

- Monitor on a single-storm-event basis (i.e., collect gross solids samples after every storm of a predetermined size unless otherwise specified by the objectives of the study).
- Capture all gross solids periodically or at the end of the season.

The advantages and disadvantages of each of the above approaches are discussed in Table 15-2.

Table 15-2 Gross Solids Sampling Options

Monitoring Type	Advantages	Disadvantages
During Event (Grab Samples)	• Investigate transport mechanisms • Ability to document observations during events • Generates multiple gross solids samples per storm	• Need to be on site before and during events • Might miss the sampling event or large portion of event • Only subsample gross solids– need to extrapolate
Post-Event (Whole Event Composite Sample)	• Collect whole event gross solids sample • Increased safety due to non-rain and daylight conditions • Compare quantities to storm characteristics	• Bypass may occur • Unknown workload (number of events)
Periodical (Composite Multiple Samples Over a Set Period)	• Predictable cost and collection schedule • Annual totals achievable	• Bypass occurs frequently due to capacity • Fewer observations

In addition, sample collection methods may also depend on the following factors:

- Whether onsite weight and volume measurements and visual observations of captured material are required
- Whether samples of gross solids are sent to a laboratory for analysis of gross solids fractions
- Whether gross solids quantities and fractions are monitored by day, event or, season
- Other factors that influence the sample collection methodology relate to the type of monitoring (baseline or BMP assessment) used and conditions at the site (e.g., catchment size and access)

Typically, gross solids monitoring in stormwater lends itself to whole event sampling, where the gross solids sample is collected over an entire storm event, unless the objectives of the monitoring program stipulate otherwise. Collecting gross solids over an entire storm event provides a complete picture of the gross solids transported for the event and also allows for a detailed analysis to be performed on a sample. A post-event monitoring regime is expected to be best suited for the conditions in most Caltrans drainage systems and the information requirements of stormwater studies.

15.8.2 Gross Solids Monitoring Equipment

Depending on the physical configuration of the stormwater outlet at a monitoring site (e.g., pipe outfalls, open channels, and BMP assessment sites), gross solids sample collection may require various equipment.

15.8.2.1 Gross Solids Monitoring Equipment—Pipe Outfalls

For moderately sized outfalls (<24-inch), a ¼-inch mesh bag (net) attached to the end of the outfall is a practical and inexpensive sample collection device. Gross solids collect in the mesh bag as stormwater passes out of the pipe and through the net.

Figure 15.1 and Figure 15-2 shows a typical mesh bag set-up used at a pipe outfall. It has a retention cable fixed at the end of the outfall, an oversized nylon mesh bag, and a chain-linked enclosure for security.

Figure 15-1 Attaching the Bag Retention Cable

Figure 15-2 Attaching the Bag Retention Cable to the Housing

The benefits of this collection method are as follows:

- No interference with water quality sampling intake tubing since the gross solids collection point is downstream of sample intake
- Minimal construction and maintenance requirements
- Sufficient gross solids storage capacity
- Protective features that discourage vandalism
- Minimal space requirements downstream of outfall (depends on catchment size and required bag size)

Mesh-bag gross solids monitoring systems should be designed so they do not interfere with the hydraulic performance of the drainage system. To avoid flooding on the road surface, nets must be designed to release when they become too full of gross solids and cause upstream water levels to rise. Several options may be considered in designing a mesh bag system to avoid blockage and potential flooding. One option is to use an attachment strap with a breaking point such that it releases the entire bag from the pipe when the upstream water places too much force on the net.

Because the monitoring nets might release before the end of an event, this is not a failsafe sample collection method, especially for larger pipes with projected high gross solids loading.

If a net is released during a storm event, the sample should be discarded. The nets must be collected after each trigger storm event and must be maintained and emptied on a regular basis. If a net has released, it is replaced during post-storm collection procedures. In addition, it is recommended that nets be checked during large storm events to make sure they are operating properly. If a larger, long duration (generally greater than 24 hours) event occurs, nets may need to be replaced mid-storm, preferably during a period of lower flow/lower intensity rainfall.

An option for larger systems is to use fixed nets with provision for alternate release mechanisms or a bypass system. A bypass system for outfall gross solids monitoring could consist of extending the outfall pipe and providing an opening in the top of the pipe for overflow. Bypass flow is not monitored unless specified in the project objectives and goals. Other alternative designs to alleviate flooding could be developed and evaluated on a project-specific basis.

15.8.2.2 Gross Solids Monitoring Equipment—Open Channels

Open channels present another challenge for monitoring gross solids, because drainage areas and flows are likely to be larger than those for outfall pipes. Material of any size can make its way into open channels. Most Caltrans drainage systems are best monitored in an outlet prior to an open channel; however, if monitoring in a channel is required, the following guidelines should be helpful.

One method evaluated for the Caltrans Drain Inlet Cleaning Efficacy Study at the Tujunga Wash site in Los Angeles was to adapt the outfall-type nets to open channel conditions (Caltrans 2003d). At this site, a concrete headwall was constructed across the ten-foot (3,048-mm) wide channel through which three 24-inch (610-mm) PVC pipes were installed (see Figure 15-3). The pipes routed flow and debris into nets attached to the discharge end of each pipe. If the monitoring bags clog, flows could bypass the nets by overtopping the headwall or an upstream diversion weir. Similar methods could also be adapted for most open channels in the Caltrans drainage system based on site-specific hydraulic design.

Figure 15-3 Gross Solids Monitoring Setup in Open Channels

Site-specific designs are required for each installation, because the pipe headwall needs to be low enough across the channel to prevent unacceptable hydraulic impedance during high flows. A detailed hydraulic analysis is required prior to construction. Net and diversion systems should be designed to eliminate flooding even if they are completely blocked with debris.

Depending on the study, instrumentation may be required to monitor for stormwater bypassing the gross solids monitoring system. If bypass occurs, the storm event gross solids sample is considered incomplete, because the collected sample would represent only a proportion of the total amount of gross solids transported.

15.8.2.3 Gross Solids Monitoring - Structural and Nonstructural BMPs

GSRDs are structural treatment BMPs designed to remove trash, vegetative material, and other relatively large particles from stormwater runoff. These BMPs are constructed on or around drainage systems, including pipe outfalls and open channels.

A GSRD is generally equipped with a solids separation unit in the form of an inclined screen, a linear radial screen, or a parabolic screen. Gross solids are first separated from stormwater using the screens and subsequently collect in the storage area of the GSRD. Gross solids collected from any of these screening devices can be analyzed according to the monitoring goals and objectives.

Inclined screen GSRDs have screens that are placed down the length of each side of a concrete vault, as shown in Figure 15-4 and Figure 15-5. Inflow is diverted to the sides of the GSRD, over the inclined screen, into a collection channel, and then ultimately into an effluent channel. The center area of the GSRD, between the two inclined screens, works as a storage area for the separated gross solids.

Figure 15-4 Example of Inclined Screen GSRD

Figure 15-5 Example of Inclined Screen GSRD, View #2

A linear radial GSRD consists of a well casing pipe with louvered openings, as shown in Figure 15-6 and Figure 15-7. The casing is mounted horizontally onto the basin inlet pipe. Stormwater flows from the inlet pipe into the linear radial device. Approximately halfway along the linear radial device, an emergency overflow is provided to prevent water from backing up to the roadway, should the device become clogged with sediment or gross solids.

Figure 15-6 Example of Linear Radial GSRD, View #1

Figure 15-7 Example of Linear Radial GSRD, View #2

A parabolic screen GSRD, also referred to as an inclined screen GSRD (see Figure 15-8), has a curved parabolic screen made of parallel wires installed in a concrete vault. The runoff enters the device through a trench and weir, which distributes the flow over the curved screen. The parabolic screen is designed so water flowing down the screen pushes gross solids downward towards the vault's gross solids storage area.

Figure 15-8 Example of Parabolic Screen GSRD

Careful consideration must be given to potential flooding risks. It is therefore important to collect hydraulic information such as water levels and flows in and around the unit. A high-flow diversion bypass is an important flood control component of structural BMPs. This feature serves to protect the structure from structural damage during flood conditions and also prevents scour and re-suspension of contents in the storage area. Where applicable, instrumentation (e.g., level indicators and flow meters) should be installed to record: (1) when and to what extent a bypass is engaged, (2) the water levels upstream, downstream, and inside a BMP, and (3) flows into and out of a device.

Nonstructural BMPs can include various types of programs designed to reduce or eliminate gross solids from a drainage area, such as housekeeping BMPs, street sweeping, the use of vegetation for erosion control, and litter management. Nonstructural BMPs can be assessed using the equipment described above in pairs of monitoring sites (one containing a BMP and the other under typical management conditions), or by alternating implementation between years of monitoring. To perform nonstructural BMP gross solids monitoring, the same equipment used for baseline gross solids monitoring can be used (i.e., nets attached to pipes, screens, etc.).

15.9 Laboratory Selection, Contracting, and Chain-of-Custody

At present, no standardized methods have been established to quantify gross solids from stormwater runoff, and many certified laboratories are not equipped to analyze gross solids. In the absence of a standard method, Caltrans has developed guidance to measure gross solids (see Appendix H). This guidance can be used to perform a gross solids characterization study.

Upon completion of the audit, the monitoring team representative and the QA/QC Manager from the proposed laboratory should review the audit results and discuss corrective actions that may be required prior to contract execution. Prior to sampling and analysis of gross solids samples, the following items must be discussed and clarified with the gross solids laboratory-selection of sample fraction of interest (i.e., litter only or including measurements for total gross constituents and/or vegetation):

- Analytical methods to be used
- Design and fabrication of sampling equipment specifically for the monitoring project
- EDD, report formats

15.9.1 Sample Delivery and Chain-of-Custody

Tracking samples from the field to their final analysis destination is an essential QA measure for each sampling event. Chain-of-custody (COC) forms provided by the gross solids laboratory must be completed each time a gross solids sample changes hands. For COC tracking, gross solids samples are treated in the same way as stormwater samples. A generic COC form is shown in Appendix G.

15.10 Monitoring Site Selection

The main consideration for selecting gross solids monitoring sites is configuration of the site (pipe outfalls, open channels, BMPs), as well as the anticipated amount of gross solids to be collected. Gross solids BMP assessment sites may have special requirements. Chapter 6 should be used as guidance for project site selection. Additional considerations for gross solids monitoring site selection include:

- Gross solids management practices within the drainage catchment. Gross solids management practices, such as gross solids pickup and street sweeping, should be documented during site selection. These practices may influence stormwater gross solids loads between sites. Gross solids management practices must be consistent between sites if data are to be compared.

- Monitoring equipment access. Gross solids sampling methodologies should be carefully considered during site selection. Samples have to be collected from the monitoring device and transported for analysis and disposal. Direct vehicle access to the monitoring location may be necessary and the use of a boom truck, winch, or other mechanical device may be required to remove a gross solids sample from the sampling equipment.
- Sample size. The anticipated sample size should also be considered in site selection. If post-event or periodic samples are collected, the samples can be very voluminous and heavy. Post-event gross solids samples from an 18-inch outfall can potentially exceed 100 pounds at the time of collection.

15.11 Preparation of Monitoring Plans

Appendix A contains guidelines for preparation of a QAPP or OM&M Plan. Following is a list of important components of a QAPP or OM&M Plan specific to gross solids monitoring:

- Gross solids monitoring equipment description and maintenance procedures
- Storm selection criteria (may differ from stormwater sampling projects)
- Storm event preparation procedures and checklists
- Gross solids sample collection procedures and associated biological hazards
- Gross solids laboratory coordination procedures
- Project-specific gross solids analysis requirements (Appendix I)
- Project-specific field checklists for pre-storm setup and sample collection activities for gross solids monitoring

15.12 Monitoring Equipment Installation and Maintenance

This section provides general guidance on gross solids monitoring equipment installation, maintenance, and safety procedures.

Safety of all personnel during installation, inspections, and maintenance is the most important consideration. The selected site must afford safe access to the monitoring location. Working in a drainage system may require special skills and/or safety equipment, including, where applicable, confined space entry certification and equipment. Appropriate equipment, procedures, and training will be required if confined space entry is necessary for either construction or maintenance.

15.12.1 Pipe Outfalls

Gross solids monitoring equipment on pipe outfalls can be completely enclosed and protected from vandalism by installing of a chain-linked fence enclosure with access from the top or side (see Figure 15-9).

If the site includes water sampling and hydrologic monitoring equipment in addition to gross solids monitoring, a larger fenced enclosure will be needed for the water samplers, data-loggers, and flow monitoring equipment. Section 4.7 provides detailed information on equipment enclosures.

Maintenance of gross solids monitoring equipment at pipe outfalls includes inspecting mesh-bags for wear, laundering as needed, and repairing or replacing bags, if necessary. Replace straps used to secure the bags, if worn. Also, clear weeds and sediment from the enclosure as needed.

Figure 15-9 Gross Solids Monitoring Net Attached to a Pipe Outfall

15.12.2 Open Channels

Designing and installing a headwall monitoring net system within an open channel requires a site-specific hydraulic design and detailed construction plans and specifications. This must be done on an ad-hoc basis by the Project Engineer.

The headwall is a permanent fixture within the open channel. The nets are attached to pipes that provide an opening for water passage through the headwall. Construction requires bypassing flows during construction and installing the headwall and pipes within the channel.

The installation must be designed and constructed so the risk of flooding is not increased. If the gross solids monitoring system does not function as designed, the system may overflow repeatedly.

After the headwall and pipes are installed, gross solids collection nets are attached to the pipes. During sample collection, each net is removed separately and replaced with an empty net. The collected gross constituents are then transported to a gross solids laboratory for analysis. Maintenance procedures are the same as for pipe outfalls.

Open channels generally do not require confined space entry, but appropriate safety precautions must always be implemented.

The gross solids monitoring component of the equipment cannot be contained within a chain-linked fence enclosure because of its location in the drainage channel. However, water sampling and flow equipment can be contained within an enclosure.

15.12.3 Gross Solids Structural and Non-Structural BMP Assessment Sites

The installation of monitoring equipment for BMP assessment sites is similar to those for pipe outfalls or open channels. However, site-specific conditions should be evaluated prior to installation.

Structural BMPs typically are incorporated into existing drainage systems to capture litter and incidental coarse solids retained on a five-mm (approximately ¼-inch) opening size screen. The gross solids are removed from these devices and collected into sample containers for speciation. The BMP screens should be inspected for any sign of wear or damage that would render the device ineffective in retaining gross solids (i.e., gaps greater than five mm) or could impair monitoring. Maintenance of these devices may require the use of lifting and moving equipment and confined space entry procedures.

15.13 Quality Assurance/Quality Control

Chapter 12. provides guidance on QA/QC samples for stormwater monitoring programs. For gross solids sampling, field duplicates are not possible. Therefore, laboratory replicates are used for QA/QC of gross solids samples. Laboratory replicate analyses involve performing gross solids analyses in duplicate at a frequency to be determined on a project-specific basis.

Performing a duplicate analysis on the same sample serves as QA/QC for methods, equipment, and calibration. Typically, analyzing ten to 20% of project samples in duplicate may be an appropriate target for projects. This procedure is feasible for smaller sample quantities, such as samples generated by the pipe outfall-net type collection systems. Alternative laboratory QA/QC methods may need to be developed for large samples, such as large gross solids collection BMPs emptied one to two times per season or samples from open channel monitoring.

15.14 Laboratory Coordination

Prior to each storm, the project team must contact the gross solids laboratory to notify them of impending storm events. In addition, the project team will provide the laboratory with available information related to the anticipated quantity of material to be delivered (number of stations and anticipated volume for each). The recommended frequency for laboratory communications is as follows:

- 72 hours before storm event when storm event is imminent
- 24 hours before storm event when field crew is mobilized
- Two hours before samples are delivered to the laboratory

15.15 Training

Staff training for gross solids monitoring should be conducted following the general guidelines presented in Chapter 9 and in accordance with the project specific QAPP and OM&M Plan. Monitoring personnel should be trained regarding gross solids monitoring preparation, sample collection and associated hazards, and sample delivery procedures.

15.16 Pre-Storm Activities

To ensure the monitoring equipment performs well during storm events, thorough preparation is essential. In general, the procedures for pre-storm preparation and logistics described in Chapter 10 should be followed. Specific preparation and logistic requirements for gross solids monitoring are described in the following sections.

15.16.1 Storm Selection Criteria

Storm selection criteria must be established in accordance with project-specific objectives and with the guidelines discussed in Chapter 10. Note that the selected trigger criteria should take into consideration hydrologic factors such as catchment area, time of concentration, and runoff coefficients, as well as the ability of flow to mobilize gross solids constituents.

15.16.2 Sample Containers

Gross solids monitoring typically requires specially fabricated sample collection devices, usually ¼-inch (6.35-mm) mesh-bags, sized on a site- or project-specific basis. Multiple sets of mesh sample bags and suitable storage containers are required to allow bags to be replaced during frequent storm events. A minimum of three sets of bags is recommended and additional sets may be considered based on project-specific logistics. Plastic storage containers are needed for transport of samples to the laboratory.

15.16.3 Gross Solids Removal Devices

All GSRDs must be inspected for obstructions prior to a storm event to allow drainage of stormwater as well as to prevent flooding conditions, scour, and re-suspension of collected constituents. Materials blocking inclined or parabolic screens, louvered openings, or other GSRD design features must be removed in preparation of a storm event.

15.16.4 Sample Labels

Sample labels should be prepared prior to attaching to each sample collection bag/container. The following information should be included on a sample label:

- Project Name – record the name of the Study Program (e.g., Drain Inlet Cleaning Evaluation)
- Sample ID Number
- Site Name – record the highway number and nearest cross street
- Site ID or Outfall Number – record the specific, unique monitoring site ID or outfall number where the samples are taken
- Storm Event Number – record unique storm event number (e.g., 2007-E01)
- Collection Date and Time – record date and time sample was taken

- Container # of ## (for multiple container samples)
- Name of Field Sampler – record name of person collecting the sample
- Non-storm Event – check as indicated Yes _____ No _____

15.16.5 Field Equipment Preparation

A sample pre-storm checklist is presented in Figure 15-10. The checklist must be completed to ensure the site is operable and water sampling and flow equipment are in working condition. Collect gross solids and/or vegetation found in monitoring nets during pre-storm setup and submit these to the gross solids laboratory for analysis as a non-storm event sample.

PRE-STORM OBSERVATIONS AND ACTIVITIES			
Project: Date:			
Time: Technician:	Site ID:	Site ID:	Site ID:
Check for damage, vandalism, stolen equipment, etc. Anything in the project area that might affect the study. Check the box if present and provide specific comments below.			
For good housekeeping of sites, clear enclosure area of trash. Place into a trash bag to dispose of later.			
One field crew member to replace existing (old) gross solids monitoring bag with clean bag. Ensure the gross solids bag is securely fastened by a strap. Chemical water quality sites must receive gross solids monitoring bags with Velcro flap on top.			
For GSRD sites, ensure that screens and louvers are free of debris and will not hinder the flow of stormwater. If practical, measure weight and volume in the field or submit to laboratory for analysis.			
Second crew member to review label and initial that it is accurate.			
Return labeled trash bag containing the non-storm gross solids sample to the laboratory.			
Check-in bag with laboratory manager or fill out bag inventory form at the laboratory.			
Check flow monitoring equipment			
Check water sampling equipment if applicable			
Comments:			

Figure 15-10 Sample Pre-Storm Gross Solids Checklist

15.17 POST-STORM ACTIVITIES

The following sections provide a discussion on post-storm sample collection procedures, documentation of onsite observations and sample delivery, and COC.

15.17.1 POST-STORM SAMPLE COLLECTION

Gross solids sample collection procedures will be unique for each site and documented in the project specific QAPP /OM&M Plan. The following procedure is suggested for guidance:

Collect gross solids samples within 48 hours or earlier if a subsequent rain event is forecast.

- Remove the gross solids from the collection device and inspect the stormwater conveyance. Materials lodged in the conveyance should be left in place since they may be collected in subsequent storms.
- Gravity-drain the collected gross solids for at least two minutes and until they are substantially drained of free water (i.e., no drips for five to ten seconds).
- Empty the gross solids into a labeled plastic bag and complete the COC form.
- Place the plastic bag in a clean plastic container for transport to the gross solids laboratory.
- Replace the empty collection device (if in suitable condition for reuse) for monitoring the next event.

Gross solids samples can be heavy depending on the size and water content of the sample (single event samples can weigh more than 100 pounds), so a mechanical winch or boom truck may be required for safe sample collection.

15.17.2 Post-Storm Observations

Documentation of post-storm observations is necessary because these observations provide valuable information regarding gross solids transport and BMP effectiveness. Figure 15-11 shows a typical checklist for post-storm observations. The checklist should be completed after every storm event.

POST-STORM OBSERVATIONS AND ACTIVITIES			
Project: Date:			
Time: Technician:	Site ID:	Site ID:	Site ID:
One crew member to remove existing (old) gross solids monitoring net and place inside plastic trash bag. Label trash bag with date and location, keeping treatment and control bags together (if applicable).			
For GSRD sites, one crew member to remove existing gross solids from collection area, screens, and louvers and place inside plastic trash bag. Label trash bag with date and location, keep treatment and control bags together (if applicable).			
Second field member to review label and initial that it is accurate.			
Look up storm drain and note whether there is material (and type) left in the drain. Leave material in place.			
Place clean monitoring bag onto outfall. Ensure the collection bag is securely fastened by strap.			
Drain sample of free water and place in properly labeled plastic bag.			
Note any of the following:			
Damage, vandalism, stolen equipment, evidence of bypass operation, evidence of downstream gross solids accumulation, any other unusual site conditions such as construction activity or damage to structures.			
Comments:			

Figure 15-11 Sample Post-Storm Gross Solids Checklist

15.18 Data Validation

Several steps are important in reviewing gross solids data after laboratory analysis and prior to data entry. After completion of laboratory sheets by laboratory personnel, data sheets are to be reviewed by the laboratory QA officer for the following items:

- Replicates – Check that the requisite number of laboratory replicate analyses were performed (see Section 15.13). Previous studies used a frequency of one per five gross solids samples. Make sure replicates were randomly selected from the available monitoring sites for a given project.
- Vegetation versus litter proportion – Confirm whether the litter portion of the total sample is consistent with field observations and expected portions per the

Caltrans LMPS. The litter portion is typically less than 30% of the total sample by weight or volume, except for small samples.

- Other data recording errors – Verify that technician names are documented, consistent number of decimal points are used, and data are legible.

15.19 Reporting

Gross solids data should be reported in tabular format. All field information, laboratory measurements, and QC data should be reported. See Chapter 14 for guidelines on report formatting.

16 SEDIMENT SAMPLING AND ANALYSIS

Nearly all Caltrans stormwater monitoring projects involve the collection and analysis only of aqueous samples such as stormwater runoff and receiving water. However, there may be circumstances where a project can also involve collecting sediment samples associated with stormwater runoff. Procedures for collecting and analyzing these sediment samples are discussed in this chapter.

Caltrans also collects solid materials from roadways to characterize them before they enter the stormwater drainage system. Although not technically sediment, they are collected as solid samples and analyzed in the same way sediment samples are analyzed, as described in Section 16.6.

This chapter discusses monitoring of sediment as a solid matrix. Solids suspended in water are discussed in Chapter 3. The following aspects of sediment monitoring are discussed in this section:

- Drivers for sediment sampling
- Project planning
- Sample collection and handling
- Collection methods and equipment
- Laboratory selection
- Sample analysis
- Data validation
- Reporting
- Training

16.1 DRIVERS FOR SEDIMENT SAMPLING

Regulatory agencies are sometimes concerned about sediment buildup in receiving waters. High levels of sedimentation can cause physical disruption of the hydraulic characteristics of receiving waters. According to the EPA National Water Quality Inventory 2000 Report (USEPA 2002a), excessive sediment buildup was a leading cause of impairment of the nation’s waters. Over time, sediments deposited on the bottom of receiving water bodies can change the ecological characteristics of the bottom in such a way as to harm benthic and bottom-feeding organisms.

Sediment carried in stormwater plays an important role in the transport and fate of chemicals, nutrients, and metals that enter stormwater discharges. Many persistent toxic contaminants, such as metals and organic compounds (e.g. pesticides and polynuclear aromatics), are strongly associated with the sediment load in rivers and streams. As the sediment in stormwater settles, these pollutants can become concentrated over time in the beds of natural water bodies where they can accumulate in the tissues of benthic and bottom-feeding organisms.

Sediment sampling may be needed for BMP pilot studies designed to test reduction of sediment discharges. Some BMPs may not be designed to collect sediment but are still sensitive to sediment buildup; for example, BMPs designed to eliminate trash and litter from Caltrans discharges can also trap large amounts of sediment. BMPs with basins and vaults may be susceptible to sediment buildup over time, which could affect their operation. In these cases, it might be necessary to study the impact of sedimentation on their effectiveness and maintenance requirements.

Although most of the sediment found in stormwater comes from natural erosion, the most concentrated sediment releases often come from construction projects or other activities that disturb large areas of soil. Sediment sampling can be used to evaluate the efficacy of construction site BMPs.

Sediment buildup in drains and catch basins located in Caltrans facilities has the potential to cause flooding. Sediment sampling may be needed to study and address such problems.

16.2 Project Planning

Most of the project planning guidelines in Chapter 2 can be used to prepare sediment sampling plans. The flowchart shown in Figure 2-1 illustrates the steps used to develop the project, from identifying the study goals through optimizing and documenting the plan. Although the planning framework discussed in Chapter 2 is written for water quality projects, it can be adapted for sediment sampling with minimal changes. The site selection process described in Chapter 3 can also be adapted for sediment sampling projects.

In 2009 the State Water Resources Control Board adopted the Water Quality Control Plan for Enclosed Bays and Estuaries – Part 1 Sediment Quality (State Water Board, 2009). The plan contains information on sediment sampling and analyses. The document includes definitions for many relevant terms, such as sediment toxicity, sediment chemistry, and benthic community condition, which can be used when planning a Caltrans sediment sampling program. When developing a project that involves sediment sample collection and testing for benthic conditions, chemistry, or toxicity the project planning team should consult this document for guidance where appropriate.

The project planning team should develop a project QAPP for use by project managers and field technicians. Appendix A contains the template that should be used to create a project QAPP. This document must contain the following elements, at a minimum:

- Description of sediment monitoring equipment and maintenance procedures
- Sediment sample collection and handling
- Sampling event selection criteria (may differ from stormwater sampling projects)
- Analytical constituents and methods
- Sampling event preparation procedures and checklists
- Sediment laboratory coordination procedures
- Project-specific field checklists for pre-event setup and sample collection activities for sediment sampling

16.3 Sample Collection and Handling

Selection of the most appropriate sampling equipment and methods will depend on the study objectives, sampling logistics, and the project analytical constituent list. Project planners will also have to take into consideration the cohesiveness of the sediment, depth of the deposit, the degree to which disturbing the sediment is permissible, the amount of litter and organic matter present, and access to the deposit.

If the constituent list includes chemical constituents, sampling devices must be made of chemical-resistant materials that will not affect the chemistry of the sample. For example, if the project objective requires analysis of the samples for metals, care must be taken to use sample collection equipment that does not bring the sample into contact with exposed metal surfaces. Plastic and rubber components may contribute organic material and must be avoided if the constituent list includes organic compounds such as polynuclear organics or pesticides. Butyl rubber seals may also contribute organics to the sample.

Sediment samples can be collected manually by physically removing accumulated sediment from the monitoring site, or passively, using a constructed device that traps or filters sediment from a discharge as it is flowing.

16.3.1 Manual Sample Collection

Manual sample-collection equipment usually consists of hand-operated items, such as grade rods, core samplers, scoops, and shovels, which are designed to measure the depth of the sediment deposit or collect a physical portion of the deposit. These items are relatively inexpensive and easy to maintain.

Table 16.1 lists applications and limitations of various manual sediment collection methods.

Table 16-1 Applications and Limitation of Particle/Sediment Sampling Methods

Sampling Method	Applications	Limitations
Core	Cohesive soils Depths > 5 cm Soil profile required Minimal impact to deposit Sampling rod extends reach	Shutoff cap required in sand, gravel, or water Presence of litter and plant material can create problems
Depth-Integrated Excavation	Cohesive soils Depths < 30 cm Soil profile required Locations with limited access to deposit	Disturbs relatively large area Sample collection may require surface to be disturbed
Scoop	All soils Depths < 50 cm, unless the entire deposit is removed Locations with limited access to deposit	Disturbs relatively large area Does not maintain the profile Sample collection may require surface to be disturbed

16.3.1.1 Core Method

A metal or plastic tube, called a soil core liner, is pushed through the entire depth of the sediment deposit in the vertical direction to extract a core sample. When the core liner is removed, the entire sediment column is represented inside. This can then be composited by the laboratory, or individual layers can be analyzed discretely.

Soil core liners are commercially available and can vary in size from approximately one inch to over four inches in diameter, and between three and 12 inches long. The liners can be pushed into very soft sediment deposits by hand; for firmer sediment deposits, a device called a slide hammer can be used to drive the core liner into the deposit. Liners can be made of brass, stainless steel, or polycarbonate.

If samples must be taken from deep within a sediment deposit, a hand auger is sometimes used to drill down into the deposit, and then a soil core liner driven into the sediment at the required depth.

16.3.1.2 Depth-Integrated Excavation

A spoon or shovel (metal or plastic) is used to excavate a sample from the entire profile of the sediment deposit. Sediment samples collected in this way are placed directly into a laboratory sample container.

16.3.1.3 Scoop Method

A scoop device (metal or plastic) is used to collect samples from the surface of the sediment deposit. Shovels, trowels, and spoons can be used as scoops. Sediment samples collected in this way are placed directly into a laboratory sample container.

16.3.2 Passive Sample Collection

Passive sampling equipment is designed to trap sediment and create deposits that are then removed from the device manually. Passive sample collection usually consists of allowing particles to settle out of a stormwater discharge, filtering particles out of the discharge, or a combination of both methods.

16.3.2.1 Settling

Particles in water can be allowed to settle naturally out of a stormwater discharge and into a collection container. Any device that lowers the velocity of the flow and causes a portion of the suspended particles to settle out can be used for this purpose.

Figure 16-1 shows an example of a double-barrel sand trap. Stormwater runoff is directed through a series of two barrels, where suspended particles are allowed to settle to the bottom before the water is discharged. Samples of the sediments that accumulate on the bottom of each barrel are collected for analysis after a predetermined number of storm events have occurred.

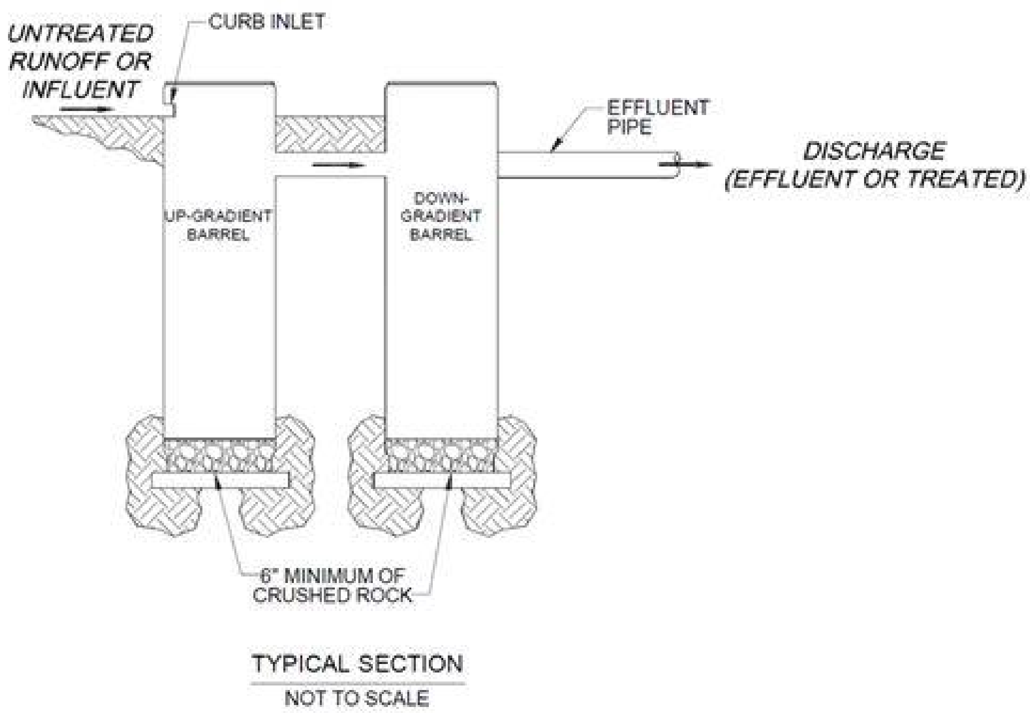

Figure 16-1 Double-Barrel Sand Trap

16.3.2.2 FILTRATION

Filtration can be applied to collect smaller particles that take longer to settle out of suspension. Filtration devices are designed to direct the flow through a filter or a series of filters, trapping the sediment on the surface of each filter.

Figure 16-2 shows an example of a passive filter system where filters are applied to a double-barrel sand trap and the sample is collected by a combination of settling and filtration. Mesh baskets are anchored to the bottom of each barrel, as shown in Figure 16-3. Larger particles settle out of the water as it passes through the barrels and are deposited in the mesh baskets. The water then passes out of the sand trap and into the metal filter screen housing (**Error! Reference source not found.**), where the smaller particles are captured. After the required number of storm events, both the wire mesh baskets and filter screens are removed from the device, and the accumulated sediment is removed for testing.

Figure 16-2 shows a metal filter screen housing and a BMP composed of a series of stacked trays that each hold a filter. The discharge flows onto the top tray and through to the next one before exiting out of the bottom. The top filter has the largest pore size followed by filters with smaller pore sizes with the bottom filter having the smallest. This graduated filter design allows the top trays to filter out the coarsest material and allows the finer materials to pass through. This design provides a way to minimize filter clogging and reduces system bypass flows. This filter box design can be applied directly in a stormwater discharge, or it may be used in conjunction with other water quality monitoring.

Figure 16-2 also shows how a passive sediment collection system can be combined with automatic water sampling and flow monitoring. The equipment associated with the auto samplers (strainers and sample tubing) and flow monitoring (weir and bubbler) is shown in relation to the passive monitoring equipment.

Filters are prone to clogging and must be cleaned or replaced regularly to remain effective. The smaller the pore size, the faster the filter will clog with debris. Pore sizes less than approximately 20 microns are not practical for use in the field. Field installations depend on gravity to force runoff through the filter, and gravity alone is not usually sufficient to force stormwater through filters with pore sizes smaller than 20 microns.

A trash grate or similar device placed upstream from the filters can remove unwanted debris and may help extend the effectiveness of the filters.

Depending upon the sediment loading and grain size distribution, filters may become clogged so quickly that it is not possible to collect sediment over the duration of an entire storm. In this case, it may only be possible to collect sediment representing only a portion of the event.

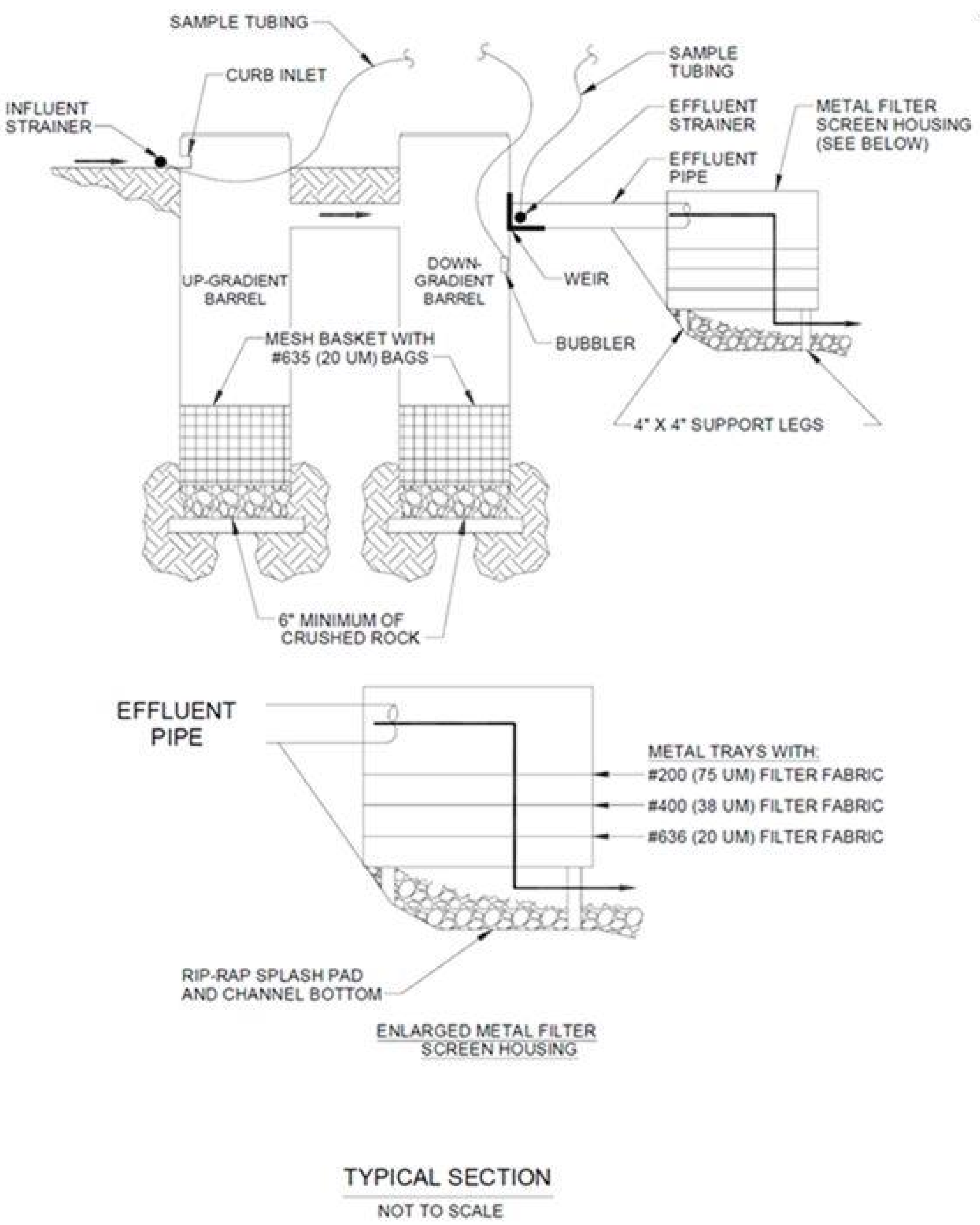

Figure 16-2 Double-Barrel Sand Trap with Passive Sediment Collection System

Figure 16-3 Barrel with Filter Bag (Left) and Trays (Right)

The filter box design can be modified to hold a single bag filter, as shown in Figure 16.4, as another means to reduce the impacts of clogging. This design may be useful because it does not impede flow while the runoff is filtered.

Figure 16-4 Filter Box with Single Bag

16.3.3 DEPTH MEASUREMENT

Sediment studies do not always involve the collection of a sample for laboratory analysis. If the study objectives include determining the amount of sediment that builds up over time, it may be necessary to measure the depth of accumulated sediment.

When the depth of sediment must be measured in an area with a concrete or metal bottom, such as a vault, constructed BMP, or artificial conveyance, depth measurements can be collected directly with a measuring rod. The rod is pushed or driven into the sediment until it reaches the bottom and the depth is measured along the rod. This method can only be used when the rod can penetrate the entire depth of the accumulated sediment.

A single depth measurement may not be representative of the average depth. Depending on the contours of the bottom of the structure, multiple measurements may be required to accurately represent the depth. Flat surfaces will require fewer measurements than uneven surfaces. If the geometry of the floor is known, depth measurements can be made in areas that, when combined, are representative of the entire structure.

The depth can also be determined indirectly by measuring from a fixed point down to the surface of the accumulated material. This distance is then subtracted from the distance from the fixed point to the floor of the structure to calculate the depth of the material. Again, multiple measurements may be required to obtain an accurate result.

In natural waterways that do not have a solid bottom with a known geometry, measuring sediment depth can be more complicated and more subjective. In these cases, it may not be possible to determine with any certainty how much sediment has been deposited by stormwater at a specific location. In cases like this, it is usually necessary to measure the level of sediment from a fixed point along the shore, and to take measurements annually, or over a relatively long period of time, and then compare them to determine how much sediment is building up in a particular area. Collecting cores of sediment at various places along the waterway and examining them for sediment consistency could also be used to differentiate recent sediment from the existing streambed.

16.3.4 Sample Containers

Unlike containers used for water samples, containers for sediment samples do not contain preservatives, and multiple container types are normally not required for different analyses. One full sample container per sample is usually all that is required to perform all the required analyses.

Both plastic and glass containers are appropriate for sediment samples. If the project constituent list includes organic compounds such as Oil and Grease, PAHs/pesticides, or toxicity, glass containers with Teflon®-lined lids should be used to avoid contamination. If the project constituent list includes unusual constituents, such as low-level mercury, the decision as to what sample containers will be used should be discussed with the laboratory before the monitoring phase of the project begins.

16.4 Sample Collection Methods and Equipment

Most Caltrans sediment monitoring projects involve collecting samples of sediment that have been deposited by past stormwater discharges and have built up over time. This kind of sample is usually collected from the bottoms of constructed BMPs or stormwater conveyances, from drainpipes, or from the streambeds and riverbeds of receiving water bodies.

Sediment can also be collected during a storm, in real-time, as it settles out of a stormwater discharge, or as it is filtered from the discharge. If this approach is taken, samples will be collected over the entire storm event, over some segment of the event, or over multiple events. See Section 16.3.2 for details on collecting a composite sediment sample from stormwater runoff.

Sediment can be collected as either composite samples or grab samples. Composite and grab samples are discussed in Section 11.2, and a comparison of the advantages and disadvantages of each is listed in Table 16-1. Although Section 11.2, is written for stormwater samples, most of the principles can be applied to sediment samples as well.

16.4.1 Grab Samples

A grab sediment sample is a single sample collected from a discrete point in the monitoring area and is representative of only that physical location at the time it is collected. In some cases, this may be adequate to answer the study question. For example, if the objective of the project is simply to verify whether the target compound is present in the bed of a receiving water body, collecting a single sample where the stormwater discharge enters the receiving water might be all that is required.

A single grab sediment sample would also suffice if the purpose of the study was to determine how much sediment builds up in a conveyance or BMP over time. If the entire sediment buildup in a structure is removed and weighed, this would also be considered a grab sample.

Grab samples are usually collected using manual methods, as described in Section 16.4.1.

16.4.2 Composite Samples

If the objective of the project is to characterize an entire study area or to characterize sediment at a single location over a period of time, it is necessary to collect composite samples. Composite samples can be collected either manually, by digging or scooping material out of an accumulated deposit, or passively, by collecting sediment from a single point as it settles or is filtered out of a stormwater discharge.

Accumulated sediments may vary both laterally and vertically throughout the cross section of the deposit. Layers of sediment representing different runoff events may form in the deposit. Heavier particles may drop out of suspension first and accumulate in a different location than smaller or less dense particles.

Composite sediment samples are made up of multiple subsamples. Compositing is simply done by weighing a specific amount of sediment from each subsample, combining them in a large container, such as a mixing bowl, and then homogenizing them with a spoon or paddle. The final composite is analyzed as a single sample. This compositing procedure may be done either by field personnel or by the laboratory.

Composite sediment samples can be made from subsamples collected at different depths in a deposit, subsamples collected at different places within the study area, or at different points in time from the same location.

16.4.2.1 Composite over Depth

The composition of a sediment deposit can vary with depth. The surface of a deposit may be substantially different in grain size or chemical composition than deeper layers. When collecting composite sediment samples, it is important to collect subsamples that represent the entire depth of the deposit.

16.4.2.2 Composite over Area

Subsamples can be collected from different points within the study area to create a sample that represents the entire area. If this kind of composite is considered for a project, it is recommended that pre-work be performed to estimate the variability and define the minimum number of subsamples that will be required. For example, a pilot study might consist of collecting and analyzing samples from multiple points in the study area; the variation in results among the discrete samples will indicate the minimum number of subsamples to collect for a composite sample to be representative.

16.4.2.3 Composite over Time

Composite samples can also be collected from a single location over a period of time. In this case, a sample is collected from discharge as it settles out of the stream and into a collection device, or it is strained out of the discharge as it passes through a filtration device. Samples collected in this way represent a single physical point in the runoff stream over a specified period.

Composite samples provide information about the mean concentrations of project constituents over the entire study area or over time and testing one composite sample instead of many discrete samples helps to hold down project costs. But composite samples do not provide any information about variability throughout the study area or over time. During the project planning phase, project planners must decide whether a single composite sample will adequately answer the study question; if information is required about variability within the study area or over time, composite samples will probably not be satisfactory.

Composite samples can be collected by using either manual or passive monitoring equipment as described in Sections 16.4.1 and 16.4.2.

16.4.3 Sample Representativeness

Each sample or measurement must be evaluated to verify that it is representative of the study area.

In situ sampling (for example, when volume is being determined using multiple depth measurements in the study area) should be done using a standard grid; this grid should be based on either the known geometry of the area or on a pilot study that characterizes the study area. Variability will increase as the geometry of the study area becomes more complex, and more measurements will be required to determine sediment volume accurately.

When sediment is being collected for offsite analysis, the sediment samples should be representative of the area from which they were taken. If possible, the entire sediment deposit should be collected; this can only be done with very small deposits. For larger deposits, a sufficient number of samples must be collected at regular points within the study area so the results are representative. As with in situ monitoring, samples should be collected that represent the entire column of accumulated sediment.

If it is necessary to weigh the sample, the sediment should be dried thoroughly before it is weighed, and the results should be reported on a dry-weight basis.

The standard for representativeness of a sample or measurement must be determined during the planning phase of a project and included in the project QAPP. If collected samples do not meet the minimum requirement, the Caltrans Task Order Manager must decide whether to analyze them.

16.4.4 Pre-Event Activities

Thorough preparation is essential to ensure the monitoring equipment performs well during storm monitoring events. Chapter 10 describes the procedures that should be followed when preparing for a storm event.

All installed sediment sampling equipment must be inspected for obstructions before storm events to ensure drainage of stormwater as well as to prevent flooding conditions, scour, and re-suspension of collected constituents.

Sediment sample collection procedures will be unique for each site and documented in the project specific QAPP. However, sediment samples should be taken within 48 hours of a storm, or earlier, if a subsequent rain event is forecast. Remove the sediment from the collection device and inspect the stormwater conveyance. Sediment that has settled in the conveyance should be left in place since it may be collected in subsequent storms.

Documentation of field observations is necessary because onsite observations provide valuable information regarding field conditions, including gross solids transport and BMP effectiveness. Examples of field observations are the depth, turbulence, velocity of flow, water clarity, and presence of floating debris.

16.4.5 Clean Sampling Techniques

As with all Caltrans stormwater monitoring projects, clean sampling techniques must be used when collecting sediment samples in order to minimize the possibility of contamination. See Appendix C for the detailed clean sampling procedure.

16.4.6 Sample Transport and Holding Time

Sediment samples must be kept at a temperature of between 0° and 6° C from the time they are collected until they reach the laboratory. Samples should be transported in sealed coolers with ice and must be sent to the laboratory as soon as possible after collection.

Samples should also be kept out of direct sunlight. Colored or opaque sample containers should be used to minimize the exposure of the samples to sunlight.

The chain-of-custody and sample-labeling procedures for stormwater outlined in Section 10.7 must be followed for sediment sampling projects as well. Chain-of-custody procedures are critical for sample tracking, for communicating with the laboratory, and for the legal record.

When composite sediment samples are collected, the sample holding time begins when the last subsample is collected. Sample collection dates and times must be noted on the chain-of-custody form.

The project team must contact the laboratory before each monitoring event to notify them of impending sample delivery, including information related to the anticipated quantity of material to be delivered (number of stations and anticipated volume for each).

Analytical holding times for solid samples are different from the holding times for aqueous samples listed in Table 5-1 and can vary between analytical methods. Project planners must contact the laboratory before the monitoring phase of the project begins and determine what the appropriate holding times are for the required analyses. These must be listed in the project QAPP.

16.5 Laboratory Selection

When selecting a laboratory to perform chemical or microbiological analysis on sediment samples, the guidelines outlined in Section 5.2 should be followed. Tests for chemical constituents, such as metals, pesticides, and nutrients, and for microbiological constituents, such as total and fecal coliform, must be performed by a laboratory that has the appropriate ELAP or NELAP certification (see Section 5.2.1).

Toxicity testing must also be performed by laboratories with the appropriate certification. Because toxicity testing on sediment is not a normal part of the Caltrans stormwater monitoring program, choosing a toxicity laboratory may involve additional investigation on the part of the project planning staff. Project planners must discuss the requirements of the project with the toxicity laboratory before the project begins to make sure the laboratory can meet the study objectives.

Most of the laboratories Caltrans uses for stormwater monitoring are qualified to test sediment samples as well, but project planners must check before the project begins to make sure the laboratory is properly certified.

16.6 SEDIMENT SAMPLE ANALYSIS

Sediment that accumulates in Caltrans-operated facilities often contains material such as leaves and twigs, litter, and other non-sediment debris. When the study objective requires sediment analysis be performed, it is necessary to decide beforehand which components of a sediment sample will be analyzed and which components will be discarded.

For example, if the project objective is simply to determine the mass or volume of material that builds up in a conveyance over time, it would probably be appropriate to remove and weigh the entire sample, regardless of composition. On the other hand, if the purpose of the study were to characterize the degree to which sediment particles transport chemical compounds in stormwater, it would be necessary to separate the non-sediment materials from the sample before it is analyzed. Depending on what material needs to be removed, this could be done either by hand (picking out trash and debris), or by screening or sieving the sample through a device that traps the larger, unwanted material.

Sediment samples may be analyzed for physical, chemical, and biological characteristics. The following kinds of sediment analyses are discussed in this chapter:

- Weight
- Volume
- Grain size distribution
- Chemistry
- Toxicity testing

16.6.1 WEIGHT

Sediment samples can be weighed either by the monitoring consultant or by a laboratory. Samples should be weighed using an analytical scale with a capacity of at least five kilograms and be reported to the nearest gram. (This may vary depending on the project requirements and the nature of the sample.) Sediment samples should be thoroughly dried before they are weighed, and the results should be reported on a dry-weight basis.

When sediment is collected on filters or in bags, the weight of the filters or bags must be recorded before sample collection begins. After the sample has been collected, the entire filter or bag is sent to the laboratory where it is dried and weighed. The initial weight is then subtracted from the final weight to get the total weight of the sediment.

16.6.2 VOLUME

If the study objective is to determine how much sediment has accumulated over some specific period of time, it may be necessary to measure the volume of the sample. This can be done by selecting a container of known volume and then placing the sediment sample in it to determine how much of the container volume is taken up by the sample.

The container used to measure sample volume will vary depending on the size of the sample. Small volumes of sediment can be measured using a one-liter beaker. Larger volumes can be measured using a five-gallon bucket, 55-gallon plastic garbage can, or a similar container that is sized appropriately for the sample. Samples that are too large to fit in the container must be divided into subsamples that are measured individually; the subsample measurements are added together to get the volume of the entire sample.

Volume measurements using this technique are usually made at the monitoring site by field technicians. These kinds of measurements may be made in a laboratory but doing this work in the field is usually more efficient than transporting large amounts of sediment to an offsite location.

Volume measurements should be made on an as-collected basis, not on a dried sample. Volume measurements should be made soon after the samples are collected, preferably within 24 hours, so they do not have time to air-dry before analysis.

Accumulated sediment deposits are often so large, it is impractical to use the measurement method discussed in this section; in these cases it is necessary to measure the depth of the sediment, as described in Section16.4.2, and then use these measurements together with the known geometry of the sample area to estimate the sediment volume.

16.6.3 GRAIN SIZE DISTRIBUTION

Sediments are composed of grains of many different sizes, and it is often useful to characterize sediment in terms of the size distribution of the component particles. Knowing the sizes of particles that make up storm-borne sediments can be useful for designing BMPs; predicting turbidity and sediment loading that are contributed by stormwater runoff; and better understanding how constituents, such as organics, metals, and nutrients, are transported by particles carried in stormwater.

For Caltrans applications, particle size distribution is most often measured in solid samples using the sieve and hydrometer method.

16.6.3.1 Sieving (Screening)

This method involves passing the dried sediment sample through a series of wire mesh sieves with square apertures of decreasing, standardized sizes. As particles pass through the sieves, they are separated into various-sized fractions.

The smallest standard sieve has an aperture size of 20 microns, so the method is not useful for separating particles smaller than 20 microns. This method is used to size particles ranging from about 20 microns to about 127,000 microns (12.7 centimeters). American Society for Testing and Materials (ASTM) Method D-1498 is a recommended sieving and screening method.

16.6.3.2 Hydrometer

A hydrometer is an instrument that measures the density of liquids and can be used to determine grain size distribution when the grain sizes are too small for sieve analysis.

To perform this test, a dried sediment sample is suspended in water. The suspended material settles out of the liquid at a rate that is proportional to the diameters and densities of the particles, and as the particles settle, the density of the water changes proportionately. Because this density change is directly proportional to the rate of sediment settling, the particle size distribution can be calculated by measuring the change in the density of the water over time.

The hydrometer method is capable of quantifying grain sizes between one and 75 microns. ASTM Method D-422 is the recommended hydrometer method.

The sieve and the hydrometer methods can be combined to measure a range of grain sizes between one and 127,000 microns. Both methods express the results in terms of the mass of particles of a certain size as a percentage of the total mass of the sample. The results can be presented in both tabular and graphic format. Table 16-2 presents an example of tabular results for particle size distribution and Figure 16-5 shows the results in a graphical format.

Table 16-2 Tabular Results from a Sieve/Hydrometer Test

Grain size (microns)	Percent Finer than the Sieve Size		
	Sample #1	Sample #2	Sample #3
12,700	100	100	100
9,530	96.54	100	100
4,750	95.58	99.44	99.94
2,000	91.07	96.03	99.74
850	77.22	87.06	98.76
425	52.03	76.13	96.49
250	31.75	65.95	92.98
150	20.25	56.07	87.65
75	11.6	41.1	71.16
38	7.22	21.9	43.67
20	5.91	15	29.62
18	4.3	12.89	26.26
9	1.75	7	20.14
5	1	5.5	12.57
2	0.63	3.25	7.79

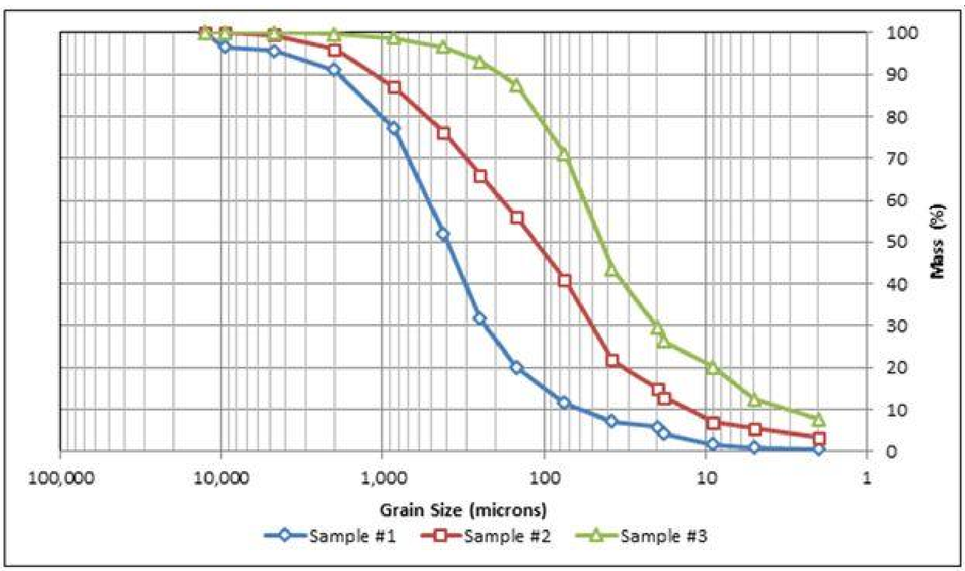

Figure 16-5 Graphical Results from a Sieve/Hydrometer Test

16.6.4 Chemistry

Sediment samples can be analyzed for many of the same kinds of chemical constituents that are found in stormwater. Metals, pesticides, petroleum compounds, and nutrients tend to adhere to the particles carried in stormwater, and the larger particles that settle out of stormwater discharges, and form accumulated deposits that can contain significant concentrations of these kinds of materials.

The sediment particles themselves may also be composed of materials that are of interest. This is particularly true of metals and organic carbon, both of which can make up a significant fraction of the mass of the accumulated sediment.

Laboratories may use either water methods that have been modified for use with solid samples, or analytical methods developed specifically for a solid matrix. This can vary among laboratories, and it is common for a laboratory to use a combination of these two approaches when analyzing sediment samples. Either approach is acceptable as long as the laboratory is accredited for every analysis they are required to perform. In cases where it is necessary to analyze sediment samples using a method that is not ELAP- or NELAP-accredited, this information must be communicated to the Caltrans Task Order Manager before the monitoring phase of the project begins.

Samples should be stored in the dark at 2^{o} to 4^{o} C. The holding times and detection limits used for water samples cannot be applied to sediment samples. Holding times are usually longer than for the same analyses in water samples, and reporting limits will invariably be higher. Sample holding times and analytical reporting limits may vary between laboratories based on what analytical methods are being employed, and it is necessary to obtain this information from each project laboratory before samples are collected.

16.6.5 Toxicity Testing

Toxicity testing is performed on sediment, either for disposal purposes or to characterize its effect on native biota. The toxicity testing methods discussed in Chapter 17 can be adapted for use with sediment samples. There are also sources of methodology for sediment toxicity testing (ASTM 2010, USEPA 1994, State Water Board, 2009).

Although the 36-hour holding time that applies to toxicity in water samples does not apply to sediment samples, the sediment samples should be transported to the laboratory as soon as possible after collection. Since the contaminants of concern and the influencing sediment characteristics are not always known a priori, it is desirable to hold sediments in the dark at 4°C and start tests soon after collection from the field. Recommended sediment holding time ranges from less than two (ASTM 1993) to less than eight weeks (USEPA-USCOE, 1994).

16.7 Data Validation

Several steps are important in reviewing sediment data after laboratory analysis and before data entry. The data validation steps covered in Chapter 13 should be followed.

16.8 Reporting

All field information, laboratory measurements, and quality control data should be reported. See Chapter 14 for guidelines on report formatting. There is currently no CEDEN-compatible template for reporting sediment data.

16.9 Training

Staff training for sediment sampling and analyses should be conducted following the guidelines presented in Chapter 9 and in accordance with the project specific QAPP. Field personnel should be trained regarding sediment monitoring preparation, sample collection and associated hazards, and sample delivery procedures.

17 TOXICITY

Many components of stormwater runoff and surface waters can have harmful (toxic) effects on aquatic animal and plant populations. Common stormwater runoff constituents include inorganic chemicals such as heavy metals and nutrients (various forms of nitrogen and phosphorous), synthetic organic compounds such as pesticides and petroleum hydrocarbons; physical factors such as pH, dissolved solids or turbidity; and biological factors such as bacteria and fungi; all of which may be harmful to aquatic species, when present in sufficient amounts.

Toxicity testing is used to determine to what degree a sample is toxic to live organisms. Many kinds of toxicity testing procedures have been developed for different applications. A standard protocol for testing of environmental waters is the whole effluent toxicity (WET) test, originally developed to test the toxicity of effluent from wastewater treatment facilities. This is the toxicity testing procedure Caltrans most often uses to test toxicity in stormwater, conforming with Clean Water Act requirements, as specified in 40 CFR 136.3 Table 1A.

Toxicity testing is considerably different from other kinds of water quality testing, such as chemical and microbiological analyses. Unlike most other laboratory tests that quantify the concentrations of individual chemical constituents in a water sample, a WET test measures the aggregate effect of the whole sample on a test species.

Toxicity testing is performed by exposing live organisms to an environmental sample and then measuring their responses in terms of chronic endpoints (sub-lethal effects such as growth or reproductive success) and/or the acute endpoint (mortality), in comparison to a laboratory control sample. In cases where a toxic effect is found in the sample, additional testing can be performed to determine the nature of the substance in the sample that is causing toxicity, typically through a toxicity identification evaluation (TIE).

Toxicity data are formatted differently than other kinds of water quality data, and adding WET testing to a monitoring project can involve additional logistical and sample-collection considerations for field crews.

The following topics are discussed in this chapter:

- Toxicity testing methodology

- Toxicity identification evaluations
- Quality assurance/quality control
- Project planning
- Field analyses
- Sample collection and transport
- Considerations for data reporting

17.1 Toxicity Testing Methodology

A toxicity test is performed by placing a test population of a specific aquatic or marine species in an environmental water sample for a predetermined period of time. Another population of the same species is placed in laboratory-prepared water that is known to be nontoxic; this is the control sample. Both populations are kept under controlled, favorable conditions for the duration of the test. At the conclusion of the test the toxicity of the sample is determined by comparing the ability of the test and the control organisms to survive, grow, and/or reproduce. Any harmful effects observed in the test population that are not observed in the control population are assumed to be caused by a toxic property of the sample.

The toxicity test can be performed in a variety of ways to produce different kinds of data. By varying test parameters, such as the number and type of organisms used, whether the sample water will be diluted, and the duration of the test, a toxicity test can be customized for specific project requirements. Toxicity data can also be expressed in several ways, depending on how the test is performed and what test species is used (see the discussion of endpoints, Section 17.2.7).

The specific variations on the WET test procedure are chosen based on the project objectives, the characteristics of the study area, or to satisfy specific regulatory requirements. The project requirements for toxicity testing should be discussed with the laboratory prior to the monitoring event so the laboratory has time to order test organisms and prepare the proper testing procedure. The WET test requirements then must be clearly communicated to laboratory staff upon sample delivery to the laboratory.

The following toxicity testing method parameters are discussed in this section:

- Test Duration – the planned length of time the test will be run prior to making final measurements, typically specified as a number of days. The test duration is specified by USEPA protocols depending upon test species, endpoint (acute or chronic), and sample matrix.
- Dilution – a toxicity test may be conducted on the “whole” (undiluted) sample, or on a sample of specified dilution, or on a series of samples of different dilutions (dilution series).
- Sample Matrix – refers to whether the samples are water or sediment samples, and are of fresh water (for example, a stormwater runoff discharge) or saltwater (estuarine water or seawater) origin.
- Test Organism – the species used for the test.
- Endpoint – the effect on test organisms being measured and reported, referred to as either acute (survival) or chronic (sub-lethal) endpoints.

17.1.1 Acute and Chronic Toxicity Tests

Toxicity testing can be divided into two types, depending on the specified endpoint (lethal or sub-lethal) of the test:

- Acute – The purpose of acute toxicity testing is to evaluate the toxicity of a sample with respect to the lethal endpoint, measured as percent survival of the test organisms. The standard indicator of toxicity in an acute toxicity test is therefore mortality (death of the test organisms).
- Chronic – The purpose of chronic toxicity testing is to evaluate toxic effects of a sample over a longer period of time than is allocated for an acute test, with respect to sub-lethal endpoints. The longer test duration is intended to expose test organisms to the sample for a period of time relative to their life cycle or during a sensitive life stage. This allows the laboratory to detect toxicity using sub-lethal indicators such as reduced growth or impaired reproduction. (Refer to Section 17.2.7 for a discussion of endpoints.)

Test duration for the acute or chronic test is the maximum amount of time test will be allowed to run prior to making final measurements. USEPA protocols define the required test duration depending upon the test species, acute or chronic endpoints, and sample matrix (water or sediment, fresh or saltwater). However, a test may finish prior to the specified test duration if a sufficiently strong toxic effect is observed. For example, if all of the test organisms in either an acute or chronic toxicity test were to die on the third day, the test would be ended.

The advantages of the chronic toxicity test are that it can provide information about sub-lethal toxic effects that might be caused by environmental samples, and that it may reveal a toxic effect that takes a longer period to manifest. The advantages of acute toxicity testing are that it is less expensive than chronic testing, and the relatively shorter exposure time might be more representative of the actual exposure of native organisms to stormwater runoff during storms.

The decision about whether to perform acute or chronic toxicity testing for Caltrans must be made during the planning phase of a project based on the study questions, the nature of the monitoring site, and any regulatory requirements must be satisfied.

It is sometimes possible to calculate an acute toxicity result from chronic toxicity data. This is possible because the laboratory makes toxicity measurements every day during a WET test. For some species, the data collected during the first 96 hours of a seven-day test allow the laboratory to calculate the acute test result. In cases where both acute and chronic data are required for a project, the laboratory must be consulted about this before monitoring begins. Using a single chronic toxicity test to calculate both acute and chronic test data will reduce analytical costs because the laboratory will only need to perform one test to obtain both results.

17.1.2 DILUTIONS

For wastewater treatment plants, WET testing has historically been performed by exposing one group of test organisms to an undiluted environmental sample and other groups of organisms to the sample that has been diluted to various concentrations. This is called testing a dilution series. A dilution series allows calculation of the degree to which a sample is toxic to the test species. If a high degree of toxicity is observed in the undiluted sample, it may not be possible to determine the degree of the toxic effect from that one test. If a dilution series is used, it is expected that the toxic effects of the sample will decrease as the sample is diluted, and observing this decreased toxic response provides insight into the degree of toxicity. Testing an undiluted sample answers the question, “Is the sample toxic to the test species?” But it may be necessary to analyze a dilution series to answer the question, “How toxic is the sample to the test species?”

The laboratory uses a standard synthetic dilution water to dilute a sample and create a dilution series. The dilution water (or control water) is prepared according to the analytical method (USEPA 2002b, USEPA 2002c, USEPA 2002d). Dilution water is made of deionized water or tap water known to be nontoxic, and the mineral content is adjusted to be similar to the sample water.

Depending on the kind of data required, the laboratory may perform a dilution series of 6.25%, 12.5%, 25%, 50%, and 100% sample concentrations for effluent samples. The observed toxic effects at each of these dilutions is recorded, and used to statistically derive a single, total value for toxicity (reporting convention for toxicity data is discussed in Section 17.8). To reduce costs, a laboratory may reduce the number of dilutions in the series from five to three. This is acceptable as long as the laboratory can be sure this approach will produce reliable data. If samples are collected from a monitoring site for which historical toxicity data are available, the historical data may be used to more accurately estimate what dilutions will be most effective.

In some cases, the WET test is performed only on an undiluted sample. If no toxic effects are observed in the undiluted sample, the sample is not toxic to the test species and no further work is necessary. This can be used as a screening test, because testing at only one concentration is substantially less expensive than testing a dilution series. If the undiluted sample exhibits toxic effects, it may be necessary to collect a fresh sample and repeat the test using a dilution series to determine the degree of toxicity in the sample. Testing only the undiluted sample is sometimes referred to as a screening test, while testing a dilution series is referred to as a definitive test.

In 2010, USEPA introduced a new statistical approach for calculating whole effluent toxicity in wastewater (USEPA 2010b). This new approach, called the test of significant toxicity (TST, Section 17.2), uses hypothesis testing to determine whether the behavior of test and control organisms differs by an unacceptable amount. This test can be performed using only an undiluted sample and produces data that can be used for regulatory compliance in many cases, as well as for screening purposes. The current Caltrans NPDES permit requires the results of all toxicity tests be reported using this method.

17.1.3 Sample Matrix – Fresh Water and Marine Water

Most samples collected for the Caltrans stormwater monitoring program consist of stormwater runoff from Caltrans facilities such as highways, parking lots, and maintenance yards. These samples are considered a freshwater (stormwater) matrix by environmental laboratories, which process and analyze them as wastewater. However, under certain circumstances, Caltrans also collects samples from estuarine and ocean locations, usually from sites that receive Caltrans stormwater runoff. These are marine water samples, which must be treated differently by the laboratory.

WET testing methods are similar for fresh water and marine water samples, but there are a few differences. Different organisms must be used for testing fresh water and marine samples; the freshwater species normally used for Caltrans stormwater samples cannot survive in seawater.

When the laboratory makes dilution water (Section 17.1.2), the process must be modified if seawater is the test matrix. Dilution water must be prepared with a salinity that is similar to the salinity of the sample. Laboratories bring the salinity of dilution water up to the level of seawater samples by adding a mixture of salts. There are several commercially available products to do this. They are made of natural seawater that has been dried into a solid mixture. Using this method, dilution water can be prepared that has the same salinity and mineral concentrations as natural seawater. When using organisms that are sensitive to the commercial sea-salt preparations, a laboratory may also alter the salinity of water using brine created from natural seawater.

17.1.4 Sample Matrix – Water and Sediments

Most toxicity testing performed for the Caltrans stormwater monitoring program involves testing of water samples, typically stormwater runoff from Caltrans facilities such as highways, parking lots, and maintenance yards. However, under certain circumstances, Caltrans may also collect sediment samples from catch basins, storm drainage systems, BMP installations, or other locations, and submit them for toxicity testing. Sediment samples must be treated differently by the laboratory, and the testing protocols (ASTM 2010, USEPA 1994, State Water Board 2009) and test species are somewhat different than those for water samples. The toxicity testing protocols described in this chapter focus principally on water testing. Refer to Chapter 16 for more information on sediment sampling and analyses procedures.

17.2 Test Organisms

Selecting the appropriate test species is one of the most critical factors when planning a toxicity testing program. Organisms used for toxicity testing by Caltrans are usually cultured specifically for that purpose, either by commercial scientific supply companies or by the laboratories themselves, under carefully controlled laboratory conditions.

Toxicity test organisms are often divided into three groups: vertebrates, invertebrates, and plants. Examples of these three types are shown in Figure 17.1. This division can be useful because these three kinds of organisms vary widely in their responses to toxicants. In many cases, a “three-species” approach is required for WET testing. This involves performing toxicity tests on one vertebrate, one invertebrate, and one plant species to obtain a multi-species profile of toxicity in the study area. The three-species approach is common in areas where the type and degree of toxicity are unknown. After some toxicity testing has been done in the study area, it is usually possible to determine which kind of organism is the most sensitive and then use that species for further testing.

When a three-species approach is required, there are three organisms that serve as the standard species for Caltrans stormwater projects; they are fathead minnow (Pimephales promelas), water flea (Ceriodaphnia dubia), and green algae (Selenastrum capricornutum). These are the three species that are specified in the analytical method (USEPA 2002a, USEPA 2002b, USEPA 2002c). In the absence of any other requirements, these are the species that should be used for toxicity testing of Caltrans samples. Another toxicity method adapted specifically for use on the West Coast specifies a much more extensive list of organisms, including topsmelt (Atherinops affinis), red abalone (Haliotis rufescens), Pacific oyster (Crassostrea gigas), mysid (Holmesimysis costata), sea urchin (Strongylocentrotus purpuratus), sand dollar (Dendraster excentricus), and giant kelp (Macroystis pyrifera) (USEPA 1995).

Figure 17-1 Examples of Toxicity Test Species

Source: Inland Fishes of New York (Online), version 4.0, Department of Natural Resources, Cornell University, and the New York State Department of Natural Conservation.

The current Caltrans NPDES permit requires chronic WET testing be performed on a single species as part of each stormwater monitoring event. Unless Caltrans directs otherwise, the species to be used for this test is Pimephales promelas, the fathead minnow. This organism was selected as the default species because it has been found to be the most sensitive of the three standard test species when exposed to Caltrans stormwater runoff (Caltrans 2005c).

There may be circumstances where other test species must be used. For example, because the permit requires Caltrans to comply with all local regulations, such as basin plans and TMDLs, testing on additional or alternate species may be necessary in some areas. In these cases, Caltrans may direct consultants to conduct background work at the study area in order to learn what toxicants are likely to be present, review applicable regulations, or to perform a literature search to determine what toxicity testing procedures have been used under similar circumstances in the past.

When selecting test species, the factors described below should be considered.

17.2.1 Regulatory Requirements

Before selecting species for toxicity testing, project planners should review the Caltrans permit and any local discharge permits, basin plans, or TMDLs to make sure the organism(s) selected for testing are satisfactory to regulatory agencies.

If the regulations that apply to a project specify which test organisms are to be used, then those are the species that must be used. The other species-selection criteria discussed in this section may be of use, but regulatory requirements take precedence over all other considerations.

17.2.2 Sample Matrix

Fresh water and marine samples require species be selected that are appropriate for the matrix. Marine organisms cannot live in fresh water and freshwater animals cannot live in seawater. Similarly, water sample testing typically requires different test species than sediment sample testing. The appropriate or required species are defined by the USEPA testing protocols for each matrix.

17.2.3 Sensitivity

Species must be selected that are sensitive to the kinds of toxic properties expected in the sample. Organisms can vary widely in their sensitivity to various chemicals and selecting a species with a low sensitivity to a suspected toxicant might result in data that are not representative of the study area.

Selecting appropriately sensitive species can be a challenge. If the nature of a suspected toxicant is known, then it is easy to find a species that is sensitive to it. However, it is more common that toxicity samples are collected from locations where no historical data are available, and where there are no obvious sources of toxicity. In these cases, project planners must research the study area to determine what kinds of toxic substances are most likely to be present.

Table 17-1 lists several toxicity studies that may be useful for this kind of research, but this list is not exhaustive. Documents like the ones listed in Table 17-1 should be reviewed during the planning stage of any monitoring project that involves toxicity testing, and test organisms should be selected based on their sensitivity to the kinds of toxicants that may be expected at the monitoring site.

Table 17-1 Stormwater Runoff Toxicity: Urban/Suburban/Mixed and Transportation

Reference	Land Use	Species	Test Type	Results/Suspected Toxicants
ToxScan (1992a,b)	Urban creek	*Ceriodaphnia*	Acute	Nonpolar organics, metals
ToxScan (1993b)	Urban creek and river samples	*Ceriodaphnia* *Pimephales* *Selenastrum*	Chronic	See ToxScan 1993a,c (TIEs performed for *C. dubia* only. Slight reduction in growth was observed for *P. promelas*, and *Selenastrum* showed no effects)
ToxScan (1992a)	Urban creek and river samples	*Ceriodaphnia* *Pimephales* *Selenastrum*	Chronic	TIEs were not conducted. *P. promelas* growth was affected in both river and creek samples. River and creek samples affected *Selenastrum* growth, creek samples were more toxic.
Medeiros et al. (1984)	Urban stream	*Pimephales*	Chronic	TIEs not conducted.
Caltrans (UC Davis, 1999)	Agricultural, urban, highway	*Ceriodaphnia* *Pimephales* *Selenastrum* *Oncorynchus*	Acute and Chronic	Diazinon (*C. dubia*), None identified (*P. promelas*)
CASQA (2013)	Urban surface waters and runoff	*Hyalella*	Acute and chronic	Widespread toxicity in urban water and sediment samples attributed largely to pyrethroid pesticides

No single species may be the most sensitive to all of the toxicants that could be present at a study location. Under certain circumstances it might be necessary to perform toxicity testing using two or more species in order to adequately characterize the study area.

Depending on the study plan and the available resources, it could be necessary to perform toxicity testing using a variety of test species to determine which species are most sensitive.

17.2.4 Consistent Response

Organisms should be selected that display a consistent response when exposed to toxic substances. Using organisms that do not respond consistently to toxicity may result in unrepresentative data. Toxicity laboratories are an excellent resource. Most laboratories have experience with a wide variety of organisms and can provide insight into which organisms are likely to give the most reliable results.

17.2.5 Applicability to the Study Area

If possible, test organisms should be selected that are indigenous to the study area, or are at least similar to indigenous species.

17.2.6 Historical Data

If toxicity data exist for a given study area, or for areas that may be comparable to the study area, it may be advisable to use the same kinds of test organisms used in the past if possible, to make the project data more comparable to historical data. This should be done with caution if the land uses and potential toxicants have changed over time in the study area.

17.2.7 Endpoints

The objective of toxicity testing is to determine the degree to which a whole water sample is toxic to the test species, and this is determined by measuring a response of a test organism when exposed to the sample. This response is referred to as the endpoint of the test.

Different test species may respond to toxicants in many different ways. However, for practical reasons, the responses of test organisms used for standard WET testing are limited to mortality, growth, and reproduction.

- Mortality (or the inverse, survival) is simply a measure of the number of test organisms that die during the test. Mortality is referred to as the lethal endpoint and is the common endpoint for acute toxicity tests.
- Growth is a measure of some aspect of the test organism's development during the test, and this is specific to the test species. For example, growth in fathead

minnows is defined as the increase in mass of the organisms. Growth in green algae is measured by counting the number of new cells produced. Growth in kelp is defined as the percent of zoospores with germination tubes at least one-spore diameter in length. Growth is referred to as a sub-lethal endpoint and is commonly applied in chronic toxicity tests.

- Reproduction is a measure of the impact on the organism's life cycle. The aspect of reproduction measured in a WET test is also species-dependent; for example, reproduction in water fleas is determined by counting the number of neonates produced by each female, and reproduction in echinoderms (an invertebrate) is expressed as the percentage of eggs fertilized. Reproduction, like growth, is referred to as a sub-lethal endpoint, and is commonly used in chronic toxicity tests.

The endpoints are usually evaluated by comparing the response of the test population to the response of the control population.

17.2.8 Pass/Fail Evaluation

WET test data are often evaluated by comparing the results of the environmental test replicates to the control sample replicates in a way that reduces the test result to one of two outcomes; either the sample is not toxic (passes) or toxic (fails). To calculate a pass/fail result, the response of the test and control organisms are compared statistically, and the test fails if the response of the test organisms in the sample is statistically different than the control response. For regulatory purposes, a result of "fail" means the sample is considered to be toxic.

The method of calculating pass/fail results for Caltrans stormwater samples is the test of significant toxicity (TST). The TST test was introduced by US EPA in 2010 (USEPA 2010b) and has largely replaced older statistical methods for calculating pass/fail WET test results. The TST method is specified in the Caltrans NPDES permit.

The Caltrans NPDES permit specifies all WET testing data be reported as pass/fail.

The State Water Board has created a Microsoft Excel-based tool for calculating TST-derived pass/fail results. This tool may be used to calculate pass/fail results from existing historical data in some cases. The tool may be downloaded from this link:

http://www.swrcb.ca.gov/water_issues/programs/state_implementation_policy/docs/tst_tool_v1_8.xls

This tool should only be used for historical data when the laboratory did not calculate TST results; TST results for new WET tests must always be reported as calculated by the laboratory.

17.3 Toxicity Identification Evaluations

The toxicity testing methodology discussed in Section 17.1 was developed to detect and quantify the toxic effects of environmental samples. However, these methods do not tell us why the samples are toxic, i.e., standard WET tests do not indicate what the toxicant(s) might be. To determine what properties of the sample may be causing toxicity, laboratories employ a second set of toxicity testing methods called toxicity identification evaluations (TIEs).

To identify what properties or substances are causing toxicity, the laboratory treats the sample in a variety of potential ways so that various known toxic properties are removed or enhanced, and then retests the sample. Depending on the degree to which various treatments remove or enhance the toxicity, investigators gain insight about what properties in the original sample are causing the toxicity.

The TIE test procedures discussed in this section can take a considerable amount of time to complete, and usually require a great deal of sample volume. In some cases, a thorough TIE test may require samples be collected and delivered to the laboratory over a period of weeks, or even months, so the laboratory can continue the test with fresh sample. A TIE is much more complicated than a normal WET test. TIEs must be planned in detail before testing begins, and the plan must be discussed in detail with the laboratory to make sure all of the details are clear before the sample-collection phase of the project begins.

TIE testing is performed in three phases:

- Phase 1 – Characterization
- Phase 2 – Identification
- Phase 3 – Confirmation

17.3.1 Phase 1 – Characterization

In Phase I of a TIE, the sample is treated to remove broad classes of potential toxicants. These treatments are performed to alter both physical characteristics, such as pH and solids content, and to remove various classes of known toxic compounds such as metals and harmful organics. The laboratory retests the sample after each of these treatments to see if the toxicity has been removed or reduced.

TIE methodology was originally developed to test municipal and industrial effluents, and some of the toxic materials that are included in the methods are not appropriate for stormwater. For example, chlorine and ammonia are two substances that are of interest when testing a wastewater treatment plant effluent but are not normally suspected of causing toxicity in stormwater discharges from Caltrans facilities.

The TIE methods allow laboratories wide latitude when selecting which kinds of toxic properties to investigate, and laboratories make this decision based on the nature of the sample. For Caltrans stormwater samples, the following treatments are usually employed:

- Aeration – Air is bubbled through the sample. Volatile compounds are carried away from the sample in the moving gas.
- Filtration – The sample is filtered to remove the majority of particulate material. This removes particulate-bound toxicants, as well as high concentrations of particulate matter that may be causing some degree of toxicity.
- Solid-Phase Extraction – The sample is run through a solid-phase column that removes nonpolar organic compounds. This treatment can also remove certain metals.
- Addition of EDTA – Ethylenediaminetetraacetic acid (EDTA) is added to the sample in small quantities. EDTA binds with certain cationic metals, which makes them unavailable for consumption and absorption by aquatic organisms.
- Addition of PBO – Piperonyl butoxide (PBO) blocks the action of metabolically activated organophosphate compounds (organophosphorus pesticides), and enhances the activity of pyrethroid pesticides.

17.3.2 Phase 2 – Identification

The second phase of a TIE is usually performed based on the results of the first phase. After one or more classes of toxicants have been identified in Phase 1, the laboratory then processes the sample to narrow down exactly what compounds or properties are causing the toxic response.

In some cases, this may be relatively straightforward. For example, if Phase 1 identifies metals as the source of the toxicity, the laboratory can simply perform an analysis for metals to identify which ones are likely causing the toxicity.

If Phase 1 identifies an organic material as the cause of toxicity, the problem can be more complicated. In this case, the sample is subjected to more specialized kinds of separation using media specific to certain classes of organic compounds. The laboratory may analyze the sample for wide ranges of potential organic compounds known to cause a toxic response in the test population. WET testing may be performed using different test species, which may yield clues as to what compound or compounds are causing the problem. Chromatography using a mass spectrometer may be used to identify organic compounds in the sample that are not part of standard test panels.

When Phase 2 of a TIE has been completed successfully, the laboratory should be able to state with a high degree of confidence which specific compounds or properties are the source of toxicity in the sample.

17.3.3 Phase 3 – Confirmation

If there is still uncertainty about the exact identity of the toxicant, the laboratory may conduct a third phase to confirm the results of Phase 2. Phase 3 consists of further analyses designed to verify the toxicants identified in Phase 2 are the source of the toxic response in the test population.

In practice, Phase 3 can often be considered as a kind of extension of Phase 2. Phase 3 testing can involve many of the same procedures used in Phase 2, but targeted for the specific toxicants that were identified in Phase 2. In other cases, different kinds of testing may be applied, including more detailed chemical testing. The US EPA methodology for Phase 3 TIE is written broadly to allow the laboratory to use their discretion and best professional judgment when developing a Phase 3 testing strategy.

17.4 Quality Assurance/Quality Control

There are several QA/QC checks that are performed internally by toxicity laboratories to assure data quality.

When the laboratory performs a WET test on a sample, they also perform the same test using synthetic control water (dilution water) prepared in the lab and known to be free of toxic substances. Testing this control population serves as a QC check to demonstrate that laboratory conditions do not cause any measurable toxicity, and provides a baseline of organism response against which to compare the environmental sample test results.

Laboratories also perform WET testing on control water that is fortified with a chemical that has a known toxic effect on the specific test organisms. This chemical, called a reference toxicant, is used to demonstrate that the test organisms are responding to toxic substances as predicted, and the laboratory is obtaining consistent, accurate results. According to the analytical methods, reference toxicant tests should be performed once per month. However, laboratories may opt to analyze reference toxicants more frequently.

Depending on the test species, WET testing is performed in replicate. Large variations in the response of test organisms are not expected between replicates. If replicate test populations do not respond similarly to the sample, the laboratory may suspect there is a problem with the test.

Water quality is monitored daily throughout every WET test to make sure the test environment remains healthy for the test organisms. Several water quality parameters must be kept within species-specific limits specified by the test method. These water quality tests are not ordered when submitting samples to the laboratory but are performed internally as part of the analytical method. The following water quality tests are typically performed to monitor test conditions:

- Temperature
- Dissolved oxygen
- pH
- Conductivity
- Salinity
- Total hardness
- Total alkalinity
- Total ammonia
- Total residual chlorine

Some or all of these tests may be used to check the testing environment, and they are selected depending on the kind of WET testing and the test species. Water quality tests are always performed at the beginning of the toxicity test, and at intervals throughout the test as specified in the method or at the discretion of the laboratory.

Like water chemistry analyses, WET testing data are validated by the CEDEN online data checking software before they are submitted to the state. Toxicity laboratories must flag qualified data with the correct CEDEN-compliant data qualifiers.

17.5 Project Planning

When planning a monitoring project that will include WET testing, the planning team must include at least one individual who has experience with monitoring projects that include toxicity. Although toxicity testing differs from other kinds of water quality analysis, from a monitoring perspective it is considered simply another analytical constituent on the project constituent list. Adding toxicity testing to a project does not change the project planning process discussed in Chapters 2 through 6. However, a few additional factors should be considered as discussed below.

17.5.1 Regulatory Considerations

The current Caltrans NPDES permit requires WET testing be performed at many discharge monitoring sites. The permit requires that one species be tested for chronic toxicity, and the results be reported as pass/fail using the TST statistical treatment (Section 17.2).

If alternate species are considered for a project, the project planners should consider what kinds of toxic substances could be expected to be present in stormwater runoff in the area. For example, in urban areas, pesticides, petroleum hydrocarbons and metals might be considered as probable sources of toxicity, whereas in rural farmland areas, pesticides and ammonia might be considered more likely to cause toxicity.

In addition to the water quality testing specified in the NPDES permit, Caltrans must also comply with local regulations. For example, Caltrans is subject to the prohibitions and requirements of the Regional Water Quality Control Plan (“Basin Plan”) in which a monitoring site resides. When conducting stormwater monitoring in coastal areas, Caltrans is also expected to comply with the requirements specified in the California Ocean Plan.

In some cases, TMDLs or other local regulations include a requirement for toxicity testing, and these local requirements may differ from the requirements listed in the Caltrans NPDES permit. In this case, project planners must review all pertinent regulations and design a toxicity testing plan that satisfies all regulatory requirements. Ideally, a single WET test can be found that satisfies all applicable regulations; however, if the regulations conflict, it may be necessary for Caltrans to perform more than one kind of toxicity test to satisfy all requirements.

When toxicity is included in a monitoring project that has been developed to test BMP performance, project planners should consider what kinds of toxic substances the BMP might remove, and where appropriate, design a toxicity testing strategy accordingly.

Toxicity data are reported electronically in the same CEDEN-compatible format as other kinds of water quality data (Section 13.1.2) but reported on a separate template and validated separately before being uploaded to the CEDEN system. The project planning team should be careful to communicate to the laboratory exactly what reporting requirements will be involved before the sample collection phase of a monitoring project begins.

17.5.2 Cost

Toxicity testing is one of the most expensive analyses that is performed as part of the Caltrans stormwater monitoring program. Laboratory costs are much higher for toxicity testing than for most other kinds of analyses. Reviewing laboratory reports can be fairly complicated, depending on the nature of the test, and this may also require extra hours for data reviewers.

When a project includes toxicity testing, project planners must keep these considerations in mind when developing the project budget.

As mentioned in Section 17.1.1, when both acute and chronic tests are required, the laboratory must be consulted to determine whether acute results can be calculated from chronic toxicity data. Using a single test when possible will cut down considerably on laboratory costs.

17.5.3 Site Selection

When selecting monitoring sites where samples will be collected for toxicity testing, care must be taken to choose sites that will produce enough sample volume for the test, even during small storms. Toxicity testing requires considerably more sample volume than most other analytical procedures, and this volume must be collected in addition to the sample required for the other tests. Monitoring sites that produce a small volume of sample during small storm events may not be acceptable for projects where toxicity testing is necessary.

Monitoring sites may be so remote that it will be difficult or impossible to transport large sample volumes to the laboratory in a short period of time. Samples must reach the laboratory relatively soon after they have been collected. In cases where multiple sites are being considered for monitoring, attention should be given to the logistics of sample transport. If a site is so remote or difficult to access under storm conditions that transporting large sample volumes might be a problem, the planning team should consider rejecting the site.

As with any monitoring project, sites selected must be free of run-on stormwater flow from non-Caltrans sources. This is always important, but project planners should be especially careful when collecting samples for toxicity. Caltrans may not be able to take the appropriate corrective action in cases where toxicity originates from a non-Caltrans source.

17.5.4 Monitoring Considerations

Samples for toxicity analysis are collected in the same way that other water quality samples are collected, as discussed in Chapter 11. Samples can be collected either as grabs or composites, either manually or with the use of automated equipment. But when WET testing is included as a project constituent, there are a few additional monitoring considerations.

The holding time for toxicity samples is very short. The test must begin within 36 hours of sample collection, so the samples must reach the laboratory no later than 24 hours after they have been collected. This may present a logistical problem because of the volume of sample involved; in many cases, 20 liters must be transported to the laboratory in this short time frame, which requires the field staff make special arrangements.

To transport toxicity samples to the laboratory, a field technician may drive them directly to the laboratory, or the field crew may use either a courier service or an overnight shipping company. If possible, the first option is preferable because the field team maintains custody of the samples and can guarantee they reach the laboratory in a timely manner. When this is not practical, one of the other options must be selected. This decision should be made during the planning phase of the project so clear guidance can be given to field personnel before each monitoring event.

The large sample volume required for most toxicity testing can add substantially to the weight of samples collected during a monitoring event. The project planning team should take this into consideration; field technicians must be assigned to each field crew who are physically able to safely lift and carry large volumes of water.

Collecting enough sample volume for toxicity testing is likely to require additional planning when monitoring stations are constructed. Additional monitoring equipment may be needed. Different sample containers may be required; for example, if samples are being collected into a plastic carboy for water quality analysis, it may be necessary to collect an additional sample volume in a glass container if pesticides are a suspected potential toxicant. These issues should be discussed during the planning phase of the project to make sure the monitoring equipment installed at each site is satisfactory for collecting toxicity samples.

WET tests are nearly always performed by laboratories that specialize in toxicity testing, so when samples are collected for both WET testing and other water quality analyses, the toxicity samples must be sent to a different laboratory. Before the sample collection phase of the project begins, the planning team must remember to contact one or more toxicity laboratories and make all necessary arrangements for sample receiving, analysis, data reporting, and billing.

17.6 Field Analyses

There are several analyses that should always be performed in the field when samples are collected for toxicity testing. This should be done at the same time grab samples are collected, or near the middle of the storm event when composite samples are collected (Section 11.2). The following field analyses will produce data that may allow data reviewers to more fully understand the water chemistry at the monitoring site, which can be useful when interpreting toxicity data.

- pH – pH is an important component in the water chemistry of any natural water body. pH can be a central factor in many chemical processes and knowing the pH of the water when the samples were taken can shed light on potential sources of toxicity.
- Temperature – Like pH, temperature can sometimes play a role in naturally occurring chemical reactions in water bodies and recording temperature may be of some use in understanding the water chemistry at the monitoring site. Additionally, test organisms are sensitive to the temperature of their surroundings

and recording the temperature at the site might help to explain toxicity that could occur in the field that is not reproduced in the laboratory.

- Hardness – The hardness of the water in a natural waterbody can have a profound effect on the toxicity of certain metals. Knowing the hardness of the water in the source waterbody can be critical when evaluating toxicity data.
- Dissolved Oxygen – Test organisms are sensitive to the level of dissolved oxygen in their surroundings. If dissolved oxygen is too low in the field, it may help to explain observed toxicity. Dissolved oxygen measurements may also be useful in helping data reviewers to more fully understand the water quality conditions in the study area.
- Conductivity – Conductivity is a rough measure of the dissolved solids in the region where the samples are taken, and like the other analyses on this list, may be of use in understanding the water chemistry at the monitoring site.
- Salinity – Analyzing salinity in the field is only required when collecting marine or estuarine samples for toxicity testing. These data must be reported to the laboratory when the samples are delivered; the laboratory may use these data to more closely match the test water to conditions in the field.

17.7 Sample Collection and Transport

Samples for toxicity testing are collected in the same way as most other samples for the Caltrans stormwater program. But because toxicity testing differs significantly from other kinds of water quality testing, there are a few additional steps field crews must take when toxicity testing is part of the project constituent list.

17.7.1 Sample Volumes

Toxicity testing can require a relatively large sample volume, depending on the species and testing protocol (acute vs. chronic). Unlike some other kinds of water quality testing, it is difficult, and often impossible, for a toxicity laboratory to complete the testing with a smaller sample volume than originally planned.

Table 17-2 shows the suggested minimum sample volumes required for the standard three WET species discussed in Section 17.2. Other species of the same types (vertebrate, invertebrate, and plant) may use the same or similar volumes, but volume requirements for some test species may vary considerably.

Table 17-2 Required Sample Volumes for Standard WET Tests

Test Organism	Acute Toxicity Minimum Volume (liters)	Chronic Toxicity Minimum Volume (liters)
Fathead Minnow	1.6	12
Water Flea	0.25	1.05
Green Algae	Not Applicable	1

17.7.2 Sample Collection

Samples should be collected in borosilicate glass carboys or other borosilicate glass containers, to allow for the possibility of both metals and organic compounds as toxicants. In this case, the carboys must be pre-cleaned by the analytical laboratory (can be the same lab that cleans the chemistry sampling equipment) before they are used. If a test species is used other than the three species listed in Table 17.2, the project planning team should check with the laboratory to determine if there are any special requirements for sample containers.

When samples for toxicity testing are collected as grab samples (Section 11.2.2), they should be collected directly into the carboy or other borosilicate glass container. Using an intermediary container, such as a lab bottle or bailer, has the potential to introduce contamination, and should be avoided if possible.

Composite samples are collected for toxicity testing as described in Section 11.2.7. When composite samples are collected manually, they should be collected directly into the carboy, if possible, to avoid using intermediary containers. The sample container must be kept on ice during the entire time the composite sample is being collected.

When an autosampler is used to collect samples for toxicity testing, the sample intake tubing, pump tubing, and strainer should be cleaned by the analytical laboratory before first use.

Because toxicity testing can require such a large sample volume, it is sometimes advisable to collect the sample using a dedicated autosampler. This approach is usually taken when the project constituent list includes other tests that require large volumes of water. For example, if a project requires not only WET testing, but also a full suite of pesticides, other organics such as PAHs, and a full list of inorganics, the sample volume requirement can exceed 20 liters, which is the standard size for a large autosampler carboy.

When dual autosamplers are used, it is important that their sample intake tubes are located as close together in the sample stream as possible to collect similar samples. It is also important that both autosamplers be triggered at the same time for each sample aliquot, so that the two samples collected are as identical as possible. To trigger two autosamplers simultaneously, a splitter is used that splits the trigger signal from a single flow meter. This is shown schematically in Figure 17.2.

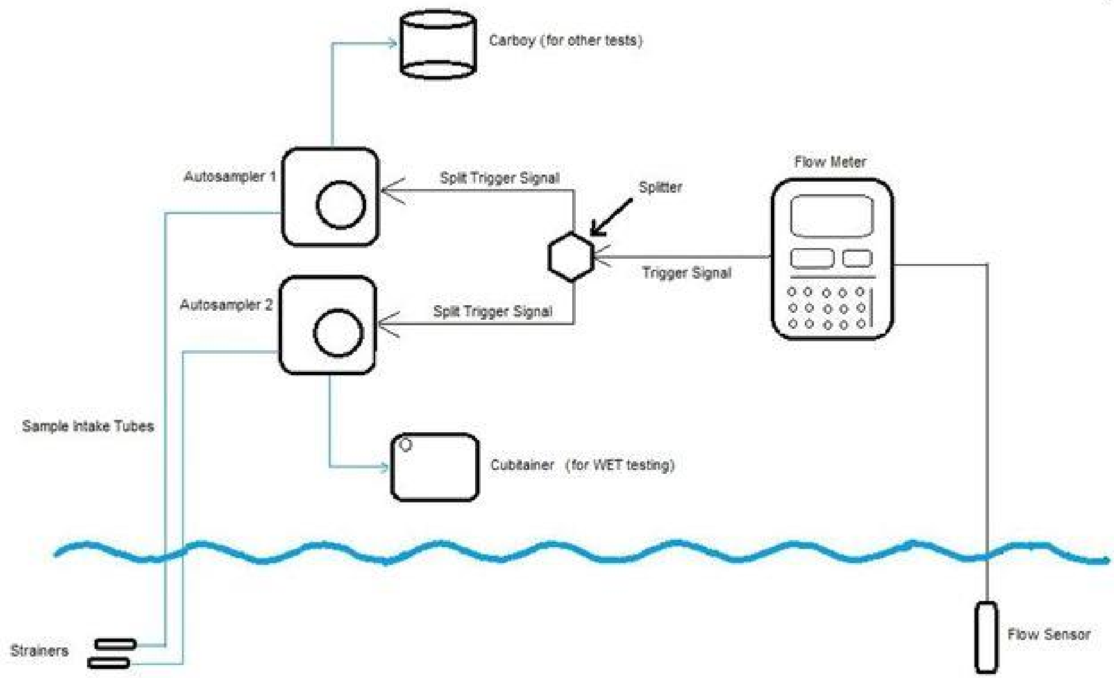

Figure 17-2 Schematic for Using Dual Autosamplers

Like other composite samples, the time at which the last aliquot of the composite is collected is designated as the collection time for the entire sample. Field technicians must keep this in mind so they can begin the process of transporting the sample to the laboratory as soon as possible after the last aliquot is collected, to ensure meeting sample holding times, even if other monitoring activities have not been completed.

Some Caltrans stormwater projects require seawater samples be collected from the surf zone on the beach. In this case, only grab samples are collected. When samples are collected from the ocean, it may not be practical to carry the entire carboy into the surf zone; in this case, an intermediary container must be used. A clean sample bottle may be used for this purpose. Intermediary containers should either be certified clean by the manufacturer or pre-cleaned by the laboratory before use. A separate intermediary container must be used for each sample site, to avoid cross-contamination.

To collect a sample from the ocean, a field technician wades knee-deep into the surf zone, submerges the sample container or intermediary container to fill it, and then comes back onto the beach. If an intermediary container is used, the technician fills it from the surf zone and then comes back on to the beach to transfer the aliquot into the carboy. It may be necessary to do this several times to obtain enough sample volume.

Collecting samples in the surf zone introduces safety concerns, particularly during stormy weather. Whenever a field technician enters the surf zone, he or she must be wearing a floatation device such as a life preserver. A rope must be tied around the technician's waist; the other end of the rope must be held securely by a second field technician who is standing on the beach, well out of the surf zone. The second technician must be physically strong enough to pull the person in the surf zone out of the water if there is any trouble.

For safety reasons, ocean samples may only be collected during daylight hours, never at night.

17.7.3 Sample Transport

Toxicity samples should always be shipped in coolers. When using a shipping company or courier, the coolers must be sealed with packing tape, duct tape, or custody tape, to make sure they are not tampered with during transport. The samples must be shipped on ice, and the coolers must be sealed thoroughly so they do not leak (shipping companies will not ship leaking containers).

When a third party is used for shipping, all transfers of custody are recorded on the COC form. A field technician relinquishes the coolers to the driver when they are picked up. When the samples reach the laboratory, the driver relinquishes them to laboratory personnel.

17.7.4 Field Quality Control

Although it is possible to send blank water to the laboratory for analysis, and to split samples in the field and send them to the laboratory as blind duplicates, Caltrans does not normally use these QC procedures when performing toxicity testing. The laboratory conducts a variety of internal QC checks, as discussed in Section 17.4.

17.8 Considerations for Data Reporting

Toxicity testing data are reported electronically in CEDEN format. Toxicity data are reported on a CEDEN template that is specifically designed for these kinds of data. As with other CEDEN deliverables, the electronic file is generated and populated in the laboratory and then completed and validated by the monitoring consultant prior to being submitted to Caltrans. This is discussed more fully in Section 13.1.2.

When reporting WET data, the following must be kept in mind:

- Data must be reported using the correct endpoints and units, in the CEDEN data format.
- CEDEN deliverables include a large amount of QA/QC data as well as the actual sample data. All records in the deliverable must be clearly marked so Caltrans can distinguish between sample data and supporting data such as lab blanks and water quality tests. If there is any ambiguity, the monitoring consultant must enter a note in the appropriate comments field that clarifies what the record represents.
- The monitoring consultant must not upload monitoring data to any state agency without prior approval from Caltrans. Under ordinary circumstances, completed and validated data files will be submitted via a file transfer system to the Caltrans Task Order Manager, who will then upload them to the appropriate state agency.

18 Trash Monitoring

Trash monitoring is a requirement of some local TMDLs. The language of the TMDL will determine what kind of approach is used for trash monitoring. This section discusses four approaches that can be used for Caltrans trash monitoring:

- Visual Trash monitoring
- Manual Trash monitoring
- Passive Unattended Trash monitoring
- Daily Generation Rate monitoring

Regardless of which method is selected, trash monitoring data shall be recorded and reported on a table in the format shown in Appendix A of the standard Caltrans QAAP Template (Appendix A is the Sampling and Analysis Plan).

18.1 Selection of Trash Monitoring Areas

Sites for TMDL trash monitoring shall be located at well-defined conveyances like pipes outfalls, drain inlets/outlets, overside drains, BMP inlet/outlets. Site selection for trash monitoring shall target trash generation areas like freeway on and off ramps shoulders, rest areas and park-and-rides, state highways in commercial and industrial land use areas, other freeway segments identified by maintenance staff, or trash surveys. General guidance for site selection is in Chapter 6 and 15.

Field teams will define each area to be monitored before the monitoring phase of the project begins. When a trash monitoring site is associated with an existing Caltrans stormwater monitoring location, the site will be identified with the Caltrans Station ID; if the trash monitoring location is not associated with any existing monitoring site, the location will be assigned a new Caltrans Station ID.

In addition to direct monitoring of trash discharge from conveyances, the areas in immediate vicinity of the site shall be included:

- Roadways: Trash monitoring shall include all parts of the roadway in the study area. Sites will encompass shoulder, median, on- and off-ramps, and any other locations within the study area that could collect trash. The monitoring area will consist of a stretch of roadway approximately 100 feet in length on either side of the sampling point for observation-only measurements. If trash is to be collected and a 100-foot stretch is not practical, a smaller area will be selected based on the best professional judgement of the field team in coordination with the Caltrans Task Order Manager.

- Inlets/Inserts: Trash monitoring at drainage inlets will be limited to an area directly adjacent to the inlet; ideally, a square or rectangle area approximately five feet from each edge of the inlet so the monitoring area is a large rectangle with the inlet at the center.
- Receiving Water: Trash monitoring area shall be a stretch along the waterbody that is approximately 100 feet length on either side of the sampling point for observation-only measurements. If trash is to be collected and a 100-foot stretch is not practical, a smaller area will be selected based on the best professional judgement of the field team in coordination with the Caltrans Task Order Manager. The monitoring area will encompass both the waterbody itself and any riparian area, shoreline, or bank area where trash can be expected to accumulate.
- Outfalls: Trash monitoring areas shall include all area that receives the outfall flow. For example, if the outfall empties into a basin, pond, swale, or other easily defined area, the entire outfall area will be used as the monitoring site, if possible. If the outfall drains into a ditch, creek, or river, the monitoring area will encompass the waterbody and banks from the point of the outfall to a distance approximately 50 feet to either side of the outfall (100-foot total area) for observation-only measurements. If trash is to be collected and a 100-foot stretch is not practical, a smaller area will be selected based on the best professional judgement of the field team in coordination with the Caltrans Task Order Manager. When defining monitoring sites in outfall areas, field crews will use professional judgement to make sure the area selected for monitoring best represents the area where trash is likely to be transported by stormwater flow.
- Parking Lots, Park-and-Ride areas: Trash monitoring will include zones that are representative of both the parking surface and the surrounding area. At these kinds of facilities, trash tends to accumulate in the region surrounding the actual paved area, so the surrounding area must be represented. Trash monitoring in these areas shall be a square approximately 100 feet around the sampling point for observation-only measurements. If trash is to be collected and a 100-foot

area is not practical, a smaller area will be selected based on the best professional judgement of the field team in coordination with the Caltrans Task Order Manager. Each monitoring site will encompass both paved parking area and surrounding land area in approximately equal proportions.

It is often necessary for field technicians to use their professional judgement when determining the location and boundaries of trash monitoring sites, using site-specific indicators such as debris-lines, high water marks, or other evident physical features of the study area. The selection process will be carefully documented for each site; field crews will take detailed notes and photographs of each site, and this information will be included in the QAPP.

A map of each monitoring site will be included in the QAPP, with the actual boundaries of the monitoring area clearly delineated using GPS coordinates. The description of each site must be detailed enough so that repeated monitoring events can be reliably performed in the same place.

As with any other kind of Caltrans project planning or site-selection, safety of field personnel is of primary importance. Before any prospective monitoring area is considered for the project, experienced field technicians and project managers will evaluate the site for safety; if there is any reason to believe project monitoring activities cannot be safely conducted at the site, the site will be rejected.

18.2 Visual Trash Monitoring

When making only visual observations of trash in the monitoring area, the trash is not removed, and no quantitative measurements are made. Using this method, a team of at least two field technicians performs a visual survey of the monitoring site and records their assessment of the amount of trash in the area. At least two field technicians will be dispatched to perform trash monitoring at each study site.

Observations are recorded both in field logs and with photographs. An assessment of trash at each site will be recorded using the following scale:

- None/Low: Little or no trash was observed in the study area. A “Low” amount of trash is defined as the amount of trash that the field technicians can pick up by hand in a minute or two.
- Medium: Some trash is observed scattered throughout the study area at first glance, but it does not dominate the area.

- High: Trash is observed scattered throughout the study area and accumulated in piles in some places. The trash in the area is clearly visible and dominates the appearance of the study area.
- Very High: Accumulated piles of trash dominate the study area, with a strong impression of unconcern for litter in the area.

These observations shall be recorded in field logs along with comments and observations made by the field team. Because of the somewhat subjective nature of observation-only trash monitoring, field technicians will take detailed notes at every site to record their observations and impressions. At least one photograph will be taken uphill and downhill of each trash sampling location during each event, and all photos will be labeled with a north arrow and be date- and time-stamped.

After each monitoring event, these field observations, notes, and photographs will be transcribed to an Excel spreadsheet. Photographs will be named using the nomenclature specified in Section 14.1, and photograph names will be referenced on the spreadsheet.

When conducting observation-only trash monitoring over multiple events, monitoring consultants will check with state, county, and municipal authorities in the area to verify there are no active trash-mitigation programs in progress that might affect the study site. Trash-removal efforts have the potential to skew the results of observation-based trash monitoring programs. For example, if three observations were made annually to monitor trash buildup along a stretch of highway, an Adopt-a-Highway program that removed trash between monitoring events without the monitoring consultant being aware would seriously impact the usability of the data.

18.3 Manual Trash Monitoring

Manual collection of trash consists of picking up the trash within the zones identified during site selection either by hand or with the use of a handheld instrument and measuring the weight and volume of the debris that has been collected.

The number of field personnel required to collect all trash from as study area will depend on the size of the area and how much trash is involved. Wherever possible, study areas should be sized so no more than three field technicians are required to collect all trash within the boundaries of the study site in a one-hour period.

All field technicians must wear protective clothing such as work boots, long pants, long-sleeve shirts, and work gloves. The field crew will traverse the site in a systematic fashion, walking the width and breadth of the monitoring site, picking up all trash as they go, and putting it in plastic trash bags.

When collecting trash from the monitoring site, field personnel will look under bushes and shrubbery, under logs and rocks, and in holes and crevices to make sure all trash in the area is collected.

When the field crew has finished collecting trash, the field team leader will walk the entire monitoring site and examine the ground for any trash that has been missed. Any remaining trash will be picked up and added to the trash bags that have been collected.

Field personnel may opt to pick up individual pieces of trash by hand; when collecting trash by hand, the technician will wear a double set of gloves consisting of latex or nitrile gloves inside, covered by leather or canvas work gloves outside. Trash may also be collected using tongs, shovels and pitchforks, and other kinds of grabbing implements that can be used to pick up trash. Under no circumstances shall field personnel sift through piles of trash by hand, or hand-collect sharp objects such as broken glass or needles.

18.4 Passive Unattended Trash Monitoring

Passive collection systems can be installed in drain inserts, outfalls, and other artificial conveyances, and are designed to trap trash that is transported by stormwater flow. Passive devices can be cleaned out after every storm event, giving trash monitoring results on a per-storm basis, or be left in place and cleaned out periodically throughout the storm season, which is useful for obtaining the total amount of trash generated at that site during the entire season.

Passive unattended trash monitoring requires the construction of collection systems that must be custom-built for particular monitoring sites. Passive trash collection systems will be constructed, operated, and maintained according to the guidelines in Chapter 15.

18.5 Calculation of Total Storm Year Trash Discharge Using Daily Generation Rate

Daily Generation Rate (DGR) is used in some TMDLs in Southern California to calculate annual trash discharges. DGR is the calculated average amount of trash deposited per day in the drainage area during the dry season. The DGR is used in calculations that quantify yearly trash discharge in a regulated area, which is compared to the interim and final Waste Load Allocations (WLAs) in that area.

In areas where this calculation is required, the Total Storm Year Trash Discharge will be calculated for each monitoring area by first calculating the Daily Generation Rate (DGR) and using the DGR to calculate the Trash Discharge.

To calculate DGR:

$$DGR = \frac{Weight_{dry\ season}}{30\ days}$$

Where:

DGR = Daily Generation Rate
$Weight_{dry\ season}$ = Total weight of trash collected in any 30-day period between June 22 and September 22

To calculate trash discharge:

$$\text{Storm Event Tash Discharge} = (\text{Days Since Last Sweeping} * DGR) - Weight_{event}$$

Where:

DGR = Daily Generation Rate
Days Since Last Sweeping = Number of days from the monitored storm event since the last street sweeping
$Weight_{event}$ = Total weight of trash recovered from the catch basins after the monitored storm event

Trash monitoring data will be reported on an Excel spreadsheet in this format. At least one photograph will be included for each monitoring station, and up to ten photos per station may be included.

18.6 Analytical Methods

The weight and volume of trash collected will be measured by the consultant. Measurements may be made in the field, or the trash may be transported to the consultant’s offices for analysis.

When all trash has been collected it will be transferred from the trash bags into 55-gallon plastic trash cans that have been graduated inside to measure volume in one-gallon increments. The trash can will be filled approximately one-half to two-thirds full and then rocked vigorously for a few seconds to make the trash settle in the can. The volume of trash in the can will be recorded to the nearest one-gallon. Then the can will be weighed, and the weight recorded to the nearest 0.1 pounds. This process will be repeated until all of the trash has been weighed and measured for volume. Discrete measurements of weight and volume and the totals for weight and volume will be recorded in field logs.

If necessary, this process will be modified to fit the conditions of the study area. For example, if there is very little trash in the study area, it may be more appropriate to measure the weight and volume of trash using a large beaker and measure volume in tenths of gallons. The field team leader is expected to use best professional judgement when modifying this procedure for individual field conditions. However, all weights will be reported in pounds and all volumes reported in gallons, regardless of the amount of trash collected.

The weight of trash may be taken on either a wet-weight or a dry-weight basis, or both, depending on the study requirements. Wet-weight measurements will be made on freshly collected trash that has not had a chance to dry. If dry-weight samples are required, trash samples must be spread out on a clean surface and left to dry for at least 24 hours before weighing. Weights of trash must always be reported as either wet- or dry-weight.

18.7 Trash Speciation

Trash-collection devices normally collect a mixture of litter and other manmade debris, vegetation, and sediment. Depending on the requirements of the project, it may be necessary to divide trash samples into separate components before measurements are taken. For example, when calculating the amount of litter that is discharged from a Caltrans facility, it is important to separate the litter component from the other components of the sample before measurements are taken.

In order to separate trash samples into their individual components, the trash is spread into a single layer on a flat surface such as a long table. Using rubber gloves, rubber aprons, and facemasks, field technicians pick through the trash manually and separate out the constituents of interest. The components required can be stored in large plastic trash cans or trash bags; the unneeded components are then discarded.

When separating trash components in this way, it is expected that some air-drying will occur during the process. Unless the trash speciation process is performed very quickly, it is not appropriate to report speciated trash samples on a wet-weight basis.

18.8 Trash Data Reporting

Monitoring data will be submitted after each monitoring event. Trash monitoring data for the season will be summarized in the end-of-season project technical memorandum.

The weight of trash may be reported on either a wet-weight or a dry-weight basis. If the trash is taken from a waterbody and weighed immediately, it will be reported as wet weight. Trash that is picked up from of the ground allowed to sit in a collection system and dry out for a long period of time will be reported on a dry-weight basis.

18.9 Post-Event Reporting

After the completion of every trash monitoring event, data from the field logs will be transcribed onto an Excel spreadsheet. Photographs of each event will be named in accordance with the nomenclature guidelines nomenclature specified in Section 14.1. These file names will be referenced on the Excel spreadsheet. At least one photo will be provided for each monitoring event at each location; up to ten photos per site may be submitted.

These materials will be submitted to the Caltrans Task Order Manager in a zip file that contains the following files:

- Excel data spreadsheet
- Event photos referenced on the Excel spreadsheet
- Photocopy of all field logs
- Any other files (maps, additional photos, documents) that the consultant believes may be useful

Caltrans operates an online file-sharing system called FILR. Zip files will be uploaded to FILR within 30 days of the end of the monitoring event.

18.10 End-of-Season Reporting

All trash monitoring data will be summarized in the annual end-of-season technical memorandum. All data spreadsheets submitted during the season will be included in electronic form on the document CD.

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Appendix A QUALITY ASSURANCE PROJECT PLAN TEMPLATE

This appendix contains a QAPP template with associated appendices. This template is intended to be used to create standalone QAPP documents that can be modified for most Caltrans stormwater monitoring projects.

The document contains entries that are to be changed to meet specific project requirements. These entries appear highlighted and in brackets. When using this document to create a new QAPP, fill in or delete these entries as necessary. Do not change any non-highlighted text without prior approval from your Caltrans Task Order Manager.

This document comes in the three sections:

- Main Document – including highlighted entries that must be either modified or deleted, depending on the requirements of the project.
- Appendix A – a Sampling and Analysis Plan (SAP) that contains all of the monitoring procedures normally used by Caltrans. Refer to this SAP when modifying the QAPP, but do not change any text in Appendix A.
- Appendix B – the set of equipment cleaning procedures normally used for Caltrans stormwater monitoring projects. Refer to this procedure when modifying the QAPP, but do not change any text in Appendix B.

This appendix is included in standalone form on the compact disc that accompanies this manual. The QAPP template is updated from time to time; the version of the template included in this document is the current version as of the date of publication. Before creating a new project QAPP, consultants should always check with the Caltrans Task Order Manager to make sure they have the most recent version of the template, and always use the latest version when preparing a new guidance document.

Appendix B CLEAN SAMPLING TECHNIQUES

During sampling operations, care must be taken to minimize exposure of the sample and sample collection equipment to human, atmospheric, and other sources of contamination. To avoid such sample contamination, clean sampling techniques are used when collecting samples and handling equipment during stormwater monitoring activities. The major components of clean sampling techniques are described in this appendix.

B.1 CLEAN SAMPLE AND EQUIPMENT HANDLING

Clean sampling techniques require at least a two-person sampling team. Upon arrival at the sampling site, one member of the sampling team is designated as “dirty hands”; the second member is designated as “clean hands.” Operations involving contact with the sample bottle, bottle lid, suction tubing; and the transfer of the sample from the sample collection device (if the sample is not directly collected into the bottle) to the sample bottle are handled by “clean hands” wearing clean, powder-free nitrile gloves. “Dirty hands” (also wearing clean, powder-free nitrile gloves) is responsible for preparation of the sampler (except the sample container itself), operation of instrumentation, and other activities that do not involve handling items that have direct contact with the sample. “Clean hands” will change into clean gloves frequently to ensure that the gloved hands contacting the sample container, container lid, and laboratory-cleaned sampling equipment have not contacted sources of potential contamination. When possible, a third team member should be present during monitoring operations to direct the team, review the monitoring plan, and complete the necessary sample documentation. Without a third team member, “dirty hands” must perform the sample documentation activities.

Although the duties of “clean hands” and “dirty hands” would appear to be a logical separation of responsibilities, the completion of the entire protocol may require a good deal of coordination and practice. For example, on projects where the sample containers come double-bagged from the laboratory, “dirty hands” must open the box or ice chest containing the sample bottle and unzip the outer bag; “clean hands” must reach into the outer bag, open the inner bag, remove the bottle, collect the sample, replace the bottle lid, put the bottle back into the inner bag, and zip the inner bag. “Dirty hands" must close the outer bag and place the double-bagged sample in an ice-filled ice chest.

B.2 Composite Bottle Changing

If an automated monitoring station is used for the collection of composite stormwater samples and a composite bottle change is required, use the following steps:

1. The automated sampling equipment is placed in pause mode (use caution not to place the equipment in the off mode) prior to the initiation of a composite bottle change. This action is accomplished in the field or by remote monitoring personnel if the monitoring station is equipped with telemetry.
2. Composite bottle changing requires two field crew members: "clean hands" and "dirty hands." Both team members wear clean, powder-free nitrile gloves. Suction tubing and Teflon® composite bottle lids will only be touched by "clean hands." Keep extra gloves within easy reach.
3. Prior to putting on clean gloves, the clean empty sample bottle is placed near the automated sampling unit.
4. Wearing clean, powder-free nitrile gloves, "clean hands" removes the lid from both the full sample bottle and the clean sample bottle.
5. "Clean hands" removes the end of the pump tubing from the composite bottle and "dirty hands" places a clean re-sealable bag over the end of the tubing, securing it with a rubber band. The inside of the bag must never be touched by sampling personnel.
6. "Clean hands" switches the bottle lids, putting the solid lid on the full bottle and the perforated lid on the clean empty bottle.
7. "Dirty hands" secures the lids on both bottles, removes the full bottle from the sampler, and replaces it with the clean empty bottle.
8. "Clean hands" holds the tubing while "dirty hands" removes the bag from the end of the pump tubing, being careful not to touch the tubing.
9. "Clean hands" inserts the tubing through the lid of the clean bottle.
10. The sampling equipment is placed in sample mode. Remote operation personnel are notified as soon as the bottle change is complete.

11. The sampling team fills out the appropriate information on the label of the full sample bottle.
12. The full bottle is surrounded with ice and secured inside the vehicle for transport.

Appendix C PREPARATION OF A HEALTH AND SAFETY PLAN

This appendix includes guidance on the components of a typical project Health and Safety Plan (HSP). HSPs are established using procedures authorized by the consulting firm's health and safety officer to provide direction on health and safety matters for the firm's employees. The procedures should be current with case law, new regulations, and emerging industry practices. Caltrans does not provide an HSP template for its monitoring projects; HSPs are specific to a firm and to the project the firm is executing. Therefore, the following information provides guidance on particular health and safety aspects as they pertain to stormwater monitoring projects. Each HSP should address the conditions specific to a project.

The following items should be addressed in the HSP:

- Assign a Health and Safety Officer
- Describe Field Activities
- Identify Potential Hazards
- Outline Health and Safety Precautions
- Document Health and Safety Training
- Develop an Emergency Response/Contingency Plan

Any Health and Safety Plan used for Caltrans projects should also comply with the requirements described in Chapters 7 and 8 of the Caltrans Maintenance Manual (Caltrans 2006b).

C.1 ASSIGN A HEALTH AND SAFETY OFFICER

A project health and safety officer should be assigned to oversee health and safety activities. The responsibilities of the health and safety officer include the following:

- Familiarize each monitoring team member with the requirements of the HSP and ensure personnel have received the necessary training.
- Ensure the information contained in the HSP is accurate and up to date.
- Implement the HSP, special safety considerations, and emergency response/contingency plan.

- Ensure field crews are never deployed without supervisor notification, including time of deployment and an approximate time the crews will be in contact with the supervisor.
- If required, alert appropriate emergency services before starting work and provide a copy of the emergency response/contingency plan to the respective emergency services.
- Record significant health and safety activities and incidents.
- Suspend work due to health- or safety-related concerns.

Health and safety activities that differ from those stated in the final HSP should be approved by the designated health and safety officer.

C.2 Describe Field Activities

Carefully review the stormwater monitoring program and list the field activities that will be involved. A stormwater monitoring program may include accessing and occupying monitoring sites in rural, residential, or industrial areas; lifting heavy or bulky equipment and other items; and handling stormwater samples; often under challenging conditions. The following sections describe some specific activities associated with stormwater monitoring and relate them to issues that must be addressed in the HSP.

C.2.1 Equipment Installation and Routine Maintenance

Flow meters, water samplers, and ancillary equipment may need to be installed or maintained depending on the objectives and scope of the monitoring program. Installation and maintenance of equipment is outlined in detail in Chapter 8.

C.2.2 Travel to and from Sites

Field crews will be required to drive to and from each monitoring site, often in adverse weather conditions and sometimes at night.

C.2.3 Establish Work Zone and Traffic Controls

Traffic may be of concern at some Caltrans sampling sites. Field crews working within traffic zones must follow the California Manual on Uniform Traffic Control Devices Temporary Traffic Control guidelines (Caltrans 2006a) as follows:

- If the workspace is in the median of a divided highway, an advance warning sign must also be placed on the left side of the directional roadway.

- The Workers (W21-1a) sign may be replaced with other appropriate signs such as the SHOULDER WORK sign, which may be used for work adjacent to the shoulder.
- The Workers (W21-1a) sign may be omitted where the workspace is behind a barrier, more than 600 millimeters (24 inches) behind the curb, or 4.6 meters (15 feet) or more from the edge of the roadway.
- For short-term, short-duration, or mobile operation, signs and channelizing devices may be eliminated if a vehicle with activated high-intensity rotation, flashing, oscillating, or strobe lights is used.
- Vehicle hazard warning signals may be used to supplement high intensity rotating, flashing, oscillating, or strobe lights.
- Vehicle hazard warning signals must not be used instead of the vehicle's high intensity rotating, flashing, oscillating, or strobe lights.

In the unlikely event that field sampling crews will need to establish a work zone and traffic controls, specific authorization and a separate permit would need to be obtained prior to storm event monitoring.

C.2.4 Opening and Closing Maintenance Hole Covers

Field crews may need to remove and replace maintenance hole covers. Maintenance hole covers should be removed and replaced using a specially designed maintenance hole hook. Maintenance hole covers must only be removed after the atmosphere inside the maintenance hole has been checked with an approved atmospheric testing device.

C.2.5 Flow Meter and Automatic Water Sampler Setup

Both the flow meter and automatic water sampler will need to be programmed and initialized before each storm. The location of the meter and the sampler will define the extent and types of dangers associated with initialization. Typically, the sampler is made operational from a keypad located on the sampler. The flow meter is made operational using a keypad, laptop computer, or remotely via telemetry. If the keypad is used, confined space entry may be required if the meter is located in an underground maintenance chamber, and vectors such as spiders should also be considered.

C.2.6 Remove and Replace Automatic Water Sampler

Replacing and servicing sample bottles in automatic water samplers located in maintenance chambers can be done by either removing the sampler from the chamber or entering the chamber itself. The sampler can be removed, and sample bottles replaced by using a cable harness as rigging for a lifting handle. (Full samplers can weigh 60 to 70 pounds.) Otherwise, sample bottles can be replaced and serviced following the confined space entry regulations outlined in Section C.3.1.

C.2.7 Manually Collect Grab Samples

Some projects may entail grab sampling using manual methods. In some cases, grab sampling can be accomplished by immersing the sample container into the channel. In other cases, a bailer or a beaker attached to a lanyard, pole, or other dipping apparatus may be required. In such cases, the sampler is lowered into the flow stream to collect the sample, which is then transferred into sample bottles.

C.3 Identify Potential Hazards

Before workers can be adequately protected, the field activities should be analyzed and the anticipated hazards to worker health and safety should be identified. The following subsections summarize the general classes of hazards expected to be present during stormwater sampling. The summary provided herein is not intended to be all inclusive; rather, it is intended to serve as a starting point for a site-specific analysis of the specific project.

C.3.1 Confined Space Entry

Storm drains are classified as “confined spaces” under Occupational Safety and Health Administration regulations. Regulations for entry into confined spaces are contained in 29 Code of Federal Regulations 1910.146 and 8 California Code of Regulations, Article 108, confined spaces. The regulations state that no person will enter a confined space without proper training and equipment. The risks associated with confined spaces include dangerous atmospheres, engulfment, falls, falling objects, and bodily harm due to explosion.

C.3.2 Vehicle Traffic

Traffic hazards may be a primary concern at most Caltrans sampling sites. These hazards are greatest during times of reduced visibility, such as during storm events and at night. The primary threats to workers associated with working in or alongside roadways are being struck by passing vehicles or being involved in a vehicular collision. The risks associated with these threats include severe bodily injury and/or death.

C.3.3 Open Maintenance Hole and Maintenance Hole Covers

Storm drain sampling sites are often located below grade, so maintenance holes must be opened during water sample collection and equipment maintenance activities. Opening maintenance holes requires the removal of heavy steel covers. Improper maintenance hole cover removal techniques can result in back injuries and/or crushed toes or feet. Specially designed maintenance hole hooks along with proper lifting techniques provide the easiest and safest way for removing maintenance hole covers.

Open maintenance holes pose a threat to workers and the general public. Limited visibility, inattention, poor site control, slips, and trips could result in a fall into an open maintenance hole. The risks of such a fall include minor to severe bodily injury and/or death.

C.3.4 Open-Water Hazards

High flows associated with storm events present a threat to workers. Slippery conditions, stream-side vegetation, and unstable stream banks could cause a worker to fall into a stream. The risks of such a fall include hypothermia, bodily injury, and drowning.

C.3.5 Biological Hazards

Potential biological hazards of concern include rodents, snakes, insects, and other site-specific animal hazards and pathogenic microorganisms (including viruses). The primary threats associated with these hazards are injury from bites and the contraction of diseases.

C.3.6 Chemical Hazards

Although most storm drains are not intended to contain hazardous materials, a potential exists for hazardous gaseous or liquid contaminants to be present as the result of roadway accidents, industrial runoff, illicit sanitary sewer connections, or illegal dumping of wastes. The presence of chemicals or chemical vapors may result in (but is not limited to) one or more of the following threats: toxic conditions, oxygen displacement, explosion, or fire. The risks associated with these threats include poisoning (acute or chronic), asphyxiation, and bodily injury.

C.4 Outline Health and Safety Precautions

The following provides an overview of safety precautions and protective measures typically used to minimize the hazards described in Section C.3.2. Remember, this guidance is general in nature; it is not comprehensive and is not a substitute for a detailed, site-specific evaluation, or established safety regulations (California Occupational Safety and Health Administration).

In addition to the items mentioned below, it should be noted that effective communication can enhance the health and safety of monitoring personnel. Cellular phones can be especially useful in this regard. If field personnel encounter unusual conditions or are unclear as to how to handle a given situation, they can contact their health and safety officer for guidance. Also, cellular phones can be used to summon help in the event of an accident or other emergency.

C.4.1 Confined Space Entry

Protective measures include use of atmospheric monitoring devices, portable ventilators, air-purifying respirators, and entrant retrieval systems. Other precautions include prohibiting entry to some sites during storms and erecting pedestrian barriers. Caltrans confined space entry standard operating procedures must be followed if it is necessary for personnel to enter a confined space for stormwater monitoring activities.

C.4.2 Physical Hazards

Field personnel should have the following personal protective equipment while working in the field:

- Hard hat
- Leather gloves (when working with maintenance hole covers, grates, and other related heavy objects, but not when handling samples or sampling equipment)
- Reflective traffic vest
- Appropriate footwear during dry weather activities (e.g., steel-toed boots)
- Rubber boots during wet weather activities
- Eye protection
- Rain gear (yellow overalls and hooded jacket with reflective tape) during wet weather activities

This list represents the minimum personal protective equipment. The site-specific hazards evaluation for each project may determine that additional equipment is warranted for some sites/activities.

C.4.3 Vehicle Traffic

Traffic must be controlled per existing Caltrans procedures (see the most recent version of the Caltrans Maintenance Manual, Chapter 7, Traffic Control, Safety, and Convenience of Traffic). Sampling personnel must be trained in proper traffic control, including precautions and installation and use of appropriate controls. To the extent possible, site visits should be scheduled for nonpeak traffic periods.

C.4.4 Open Maintenance Hole and Maintenance Hole Covers

Maintenance hole safety precautions include both handling the heavy covers and controlling access to maintenance hole openings. Maintenance hole covers must only be moved using a hole hook (also known as a puller hook); picks and crowbars are not acceptable substitutes. Puller hooks are designed not to slip out of the pick-up hole while moving the cover. Safe lifting practices must be used when working with maintenance hole covers. Controlling access to maintenance hole openings can be done by erecting barriers and assigning a crew member to act as lookout and warn people away.

C.4.5 Open-Water Hazards

The most effective precaution against open-water hazards is to conduct work from a safe location. Work conducted from a boat, on a shoreline, or from a bridge must follow open-water precautions. If access to the water's edge or open water is required, then a flotation vest and lifeline must be used.

C.4.6 Biological Hazards

To protect against bacterial and viral hazards, crews must avoid contact with stormwater samples. The use of clean, powder-free nitrile gloves when handling samples is recommended. Crews should wash hands with soap and water before handling food or drink. Animals encountered during sampling must be avoided.

C.4.7 Chemical Hazards

Hazardous chemicals in storm drains can be in three physical states – liquid, vapor, and solid. Precautions against the liquid and solid phases are similar to those described for biological hazards. Precautions against chemical vapors include use of air-purifying respirators and portable ventilators.

C.5 Document Health and Safety Training

Persons who engage in stormwater sampling should receive formal health and safety training. At a minimum, the project HSP should be presented and discussed in detail. This training should be recorded using an employee acknowledgment form. Additionally, regular safety meetings should be held during the project to review and update safety procedures. The meeting content and persons in attendance should be documented.

Additional training in confined space entry may be necessary. Confined space entry requires specialized training as described in 29 Code of Federal Regulations 1910.146 (or consult Caltrans existing standard operating procedures). The training should include identifying confined spaces, atmosphere monitoring, lock-out and tag-out procedures, retrieval systems, emergency response, and permit preparation. Persons entering a confined space must have documentation that they have received the required training.

Establish protocols to ensure that new members of the monitoring team receive the proper health and safety training. Also, the training program should include periodic “refresher” courses.

C.6 Develop an Emergency Response/Contingency Plan

An emergency response/contingency plan must be developed prior to sampling activities. The plan should include instruction and procedures for medical emergencies, fires/explosions, hazardous material spills, and site evacuations. Emergency conditions require concise and timely actions conducted in a manner that minimizes health and safety risks. Monitoring personnel should be familiar with the emergency response/contingency plan.

In most instances, the health and safety officer is responsible for assessing emergency situations and contacting the appropriate emergency services. If the health and safety officer is not available, emergency assistance should be contacted immediately. Personnel should have knowledge of basic first aid, be familiar with proper evacuation procedures, and have access to emergency numbers and routes to the nearest medical emergency facilities from each site. Emergency numbers should include the following: local police and fire department (911), closest hospital, county environmental health, and Hazmat team. When identifying the closest hospital, verify the hospital can provide emergency services.

Appendix D SAMPLE BOTTLE AND EQUIPMENT CLEANING PROCEDURES

Cleaning procedures for sample bottles and equipment must be established prior to sample collection in the field or sample storage in the laboratory. Tubing, lids, and strainers may contact the sample during collection; therefore, they must also be cleaned and dried using the appropriate procedures. Procedures for drying equipment and containers can vary depending on the samples being collected and must be discussed with laboratory personnel prior to sample collection. In addition, while performing these procedures, personnel must use the correct equipment and safety gear.

The following examples outline cleaning procedures that may be used by the laboratory for polyethylene plastic composite carboys, borosilicate glass composite carboys, and tubing and strainers. Appropriate safety precautions and quality control are also discussed.

D.1 CLEANING PROCEDURES

D.1.1 POLYETHYLENE PLASTIC CARBOYS

1. Clean inside composite carboy and cap with hot tap water and phosphate-free laboratory detergent. Scrub inside of carboy and cap with plastic brush.
2. Rinse carboy and cap twice with hot tap water.
3. Rinse capped carboy three times with 100 mL hexane, rotating carboy to cover entire inside surface and cap.
4. Rinse capped carboy once with 500 mL de-ionized water.
5. Rinse capped carboy three times with 200 mL 2N nitric acid.
6. Rinse capped carboy four times with 500 mL de-ionized water.

Notes:

1. If composite sample containers will not be cleaned the same day they are received by the laboratory, they must be emptied and rinsed thoroughly with hot tap water. Dirty containers must never be allowed to dry out without being rinsed.
2. The plastic brush used to clean carboys must be dedicated to the project. The brush must be stored with the brush head in a clean re-sealable bag.

3. The laboratory must use the same reagent-grade nitric acid for cleaning carboys as it routinely uses for metals digestion. Laboratory de-ionized water must meet American Society for Testing and Materials Type 1 standard.
4. Clean, powder-free nitrile gloves must be worn while cleaning carboys and handling cleaned carboys.
5. The technician must take care to rotate the composite sample carboy completely during each step to ensure the entire inner surface of the carboy is rinsed.
6. The technician must be alert for composite carboys that do not appear to have a completely clean, unblemished inner surface. If a carboy appears to contain contaminating material that has not been completely removed by the cleaning process, or has visible scratches on the inner surface, it must be set aside, and the laboratory must notify the client.
7. Do not store rinsed/cleaned carboys uncapped.

D.1.2 Blank-Testing Protocol for Polyethylene Carboys

A minimum of one composite sample carboy per cleaning batch must be blank-tested. A batch is defined as no more than 20 carboys, and may be fewer, at the laboratory's option. A new cleaning batch must be opened each time a new manufacturer's lot of methylene chloride or nitric acid is used. A cleaning batch may not span a period of greater than four days. The following protocol should be used for blank-testing of polyethylene carboys:

1. Fill a cleaned composite sample container with the minimum amount of de-ionized water necessary to perform the required analyses.
2. Rotate capped carboy several times to ensure the blank water comes into contact with the entire inner surface of the carboy.
3. Allow the blank water to stand in the composite sample carboy for a minimum of one hour.
4. Decant the blank water and test for analyses on the blank-test requirements list.

Table D.1 is a list of constituents that would be blank-tested on a typical Caltrans project. This is an example only. The actual requirements for blank-testing will vary from project to project, depending on the project constituent list.

Table D-1 Example of a List of Constituents to Blank-Test

Blank-Test Constituent List	
Metals (Total)	**Physical and Aggregate Properties**
Antimony	Conductivity
Arsenic	pH
Beryllium	Total Suspended Solids
Cadmium	Total Organic Carbon
Chromium	**Organic Compounds**
Copper	Polynuclear Aromatic Hydrocarbons
Lead	Organochlorine Pesticides
Mercury	Organophosphorus Compounds
Nickel	**Nutrients**
Selenium	Nitrate as Nitrogen
Silver	Total Phosphorus
Thallium	Ammonia as Nitrogen
Zinc	

D.1.3 Borosilicate Glass Carboys

The following steps are to be used to clean borosilicate glass carboys.

1. Clean inside the composite carboy and cap with hot tap water and phosphate-free laboratory detergent. Scrub inside the carboy and cap with plastic brush.
2. Rinse the carboy and cap twice with hot tap water.
3. Rinse capped carboy three times with 100 mL methylene chloride, rotating carboy to cover the entire inside surface and cap.
4. Rinse the capped carboy once with 500 mL de-ionized water.
5. Rinse the capped carboy three times with 200 mL 2N nitric acid.
6. Rinse the capped carboy four times with 500 mL de-ionized water.

Notes:

1. If composite sample containers will not be cleaned the same day they are received by the laboratory, they must be emptied and rinsed thoroughly with hot tap water. Dirty containers must never be allowed to dry out without being rinsed.
2. The plastic brush used to clean carboys must be dedicated to the project. The brush must be stored with the brush head in a clean re-sealable bag.
3. The laboratory must use the same reagent-grade nitric acid for cleaning carboys as it routinely uses for metals digestion. Laboratory de-ionized water must meet American Society for Testing and Materials Type 1 standard.
4. Clean, powder-free nitrile gloves must be worn while cleaning carboys and handling cleaned carboys.
5. The technician must take care to rotate the composite sample carboy completely during each step to ensure the entire inner surface of the carboy is rinsed.
6. The technician must be alert for composite carboys that do not appear to have a completely clean, unblemished inner surface. If a carboy appears to contain contaminating material that has not been completely removed by the cleaning process, or has visible scratches on the inner surface, it must be set aside and the laboratory must notify the client.
7. Do not store rinsed/cleaned carboys uncapped.

D.1.4 Blank-Testing Protocol for Borosilicate Glass Carboys

A minimum of one composite sample carboy per cleaning batch must be blank-tested. A batch is defined as no more than 20 carboys and may be fewer at the laboratory's option. A new cleaning batch must be opened each time a new manufacturer's lot of methylene chloride or nitric acid is used. A cleaning batch may not span a period of greater than four days. The following protocol may be used for blank-testing of borosilicate glass carboys.

1. Fill a cleaned composite sample container with the minimum amount of de-ionized water necessary to perform the required analyses.
2. Rotate capped carboy several times to ensure the blank water comes into contact with the entire inner surface of the carboy.

3. Allow the blank water to stand in the composite sample carboy for a minimum of one hour.
4. Decant the blank water and analyze it for all constituents in the project blank-test list.
5. Analytical results for the blank must be below project RLs. If analytes are found in the blank above the RL, composite sample containers in the cleaning batch must be cleaned and tested again before being released back to the client.

D.1.5 Cleaning Procedure for Tubing and Strainers

The following steps are to be used to clean sample tubing and strainers.

1. Make up cleaning solution with two percent phosphate-free laboratory detergent in hot tap water.
2. Rinse inside tubing with cleaning solution three times. Wash strainers in cleaning solution and scrub using a plastic brush.
3. Rinse inside tubing and strainers three times with hot tap water.
4. Rinse inside tubing and strainers with 2N nitric acid.
5. Soak equipment that does not have exposed metal surfaces for 24 hours in 2N nitric acid.
6. Rinse inside tubing and strainers three times with de-ionized water.
7. Seal tubing at both ends with latex material.
8. Individually double-bag each tube in new polyethylene bags. Individually double-bag each strainer in new re-sealable bags.

Notes:

1. Clean, powder-free nitrile gloves must be worn while cleaning and handling tubing and strainers.
2. The technician must be alert for pieces that do not appear to be completely clean. If a piece appears to have contaminating material that has not been completely removed by the cleaning process, it must be set aside and the laboratory must notify the client.
3. Tubing and strainers must be stored double-bagged.

D.1.6 Blank-Testing Tubing and Strainers

On a seasonal basis, after completion of equipment cleaning and prior to sampling, the tubing and strainers must be blank-tested by the field personnel. The de-ionized water (American Society for Testing and Materials Type 1 standard) and sample bottles used in collection of the blank sample must be supplied by the laboratory performing the analysis. Generally, the blank samples can be developed by purging two liters of laboratory-supplied water through the tubing and strainer into a laboratory-supplied carboy (the amount of water is dependent on test requirements). Upon completion of the blank sample collection, the bottle must be sealed and stored between 0° and 4°C for shipment.

The blank sample must be analyzed for the constituents on the project blank-test list. Concentrations from the blank sample must be compared to the blank acceptability criteria (project specific RLs). If the blank exceeds acceptability criteria, then the tubing and strainers must be cleaned and tested again prior to sampling. Blank samples must be assessed at a frequency of one carboy per cleaning batch and used to isolate potential problems associated with the cleaning and installation procedures. As an alternative, the laboratory may blank-test the tubing immediately after cleaning it and before releasing it for installation.

D.2 Safety Precautions

The appropriate personal protective equipment must be worn by personnel involved in the cleaning procedures due to the corrosive nature of the chemicals being used to clean the carboys, tubing, and strainers. The personal protective equipment must include protective gloves, laboratory coats, chemically resistant aprons, goggles with side shields, and respirators. Material safety data sheets must be read and understood by personnel.

D.3 Quality Control

Clean, powder-free nitrile gloves must be worn while cleaning and handling bottles and equipment. Care must be taken to avoid the introduction of contaminants from outside sources.

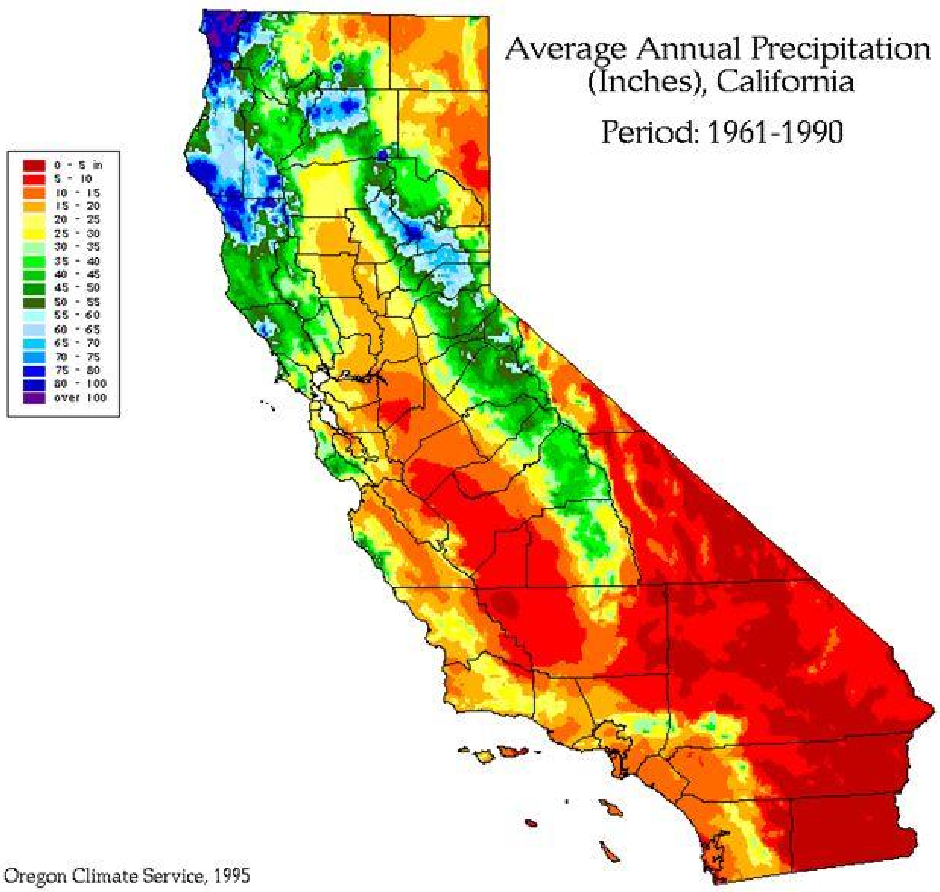
To account for contamination introduced during sample collection, blank samples must be prepared and submitted “blind” to the laboratory. Collection of sample container blanks is not required if certified pre-cleaned sample bottles are used. In this case, the manufacturer provides a certification form that documents the carboys are "contaminant-free"; however, these concentrations must be equivalent to or less than the project-specific RLs. If the certification level is above the project-specific RLs, a minimum of one blank sample per batch (a batch is defined as no more than twenty sample bottles, and may be fewer at the laboratory's option), must be prepared and analyzed for chemical constituents specified in the QAPP or Operation, Monitoring, and Maintenance Plan. The results must be less than or equal to the project specific RLs before that batch of bottles may be used on the project.

Appendix E WEATHER TRACKING

This appendix provides general information on California's climate and weather information sources that are used to forecast weather and track storms, as well as guidance on tracking storms by utilizing project-specific storm selection criteria and weather forecasting tools. Weather information sources include the National Weather Service (NWS), a federal agency, and local ALERT systems. In addition, custom forecasting can be obtained from a private weather forecasting service. This type of service is available on an as-needed basis just prior to and during monitored events. Major components of weather tracking are described below.

E.1 CALIFORNIA CLIMATE

California weather is generally characterized by a wet season (i.e., October first through April 30th) and an extended dry season (i.e., late spring through early fall). Annual average rainfall ranges from less than five inches in desert areas of southeastern California to over 40 inches in northern coastal areas (Table E-1). For example, the highest average annual precipitation in California was reported as 104.18 inches in Honeydew, while the lowest average annual precipitation on record was 2.25 inches in Death Valley. Valley and coastal areas receive virtually all their precipitation as rainfall and rarely receive snow, while mountainous areas typically experience abundant snowfall, particularly at higher elevations. Table E-1 provides information regarding California climate extremes.



Desert Research Institute. 2008. http://www.wrcc.dri.edu/htmlfiles/state.extremes.html

Figure E-1 Average Annual Precipitation in California

Table E-1 California Climate Extremes

Climatic Factor	Value	Year	Location
Record Highest Temperature (^{o}F)	134	7/10/1913	Greenland Ranch
Record Lowest Temperature (^{o}F)	-45	1/20/1939	Boca
Highest Average Annual Temperature (^{o}F)	76.3	1/7/1944	Death Valley
Lowest Average Annual Temperature (^{o}F)	27.4	1/20/1937	White Mountain
Consecutive Days Max >= 90	205 days	Apr-Oct 1992	Death Valley
Consecutive Days Min <= 32	265 days	Sep 72-May 73	White Mountain
Record Maximum Annual Precipitation (inch)	153.54	3/23/1905	Monumental
Record Minimum Annual Precipitation (inch)	0	4/12/1905	Death Valley
Record Maximum 24-hour Precipitation (inch)	26.12	22-23 Jan 1943	Hoegees Camp
Highest Average Annual Precipitation (inch)	104.18	4/8/1905	Honeydew 1 SW
Lowest Average Annual Precipitation (inch)	2.25	5/19/1905	Death Valley
Consecutive Days with no Measurable Precipitation	468 days	Aug 55-Jan 57	Ocotillo

The vast majority of storm systems approach California from the Pacific Ocean. Storm tracks tend to follow the jet stream, a high altitude, high speed wind current that moves generally from west to east around the globe. The most common storm track for weather approaching California begins with low-pressure systems that originate in the Gulf of Alaska and follow the polar jet as it bends southeasterly towards California during winter months. These systems produce snow, but very rarely produce snow west of the Sierra Nevada mountain range, except for the higher elevations of the Coast Range and Cascade Range. East of the Sierra Nevada (at elevations of 4,000 feet or greater), most winter precipitation falls in the form of light snow.

E.2 WEATHER INFORMATION SOURCES

E.2.1 NATIONAL WEATHER SERVICE

The NWS is a primary source of weather information for public and private sector forecasters. NWS collects and processes satellite imagery and other atmospheric data, and runs the major weather forecast models. Models are available for near-term (one to two days), medium range (three to five days), and long-range forecasting. Model reliability and specificity decline with extended time periods. The model output can be used to indicate potential candidate monitoring events up to one week in advance; however, at that time interval, the model predictions are useful only as an approximate indication of the likelihood of a precipitation event.

NWS forecasters, as well as web-based providers, private contractors, and news media (television) forecasters, use the model outputs together with other meteorological data (e.g., satellite and radar imagery, water vapor/atmospheric pressure/temperature data, etc.) to make their predictions. The NWS makes its forecast predictions available to the public. The NWS forecasts are produced every 12 hours (at approximately 9:00 am and pm), along with a written discussion of model output and weather observations. These discussions are meant for a professional meteorological audience, and are highly abbreviated and cryptic; however, they often provide insight into the basis for the published forecast. The following web-based forecast services analyze and repackage NWS feeds into user-friendly formats:

http://www.accuweather.com/

http://www.weather.com/

E.2.2 National Weather Service Tools

The NWS offers several tools for weather forecasting and tracking. Weather tracking information includes storm start and end times, quantitative precipitation forecasts, and probability information. These tools are described below and are illustrated in Figure E-2 National Weather Service Weather Forecasting and Storm Tracking Tools.

- Area Forecast – Provides a weekly summary of predicted weather conditions including the percent chance of precipitation.
- Point Forecasting – Weather forecasting points provide weather information for points on a grid with grid points located every three miles. These points provide a more accurate forecast than station forecasts located at local airports.
- Forecast-at-a-Glance – This forecast provides short one- to three-word forecasts for locations throughout the NWS monitoring network. These are not as detailed as other forecasts.
- Hazardous Weather and the Detailed Forecast – Provides hazardous weather watches, warnings, advisories, and outlooks for locations as well as full text forecasts for a seven-day outlook.
- Current Weather Conditions – The most useful feature of this forecast is the hourly, three-hourly, and six-hourly rainfall totals.
- Doppler Radar and Satellite Images – Provides thumbnail images of the area of interest, from local Doppler radar, and an overview of infrared Geostationary Operational Environmental Satellite images. Doppler radar is advantageous because it tracks changes in the storm cell to give a “real-time” image of how the storm is evolving or downgrading. One limitation of Doppler radar is that sometimes images come through as continuous storm cells but may contain “holes” or areas where precipitation has broken up and is not as strong as shown on the Doppler image. Alternatively, non-precipitation features (e.g., migrating birds) appear to be precipitation features on the Doppler image.

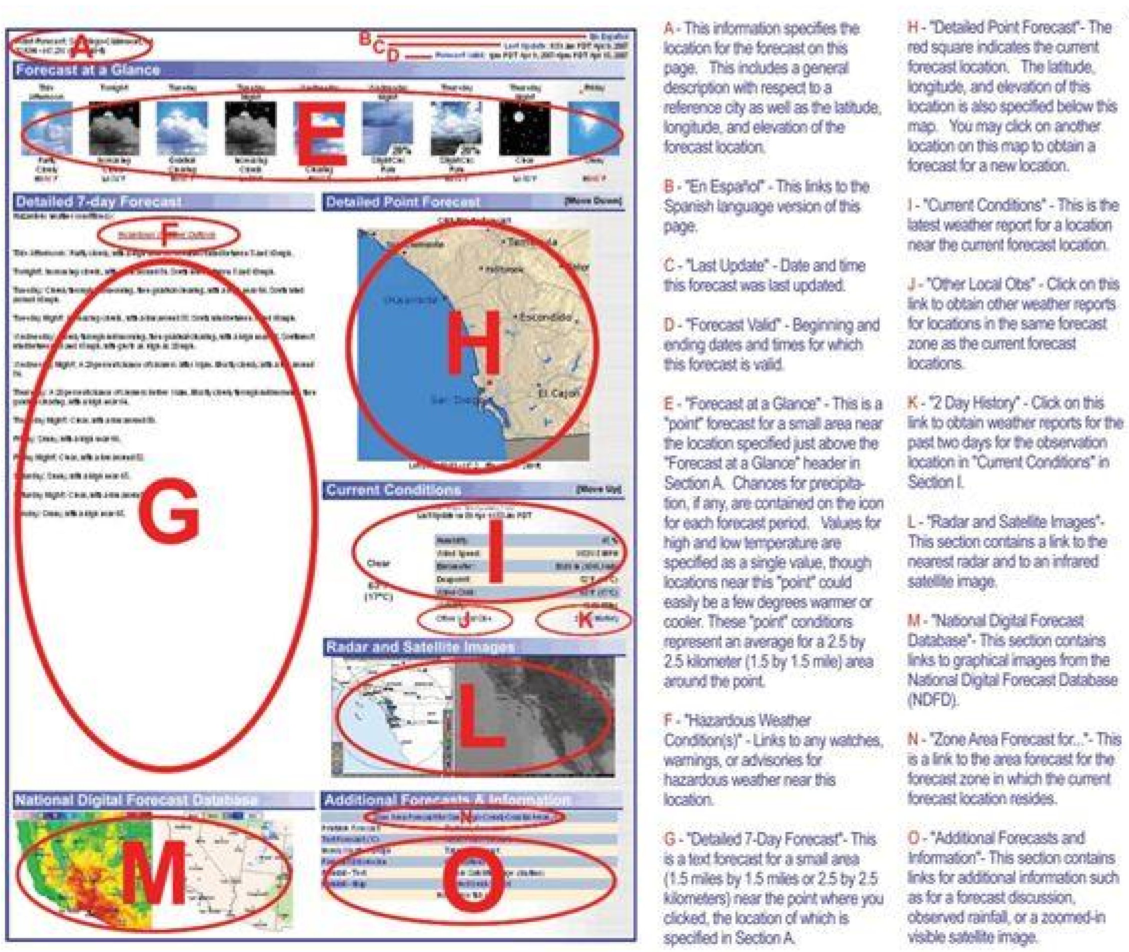


Figure E-2 National Weather Service Weather Forecasting Tools

E.2.3 PRIVATE WEATHER FORECASTING SERVICES

Private weather forecast services can be found by conducting a search on the internet. Most private forecast services will provide semiweekly written forecasts and 24-hour availability for telephone consultation. California weather forecast services include:

- Weather States Weather Service
- Weather Network
- Fox Weather, LLC

E.3 Tracking Storms

E.3.1 Storm Selection Criteria

Pacing samplers and mobilizing sampling crews are only a few of the reasons why weather tracking is a critical component for Caltrans stormwater monitoring projects. Tracking storms requires establishing storm selection criteria and then using these criteria while following the field deployment flow chart (Figure 10-4). Storm selection criteria are defined in the project-specific Operations, Maintenance, and Monitoring Plan. As an example, the criteria listed below indicate what should be considered when determining whether to conduct stormwater quality monitoring during an impending event.

- Quantity Precipitation Forecast (QPF) – The amount of precipitation the incoming storm is expected to produce
- Probability of Precipitation (POP) – The percent probability the expected storm will occur
- Antecedent Dry Period – The time elapsed since the end of the previous measurable storm event

For gross solids monitoring, the criteria listed below provide an example of what should be considered during an impending event.

- Storms monitored must be forecasted to produce at least 0.50 inches of rain.
- The probability of precipitation must be greater than or equal to 50% for a decision to be made without Caltrans consultation.
- The Caltrans project coordinator must be consulted prior to monitoring storms with a probability of precipitation less than 50% or less than 0.50 inches of rain.
- Storm events must be preceded by at least 72 hours of dry conditions (<0.1 inches of precipitation) unless otherwise directed by the Caltrans project coordinator.

E.3.2 Weather Tracking

Once the criteria are established, a project team member designated as the responsible party for tracking storms uses the criteria, along with weather forecasting tools, to identify storms that match the storm selection criteria. Weather is tracked on a weekly basis by visiting the NWS web site and indicating the city and state where the project is located. Using the detailed seven-day forecast, the responsible party can review the weather forecast and determine if a rain event is anticipated. From the detailed forecast, if a rain event is likely, the responsible party must continue to track the weather every 24 hours. Chapter 11. At this point, it is also necessary to obtain data regarding the forecasted inches of rain and the probability of precipitation. This information is available by selecting the Hourly Weather Graph (see Figure E.3) and reviewing the percent precipitation potential, the predicted inches of rain in the project area, as well as the anticipated time of the storm event. If data in the Hourly Weather Graph matches the storm selection criteria, the weather is monitored on a more frequent basis (i.e., every four hours) as well as during the storm.

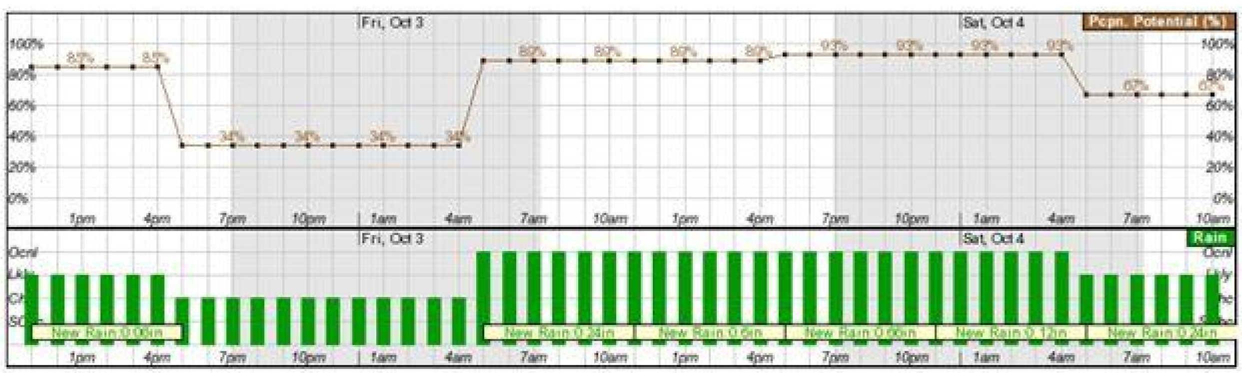


Figure E-3 Hourly Weather Forecast Graph from the National Weather Service

E.3.3 DOPPLER MAPS AND SATELLITE IMAGES

In addition, Doppler radar maps and satellite images are useful for predicting storm events. Specifically, radar images provide short “real-time” analysis of current conditions.

Figure E-4 provides an example of a typical Doppler radar image. The color scale at the right of the image represents the strength of returned energy to the radar and is expressed in values of decibels. These decibel values equate to the approximate rainfall rates indicated in Table E-2.

Table E-2 Decibel Values and Rate of Precipitation

Decibel Value	Precipitation Rate (inches/hour)
<20	No rain
20	Trace
30	0.1
36	0.25
41	0.5
47	1.25
52	2.5
55	4
60	5
65	16+

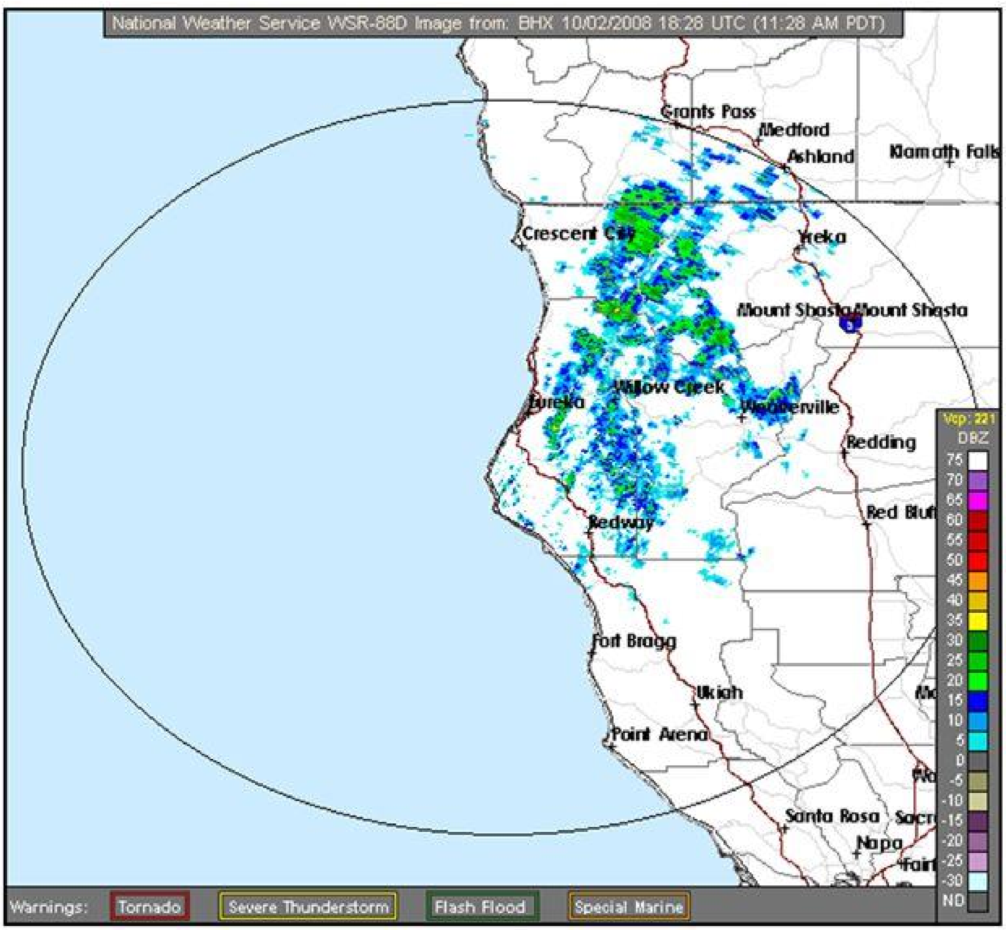


Figure E-4 Doppler Radar Image

Table E-2 provides hourly rainfall rates only and does not provide the actual amounts of rain a location receives. The total amount of rain received varies with intensity changes in a storm as well as a storm's motion over the ground. The value of 20 decibels is typically the point at which light rain begins. The values of 60 to 65 decibels represent an approximate point where ¾-inch hail can occur; however, it does not signify that severe weather is occurring at that location.

Satellite imagery (e.g., visual, infrared, water vapor, etc.) and satellite interpretation messages also provide information regarding weather features, significant weather areas, and significant cloud and meteorological features. Specifically, the use of satellite imagery allows one to locate hazardous weather areas over land and sea and to describe general meteorological conditions. A visual satellite image is displayed in Figure E.5.

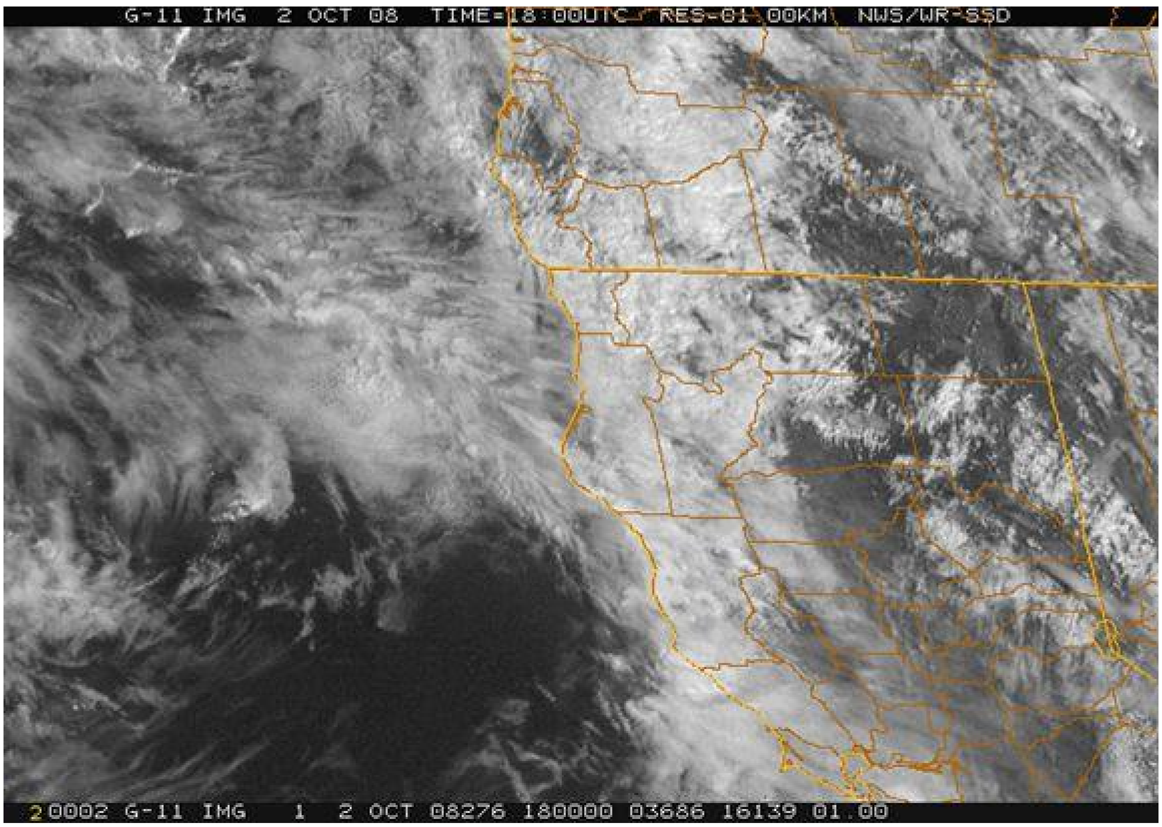


Figure E-5 Visual Satellite Image

Appendix F FIELD FORMS

This appendix contains field forms that are commonly used by Caltrans stormwater monitoring consultants. The forms shown in this appendix are intended to act as templates that can be printed and used in the field.

Three forms are included this appendix:

1. Chain-of-Custody (COC) Form – Used to keep a record of every time environmental samples are transferred from one individual's custody to another, from the time they are collected to the time they are relinquished to the laboratory. The COC is also used to communicate what analyses are required and any other special instructions that must be followed by the laboratory.
2. Post-Storm Inspection Form – Used to record the status of the monitoring station after each monitoring event.
3. Best Management Practice (BMP) Pilot Study Water Quality Empirical Observation Form – Used to make a thorough inspection of the conditions at each BMP monitoring station.

F.1 CHAIN-OF-CUSTODY FORM

Chain of Custody

Company Name: Project:
Mailing Address: Billing to:
City: State: Zip Code:
Telephone: Fax #: P.O. #
Report To: E-mail Address: QC Data: ☑ Level II (standard) ☐ Level III ☐ Level IV
Sampler name and signature:

Turnaround Time: ☑ 10 Working Days (Standard TAT) ☐ 7 Working Days ☐ 5 Working Days ☐ 72 Hours ☐ 48 Hours ☐ 24 Hours ☐ 2-8 Hours

Comments:

Analyses Requested

Client Sample I.D.	Date/Time Sampled	Matrix Desc.	# of Cont.	Container Type	Lab Sample ID										Comments (If required)
1.															
2.															
3.															
4.															
5.															
6.															
7.															
8.															
9.															
10.															

Relinquished By:	Received By:	Date / Time:
Relinquished By:	Received By:	Date / Time:
Relinquished By:	Received By:	Date / Time:
Relinquished By:	Received By:	Date / Time:

Were Samples Received in Good Condition? ☐ Yes ☐ No Samples on Ice? ☐ Yes ☐ No Temperature: ____________ Page____ of ____

F.2 STORM INSPECTION FORM

Caltrans Best Management Practice Pilot Study
Post-Storm Inspection Form

GENERAL INFORMATION:

Date:	Time In:	Time Out:
Personnel (list):		

GENERAL INFORMATION

Caltrans Monitoring Site ID: Monitoring Site Location Name: ____________________

First Successful Sample (Date/Time): ________________

Last Successful Sample (Date/Time): ________________ Sampler Pacing: ____________ cf

(An Empirical Observation Log must be filled out during all storm visits)

Stage level (in): ____________		Flow Meter Battery(V):__________
Flow Q (cfs): ______________	# Successful Samples: _____	Sampler Battery(V):____________
Total Flow (cf):____________	# Missed Samples: _____	Telemetry Battery(V):___________
Total Rain (in):____________		

MANUAL WATER QUALITY MEASUREMENTS (Storm only)

Water Temperature (°C) _______ Rain Gauge Reading (in) _______

Thermometer Number _______ Water Depth in Flume (in) _______

SAMPLER INFORMATION	
Sample after 1 pulse Bottle Volume:_________	Bottle # in: _______
Record Each Missed Sample Number (aliquot number):________________	
Bottle ID No(s): ______________________	Bottle # out: ________

ACTIONS TAKEN:

Download Data ____ Yes ____ No File: __________

Reset Logger? ____ Yes ____ No

Set Pacing to 99999999 ____ Yes ____ No

Drainage Area Observations:

Comments/Notes:

Team Leader's Signature ____________________________________

F.3 BMP Pilot Study Water Quality Empirical Observation Form

Caltrans BMP Pilot Study
Water Quality Empirical Observation Form (page 1 of 6)

GENERAL INFORMATION:

Date:	Time in:	Time out:
Team Leader:		Stormwater Consultant:
Other personnel:		Monitoring Site Location Name:

Purpose of visit (check all that apply): ☐ Storm monitoring ☐ Routine inspection
☐ Special inspection ☐ Maintenance

METEOROLOGICAL CHARACTERISTICS:

Time since end of previous storm event: ☐ > 72 hours ☐ 48-72 hours ☐ 24-48 hours ☐ < 24 hours

Present Rainfall: ☐ None ☐ Intermittent ☐ Very Light (averaging < 0.01 inch/hour)
☐ Light (averaging ~ 0.01-0.10 inch/hour) ☐ Moderate (averaging ~ 0.10-0.30 inch/hour)
☐ Heavy (averaging > 0.30 inch/hour)

Time: __________
Time present rain event started: __________
Time present rain event ended: __________

Meteorological characteristics comments:

HYDROLOGIC AND HYDRAULIC CHARACTERISTICS:

Flow conditions (check all that apply):
☐ Runoff entering BMP Inflow Water Temperature _________°C
☐ BMP discharging through BMP outlet
☐ BMP discharging via emergency overflow
☐ Flow bypassing/overflowing facility

Standing water conditions (record measurements as appropriate and check all that apply):
☐ Water standing over entire basin. Depth: __________
☐ Water standing in one isolated pool.
Describe Location: ____
Depth: __________
☐ Water standing in multiple pools.
Describe Locations: ____
____
Depths: ____
If during a storm event:
Record maximum depth of pooled water. Depth: ______________________________
Time to drain from the first entrance of runoff? ______________________________
Time to drain from the maximum depth? ______________________________
Comments:

Caltrans BMP Pilot Study
Water Quality Empirical Observation Form (page 2 of 6))

INLET CONDITIONS:

Describe any erosion or resuspension of settled solids being caused by the flow in the influent channel and/or the basin:

____

____

Describe any obstructions or restrictions interfering with inflow/influent:

WATER QUALITY APPEARANCE:

Check all that apply and describe under comments

Odor:
☐ Hydrogen sulfide ☐ Musty ☐ Sewage ☐ Ammonia ☐ Hydrocarbon ☐ Pesticide or herbicide
☐ None

Floating materials:
☐ Oil and grease (see below) ☐ Trash or debris ☐ Surface film ☐ Organic material ☐ None
☐ Other: ______________

Oil and grease:
☐ Sheen ☐ Heavy floating concentration ☐ Emulsion ☐ Deposit ☐ None

Color:
☐ Colorless ☐ Red ☐ Orange ☐ Yellow ☐ Green ☐ Blue ☐ Violet ☐ Brown ☐ Black
☐ Gray ☐ White ☐ Other: ________

Turbidity
☐ None ☐ Some cloudiness but transparent ☐ Cloudy, translucent ☐ Heavy cloudiness, opaque

Water quality appearance comments:

NOTE: please record inflow water temperature on Page 1.

Caltrans BMP Pilot Study
Water Quality Empirical Observation Form (page 3 of 6)

SOLIDS DEPOSITION AND RESUSPENSION:

For the following locations, record the type (trash or debris, oil and grease, other organics), location(s), area(s) covered, and depth(s), as applicable:

In inflow/influent channel:

Over entire basin:

In one spot:

In multiple spots:

In outflow/effluent channel:

Solids resuspension evident (*check all that apply*):
☐ In inflow/influent channel ☐ Near inlet ☐ Near outlet ☐ In outflow/effluent channel
☐ Other (describe): ____

Solids deposition and resuspension comments:

EROSION:

For the following locations, record erosion locations, area(s) covered, and depth(s), as applicable:

In inflow/influent channel:

Near inlet:

Basin bed:

Basin side slopes:

Near outlet:

In outflow/effluent channel:

Comments:

Caltrans BMP Pilot Study
Water Quality Empirical Observation Form (page 4 of 6)

VEGETATION CONDITION:

Basin bed vegetation cover:
☐ Complete ☐ Few small bare spots ☐ Few large bare spots ☐ Many small bare spots
☐ Many large bare spots ☐ Large areas bare ☐ All or nearly bare
Comments:

Basin side slopes vegetation cover:
☐ Complete ☐ Few small bare spots ☐ Few large bare spots ☐ Many small bare spots
☐ Many large bare spots ☐ Large areas bare ☐ All or nearly bare
Comments:

Basin bed vegetation type:
☐ All grasses ☐ Mostly grasses, some wetland plants ☐ Mostly wetland plants, some grasses
☐ All wetland plants
Extent of woody shrubs or trees:

Basin side slopes vegetation type:
☐ All grasses ☐ Mostly grasses, some wetland plants ☐ Mostly wetland plants, some grasses
☐ All wetland plants
Extent of woody shrubs or trees:

Other vegetation condition comments:

OUTLET CONDITIONS:

Describe any obstructions or restrictions interfering with outflow/effluent:

STRUCTURAL CONDITION OF FACILITY:

Record the presence of the following (check all that apply and give location in comments):
☐ Inlet structure damage ☐ Outlet structure damage ☐ Vandalism
Comments:

Caltrans BMP Pilot Study
Water Quality Empirical Observation Form (page 5 of 6)

MONITORING EQUIPMENT CONDITIONS:

Inspection checklist (*check appropriate boxes*):
Sampler strainer & bubbler tubing free of sediment and debris?
☐ Yes ☐ No If no: please clear, remove sediment/debris
Flume(s) free of sediments and debris?
☐ Yes ☐ No ☐ Not applicable ☐ See comments below
Power supply functioning?
☐ Yes ☐ No ☐ Not applicable ☐ See comments below
Flow meter(s) functioning normally?
☐ Yes ☐ No ☐ Not applicable ☐ See comments below
Flow meter desiccant OK or replaced?
☐ OK ☐ Replaced ☐ Not applicable ☐ See comments below
Flow meter calibration:
☐ OK ☐ Recalibrated ☐ Not applicable ☐ See comments below
Samplers functioning normally?
☐ Yes ☐ No ☐ Not applicable ☐ See comments below
Sampler desiccant:
☐ OK ☐ Replaced ☐ Not applicable ☐ See comments below
Sampler suction line:
☐ OK ☐ Cleared ☐ Replaced ☐ Not applicable ☐ See comments below
Sampler intake:
☐ OK ☐ Cleared ☐ Replaced ☐ Not applicable ☐ See comments below
Sampler strainer:
☐ OK ☐ Cleared ☐ Replaced ☐ Not applicable ☐ See comments below
Peristaltic pump tubing:
☐ OK ☐ Cleared ☐ Replaced ☐ Not applicable ☐ See comments below
Comments:

Inspection checklist (*check appropriate boxes*):

BMP Technology Type: (i.e., Skimmer, Filtration, Hold & Release) Basin No.:

Observations made on: Date ________ Time _______
Is the equipment intact?
☐ Yes☐ No
Is the equipment operational?
☐ Yes☐ No
Is the technology working such that water is allowed to drain (check outlet bubbler flow reading; listen for outlet flow)?
☐ Yes☐ No
Comments:

Caltrans BMP Pilot Study
Water Quality Empirical Observation Form (page 6 of 6)

Comments:

____

____

____

____

____

____

____

____

____

____

____

(Team Leader's Signature)

Appendix G REPORT DISTRIBUTION AND COVERS

Regular distribution is project-specific and identified by the Caltrans Task Order Manager. The deliverables requirements for each project will be specified in the project task order. The information in this appendix should be used only as a guideline; the number of copies of each deliverable and their distribution should be arranged with the Caltrans Task Order Manager during the project planning phase.

G.1 DELIVERABLES DISTRIBUTION

At least two copies of each deliverable must be provided to Caltrans, as well other copies delivered either to Caltrans or to other organizations, as directed by the Task Order Manager. Each hardcopy report must include an electronic copy on compact disk or DVD. This should be submitted in a CD pocket affixed to the inside back cover of the report. Detailed distribution is discussed in the following subsections.

G.2 HARDCOPIES (PAPER DOCUMENTS)

Hard copies should be double-sided and bound in a three-ring binder unless otherwise directed by the Task Order Manager.

G.3 ELECTRONIC DELIVERABLES

Complete documents should be provided on compact disks (CDs) and include the source document(s) in Microsoft Word and Adobe PDF formats. Component files used in the production of the document, such as Excel spreadsheets, scanned files, and pictures, should also be included on the CD in a separate folder.

Each document should consist of a single PDF file created with the latest version of Adobe Acrobat. PDF files must be created electronically, not scanned from paper documents.

Adobe PDF files must be accessible to people with disabilities, as specified by the US Americans with Disabilities Act (ADA). Adobe Acrobat Professional has a built-in checker for ADA compliance, which must be used to check all Caltrans deliverables. In addition, documents must also be checked using the Pac3 PDF checker, provided free of charge from the manufacturer.

The Pac3 checker can be downloaded here:

https://access-for-all.ch/en/pdf-lab/pdf-accessibility-checker-pac.html

Documents should pass both the Adobe Acrobat and Pac3 checkers with no errors before they are delivered to Caltrans.

CDs should be labeled clearly showing all relevant information, including report number, date, contract number, and Caltrans logo. A sample CD label is shown in Figure G.1 Example of a CD Label for Caltrans Report.

Figure G-1 Example of a CD Label for Caltrans Report

Appendix H GROSS SOLIDS LABORATORY ANALYSIS

H.1 TERMINOLOGY

Gross Solids – A combination of litter, vegetation, and other particles of relatively large size collected in stormwater monitoring devices (Caltrans 2000c).

Litter – Manufactured items made from paper, plastic, cardboard, glass, metal, etc. that can be retained by ¼-inch mesh or other trash collection screens. Litter does not include materials that are of natural origin such as sand, soil, gravel, vegetation, etc.

H.2 INTRODUCTION

The Caltrans gross solids analytical method was designed to measure the weight and volume of gross solids discharged from stormwater conveyance systems. This method applies to both samples that are freshly collected and samples that have been air-dried for 24 hours. This method provides a standardized approach to measurement methodology, terminology, equipment and supplies, data quality control, and safety. This method does not cover classifying the litter by material type or size.

H.3 EQUIPMENT

Equipment that is used for gross solids analysis may include:

- Balances – Balances that are sensitive to the reporting limit of one gram or less
- Calibration Masses – "S" Class or traceable to American Society for Testing and Materials Class 1
- Polyethylene Carboys, graduated to 55 liters (L); sensitive to one L for samples less than 55 L
- Graduated Cylinders – Cylinders sensitive to ten milliliters (mL) for samples up to one L; sensitive to 100 mL for samples between one L and ten L; sensitive to one L for samples greater than ten L
- Digital Camera
- Drying Trays
- Disposable Aprons, Coats, or Coveralls

- Data Logbooks or Worksheets

H.4 METHODS

Protective clothing, safety glasses, and gloves should be worn while handling gross solids. Duplicate sample bags should be identified and clearly labeled before proceeding with measurements. Every fifth bag during the first three storm events, and every tenth bag thereafter, should be tagged as a duplicate sample.

H.4.1 DETERMINATION OF TARE WEIGHT

Choose the appropriate weighing vessel (graduated cylinder or polystyrene weighing dish). For example, for total weight of gross solids, the 55 L graduated carboy will be utilized; for small-volume samples, a 100 mL or 1000 mL graduated cylinder will be utilized and for individual items (e.g., cigarette butts), a polystyrene weighing dish will be utilized.

Place appropriate weighing vessel on balance.

Weigh the empty weighing vessel and record this value on laboratory data sheet. This is the tare weight.

H.4.2 TOTAL WEIGHT GROSS SOLIDS

Pour contents of a gross solids collection bag into the empty weighing vessel. Place the filled weighing vessel onto the balance. Determine total weight of gross solids and weighing vessel. Subtract tare weight from total weight and record this value on laboratory data sheet:

Total Weight – Tare Weight = Sample Weight

H.4.3 TOTAL VOLUME GROSS SOLIDS

Visually check the volume of gross solids using volumetric graduations on the polyethylene container. The sample should be evenly distributed within the container. Air voids should be removed, as much as possible, by tapping the container on a hard surface at least three times. Record the volume on laboratory data sheet.

H.4.4 LITTER WEIGHT

Transfer gross solids from the polyethylene container to a plastic tray at the worktable. Sort gross solids into two groups: vegetation and litter.

Measure weight of litter material using the procedure for measuring total weight gross solids described earlier. Record the data on laboratory data sheet.

H.4.5 Litter Volume

Transfer litter to an appropriate graduated cylinder or polyethylene container. The sample should be evenly distributed within the container. Air voids should be removed, if possible, by tapping the container on a hard surface at least three times. Record the volume on laboratory data sheet.

H.4.6 Vegetation Weight

Measure weight of vegetation using the procedure for measuring total collected weight gross solids described earlier. Record the data on laboratory data sheet.

H.4.7 Vegetation Volume

Transfer vegetative materials to an appropriate graduated cylinder or polyethylene container. The sample should be evenly distributed within the container. Air voids should be removed, if possible, by tapping the container on a hard surface at least three times. Record the volume on laboratory data sheet. Discard vegetative material into a recycle trash bin.

H.4.8 24-Hour Air-Dried Gross Solids Measurements

Transfer the gross solids sample to a drying tray. The material should be distributed on the tray in such a way that it dries evenly.

Take a digital photograph of the sample before it is air-dried. Place two rulers along the edges of the drying tray. Write the Sample ID and date on a piece of paper or index card and place it near the drying tray. Photograph the gross solids from above, being careful the sample, the rulers, and the sample label are all clearly in focus in the photograph.

Air-dry the litter for a minimum of 24 hours. Record date and time the drying process was started.

After 24 hours, visually check the litter for dryness. If litter is dry, record the date and time on laboratory data sheet. If litter is still visibly moist, air dry for up to an additional 24 hours. Record date and time at end of drying on the laboratory data sheet. Use best professional judgment to decide when the sample is dry.

Determine the dried weight and volume of the litter sample using the same procedures described above.

H.4.9 Disposal

Dispose of recyclable materials into the recycle trash bin. Dispose of non-recyclable materials into the trash bin.

Thoroughly rinse drying trays, plastic trays, and graduated carboys with water and allow to air dry.

Sediments contained within gross solids removal devices may contain chemical contamination. To determine the extent and potential type of chemical contamination, two confirmation soil samples should be collected and submitted to a laboratory for analysis using analytical methodologies specified in the Operation, Maintenance, and Monitoring Plan. If the sediment samples contain contaminants above any regulatory threshold for municipal waste, the entire sample must be transported to an appropriate facility for disposal.

H.5 Quality Control

H.5.1 Calibration of Top Loading Balance

Laboratory balances should be sensitive to one gram. The balance must be on a stable and level base. The area surrounding the balance should always be kept clean. The balance calibration should be checked three times daily using an appropriate size “S” Class weight: at the beginning of the day before sample processing; mid-day; and after sample processing at the end of the day. Document all results in the QA/QC notebook. If the balance cannot be correctly calibrated, the laboratory must take corrective action.

The most important requirement for accurate and reproducible results is a clean balance. All balances will be cleaned on an as-needed basis. All balances must be serviced and calibrated at least annually by a manufacturer’s service representative.

H.5.2 Analysis of Duplicate Samples

To determine and maintain analytical precision at the onset of sample analysis, duplicate samples will be analyzed for both weight and volume measurements. The Relative Percent Difference will be calculated to determine precision. As data from duplicate samples are generated, the mean and standard deviation will be calculated. These values will be incorporated into a means chart for analytical precision control.

For quality control of all samples during the first three storm events, the weight and volume of every fifth sample shall be determined in duplicate by a different laboratory technician for each test parameter. Through the remainder of the season, the weight and volume of 10% of the samples shall be determined in duplicate.

H.5.3 Determinations of Relative Percent Difference

Duplicate samples are analyzed to determine precision. The Relative Percent Difference between the duplicate values is calculated as follows:

$$RPD\,(\%) = \left[\frac{|A-B|}{(A+B)/2} \right] * 100\%$$

Where:

A	=	Original Sample Result
B	=	Duplicate Sample Result

H.5.4 Volume Measurement Control Level

Volumetric air-dried litter measurements for the Litter Management Pilot Study (Caltrans 2000c) were reproducible to within ±12%. For purposes of laboratory quality control, an out-of-control level is defined as 15%.

As volumetric data are generated, the mean of the duplicate samples and standard deviation will be calculated. A means chart will be developed that will include upper and lower control levels. The control level may be updated based on these data. Common practice is to use ± three sigma (s) limits for the control level.

H.5.5 Weight Measurement Control Level

Air-dried litter weight measurements for the Litter Management Pilot Study (Caltrans 2000c) were reproducible to within ± five percent. For purposes of laboratory quality control, an out-of-control level is defined as five percent.

As weight data are generated, the mean and standard deviation will be calculated. A means chart will be developed that will include upper and lower control levels. The control levels may be revised based on these data. Common practice is to use ±3 s limits for the control level.

If a measurement exceeds a control level, then a third analyst will perform the duplicate analysis.

H.6 REPORTING LIMITS

Report the weight to the nearest 0.1 pounds.

Report volume according to the sample size, as follows:

- Samples from ten mL ≤ one L report to the nearest ten mL
- Samples from one L ≤ ten L report to the nearest 100 mL
- Samples >ten L report to the nearest one L

Appendix I PERFORMING ANALYSES IN THE FIELD

I.1 FIELD MEASUREMENTS

USEPA now requires pH measurements to be performed immediately in the field, not on samples that have been transported to the lab. Temperature must always be measured within the runoff stream. Typically, turbidity and dissolved oxygen are also measured in the field.

I.1.1 TEMPERATURE

Temperature is always taken directly from the runoff stream. Temperature can be taken with any reliable mercury-filled Celsius thermometer or with a thermistor (found in many modern field pH and conductivity meters). Infrared thermometers may also be used. An infrared thermometer is a handheld electronic device that measures the infrared intensity emitted by an object (in this case, a runoff stream) and converts it to a temperature. Infrared thermometers have the advantage that they can be used at a distance of several feet and do not require field personnel to collect a sample. This can be a safety benefit in areas where physical access to the runoff stream is difficult or precarious.

I.1.2 PH, CONDUCTIVITY, DISSOLVED OXYGEN

Field measurements of pH, conductivity, and dissolved oxygen are usually performed using ion-specific electrodes (ISEs). The ISE incorporates a transducer that converts the activity of the target ion in aqueous solution into a voltage. This voltage is converted to concentration by the instrument’s circuitry.

Many analyses, including pH and conductivity, are dependent on temperature. Most modern ISEs also have the capacity to measure the temperature of the sample and to automatically compensate for temperature when calculating a value. These temperature-compensated ISEs should be used when performing temperature-dependent analyses.

To meet the USEPA requirement, field measurement of pH must be performed at the time of grab sample collection as well as at the time of composite sample collection. The measurement should be performed using a meter equipped with a glass electrode in which the electrolyte solution can be replaced. Because the accuracy of field pH measurement depends principally upon the condition of the electrodes, the probe must be scrupulously maintained according to manufacturer specifications.

I.1.3 Turbidity

Turbidity is a measure of the cloudiness of water, or, more accurately, the degree to which a water sample becomes less transparent as a result of the presence of suspended matter. The most common cause of turbidity in stormwater is suspended sediment, although other materials such as phytoplankton and algae can contribute to the turbidity of a stormwater sample.

The instrument used to analyze turbidity is called a nephelometer; the units of a turbidity measurement are nephelometric turbidity units (NTU). Nephelometers are commonly referred to as turbidimeters.

Appendix J POST-STORM ACTIVITIES

Once monitoring has ended, the auto-sampler may be shut down or prepared for the next storm event if there is insufficient time for a maintenance visit between storms. Typically, the flow meters are kept on throughout the monitoring season to record any trace precipitation or dry weather flow that may occur between target events. The following post-event activities must be performed and documented in a field logbook:

1. Complete a Post-Storm Inspection Form (see Appendix F).
2. Reset the storm-monitoring program on the auto-sampler to prepare for another event.
3. Replace the sample container(s) and reset the auto-sampler.
4. Physically inspect the station to determine if damage was sustained during the storm event; determine if the flow sensor is blocked by debris or if the intake is clogged.
5. Download the data from the data logger and perform preliminary data integrity checks.
6. Check each of the battery voltages and replace those that are low.
7. Use the hydrologic utility to calculate percent capture and view the hydrograph to determine if the storm peak was captured.
8. Before sending samples for laboratory analyses, perform a sample representativeness evaluation and consult the department Task Order Manager if storm event representativeness criteria were not met.

Data must be downloaded from the data logger after each storm event during the storm season. During dry weather, data downloads must be performed as necessary depending on available memory capacity. If data are remotely downloaded and the telemetry session is interrupted, the flow meter data-loggers may assume all data were successfully downloaded. In such instances the downloaded data must be manually scanned immediately to ensure all data for the full period of the event at specified time intervals are recorded in the file. If repeat attempts fail, data must be directly downloaded in the field.

Appendix K PERMIT REQUIREMENTS

The current California Construction General Permit (CGP) requires pH and turbidity be measured multiple times per day at construction sites when stormwater runoff flows from the construction site. In order to comply with this permit, Caltrans personnel and monitoring crews must know how to conduct these two analyses and be familiar with the instruments used to test them. Measurement of pH in the field is also important when toxicity is included as part of stormwater monitoring. Table K.1 shows pH and turbidity requirements for a General Permit.

Although it is advisable to order a pH test from the laboratory to corroborate field data, only field pH may be used for regulatory purposes because this test must be performed within 15 minutes of sample collection.

Table K-1 General Permit Requirements for Field Testing

Parameter	Test Method	Discharge Type	Max. Detection Limit	Reporting Units	Numeric Action Levels	Numeric Effluent Limitation (LUP Type 3)
pH	Field test with calibrated portable instrument	Type 2 and 3	0.2	pH units	Lower = 6.5 Upper = 8.5	Lower = 6.0 Upper = 9.0
Turbidity	EPA 180.1 and/or field test with calibrated portable instrument	Type 2 and 3	1	NTU	250 NTU	500 NTU

The minimum requirements for pH and turbidity tests appear on Page 43 of the CGP (State Water Board 2010) and are outlined below:

"Dischargers shall conduct their own field analysis of pH and may conduct their own field analysis of turbidity if the discharger has sufficient capability (qualified and trained employees, properly calibrated and maintained field instruments, etc.) to adequately perform the field analysis.

"pH: LUP Type 2 and 3 dischargers shall perform pH analysis on-site with a calibrated pH meter or a pH test kit. The LUP discharger shall record pH monitoring results on paper and retain these records in accordance with Section M.4.º, below.

"Turbidity: LUP Type 2 & 3 dischargers shall perform turbidity analysis using a calibrated turbidity meter (turbidimeter), either on-site or at an accredited lab. Acceptable test methods include Standard Method 2130 or USEPA Method 180.1. The results will be recorded in the site logbook in Nephelometric Turbidity Units (NTU)."

The permit requires a turbidity measurement conform to EPA Method 180.1 and have a maximum detection limit of 1 NTU. Measurements of pH must be with a meter with a minimum detection limit of 0.2 pH. The CGP does not have requirements for the test procedures other than all equipment "should be calibrated and maintained in accordance with manufacturers' specifications to ensure accurate measurements." For both measurements, a wide variety of instruments will meet the maximum specifications.

Although pH meters may be calibrated at up to five points on some models, this increases the complexity of the calibration and the setup time. For this reason, it is recommended that pH meters be used that require a three-point calibration. Turbidity meters are normally calibrated using three-point calibration. Other features of these instruments, such as waterproofing and data logging, are useful but not necessary.

When calibrating and using pH meters and turbidimeters, field technicians should follow manufacturer instructions. All field pH and turbidity measurements must be recorded immediately in field logs, and written records must be imported into excel sheets, saved electronically, and included in the EDD.

Standard forms for recording sample and equipment calibration/maintenance data for CGP Stormwater Monitoring are available at the following Division of Construction web site: https://dot.ca.gov/programs/construction.

Appendix L COMPOSITE SAMPLE COLLECTION OPTIONS

Several methods are available for composite sample collection. The various options are presented here principally to provide guidance for composite sample collection in situations where the standard automated approach is not feasible.

Composite samples may be either flow-proportioned or time-proportioned. A flow-proportioned sample is produced by varying one of two parameters:

- The time interval between aliquots – Aliquots of equal volume are collected each time a pre-set flow volume passes through the monitoring station. Aliquots are therefore collected more frequently during periods of high flow and less frequently during periods of lower flow. This is the standard approach used with automated monitoring equipment.
- The volume of each aliquot – Aliquots are collected at equal time intervals, but the volume of each aliquot varies in proportion to the discharge at the time of sample aliquot collection. Large aliquot volumes are collected during periods of high flow and smaller volumes are collected during periods of lower flow. This approach is more commonly used when automated sample collection is not practical.

Depending on the expected size and duration of the storm, field personnel must use their judgment and knowledge of the rainfall/runoff characteristics of the catchment to set either the time interval or the aliquot volume so the storm is represented proportionately and so the carboys do not overfill.

L.1 STANDARD AUTOMATED FLOW-PROPORTIONED COMPOSITE

In Caltrans stormwater monitoring programs, composite sample collection typically is performed using automated sampling and flow-monitoring equipment to collect flow-proportioned composite samples throughout the duration of a storm event. The autosampler equipment is programmed to collect a sample aliquot of equal volume each time a corresponding set volume of flow is measured in the stormwater stream by the automated flow meter. The time interval between aliquots depends upon the flow rate. This “Flow-Proportioned–Constant Volume” approach is shown in Figure L-1.

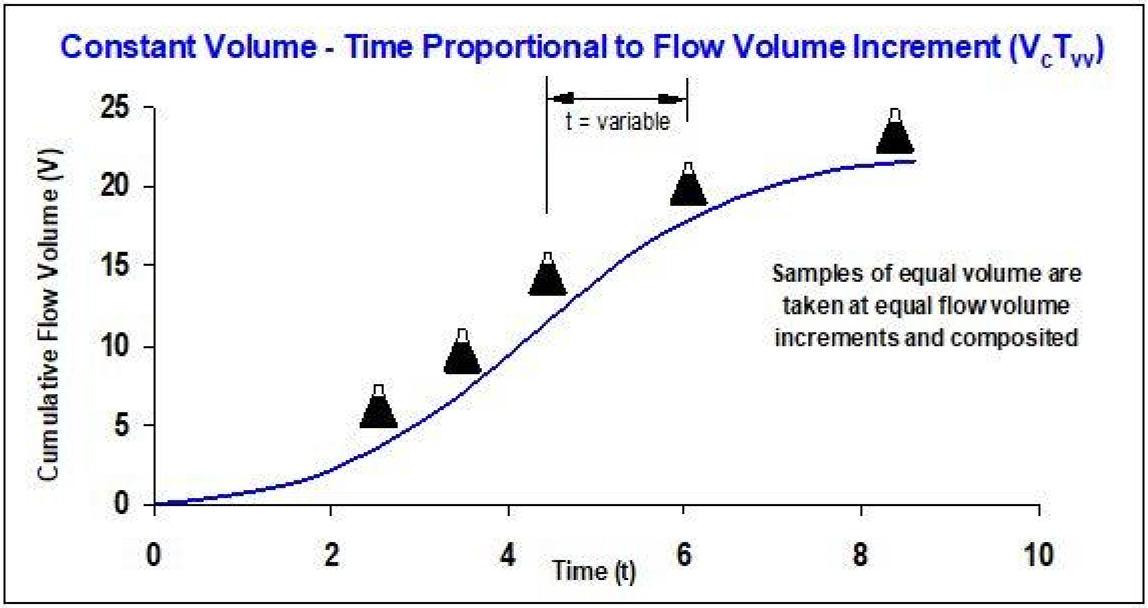


Figure L-1 Flow Proportioned: Constant Aliquot Volume/Varying Time

L.2 FLOW-PROPORTIONED COMPOSITE: CONSTANT TIME/VARYING ALIQUOT SIZE

When automated sample collection is not feasible, flow-proportioned composite samples can still be collected manually if the instantaneous flow rate can be measured at the time of each aliquot collection. Sample aliquots are collected at a regular time interval (e.g., every 15 minutes), and aliquot volume is set proportional to instantaneous flow rate at the time of sampling. For this technique, flow rate may be measured either manually (e.g., by measuring depth and converting to flow rate using Manning's Equation) or by use of an automated flow meter. Aliquots are collected using one of the grab sample techniques described in Chapter 10 and poured into a composite bottle to generate a composite sample for the storm event.

The sampling time interval is set to ensure collection of the minimum number of aliquots required for adequate storm representativeness (see discussion later in this section), based on the expected (forecast) storm duration. Sample aliquot volumes are set to ensure collection of the required composite volume over the course of the expected storm event, based on the storm Quantity of Precipitation Forecast QPF and the expected runoff volume.

This method requires advance preparation of a table showing the aliquot volumes to collect for a range of expected flow rates, over a range of possible storm event (QPFs). In this table, the aliquot volumes are set to ensure collection of the full composite sample volume required to perform all planned analyses for a given QPF. This requires advance knowledge of rainfall/runoff relationships in the monitored watersheds. This sample collection method is shown diagrammatically in Figure L.2.

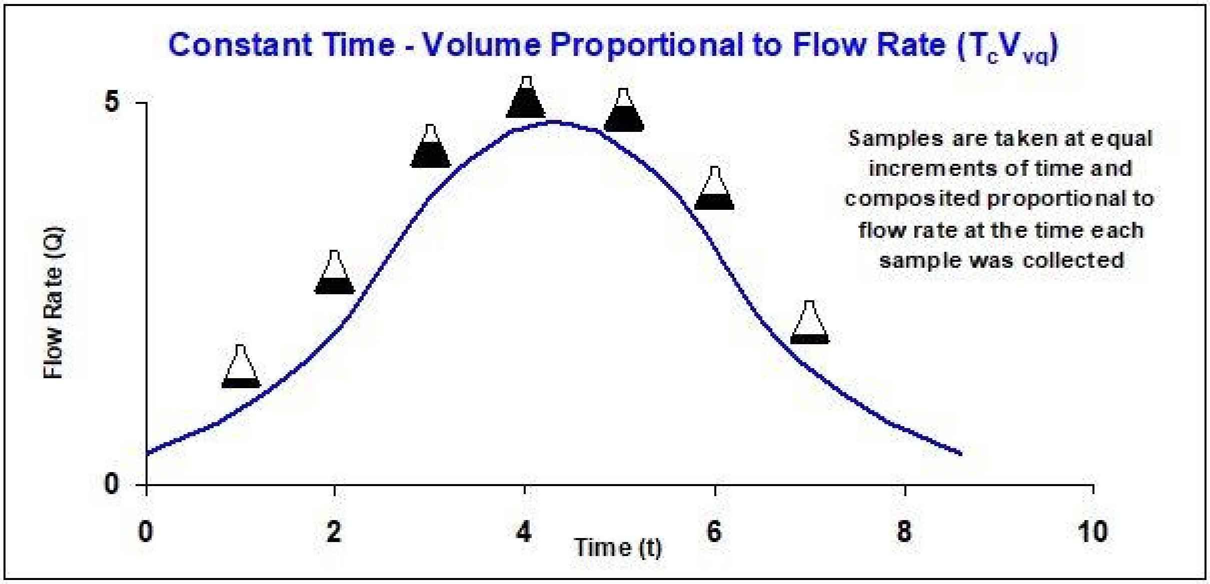


Figure L-2 Flow Proportioned: Constant Time/Varying Aliquot Volume

L.3 FLOW-PROPORTIONED COMPOSITE: CONSTANT TIME/VARYING ALIQUOT SIZE

As an alternative to the preceding method, when automated sample collection is not feasible, flow-proportioned composite samples can be collected manually, based on the flow volume increment at the time of each aliquot collection. Sample aliquots are collected at a regular time interval (e.g., every 15 minutes), and aliquot volume is set proportional to the incremental flow volume recorded in the intervening time interval since collection of the previous sample aliquot. For this technique, an automated flow meter generally is required to produce an accurate record of cumulative flow volume. Aliquots are collected using one of the grab sample techniques described in Chapter 10, and poured into a composite bottle to generate a composite sample for the storm event.

The sampling time interval is set to ensure collection of the minimum number of aliquots required for adequate storm representativeness (see discussion later in this section), based on the expected (forecast) storm duration. Sample aliquot volumes are set to ensure collection of the required composite volume over the course of the expected storm event, based on the storm QPF and the expected runoff volume.

This method requires advance preparation of a table showing the aliquot volumes to collect for a range of expected flow volumes, over a range of possible storm event QPFs. In this table, the aliquot volumes are set to ensure collection of the full composite sample volume required to perform all planned analyses for a given QPF. This requires advance knowledge of rainfall/runoff relationships in the monitored watersheds. This sample collection method is shown diagrammatically in Figure L.3.

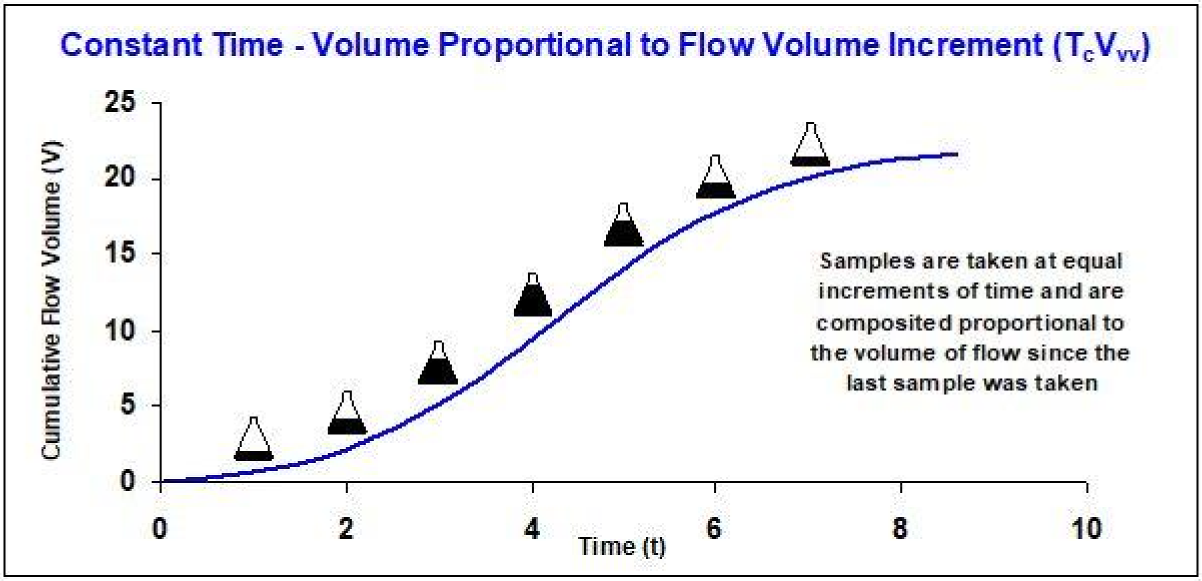


Figure L-3 Flow Proportioned: Constant Time/Varying Aliquot Volume (B)

L.4 TIME PROPORTIONED COMPOSITE

When flow measurement is not feasible, the composite sample may be collected on a time-proportioned basis. In this mode, aliquots of equal volume are collected at equal time intervals throughout the storm. This is the simplest kind of proportioned compositing scheme. Sample aliquot collection can be performed manually or by use of an automated sampler. The time interval and aliquot size should be set such that enough sample volume is collected for analysis, but also to ensure there is minimal risk of overfilling the carboy before the storm ends.

Time-proportional sample compositing is shown diagrammatically in Figure L.4

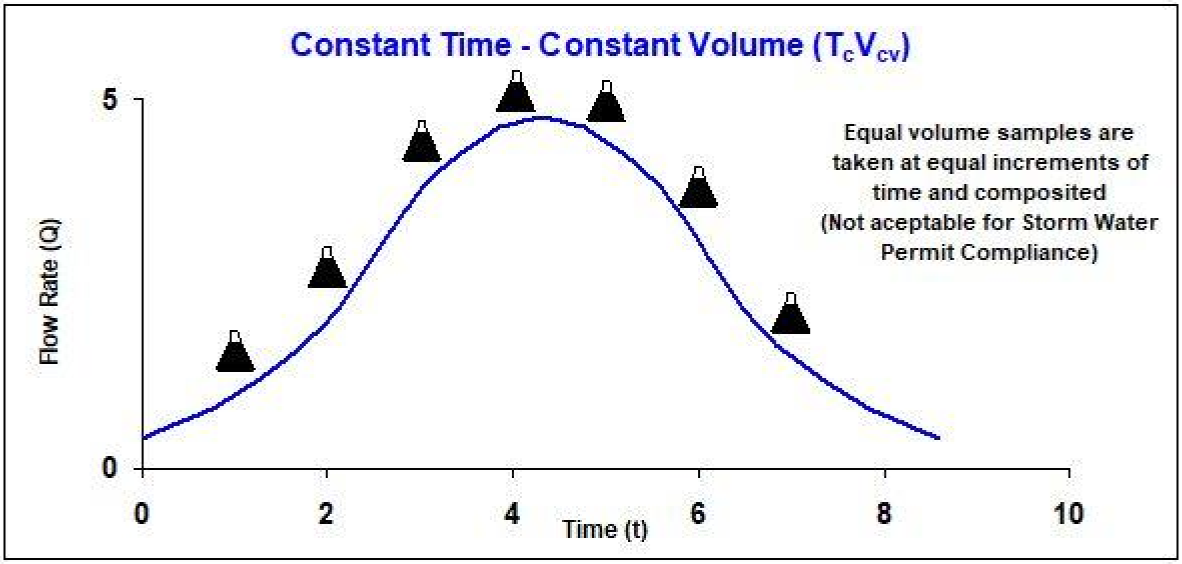


Figure L-4 Time Proportioned: Constant Time/Constant Aliquot Volume

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Appendix M METHODS FOR PHYSICAL AND AGGREGATE PROPERTIES

M.1 METHODS FOR PHYSICAL AND AGGREGATE PROPERTIES

Physical and aggregate properties of stormwater generally include temperature, pH, turbidity, suspended and dissolved solids, conductivity, dissolved oxygen, and hardness.

Tests for temperature, pH, and dissolved oxygen must be performed in the field. These properties of stormwater change quickly over time and cannot be reliably tested in the laboratory. Field testing must be performed by experienced technicians trained to use the analytical equipment and observe good QC practices. Field equipment must be calibrated, used, and maintained in accordance with manufacturers' instructions.

M.1.1 TEMPERATURE

Temperature is always taken directly from the runoff stream. Temperature can be taken with any reliable mercury-filled Celsius thermometer or with a thermistor (found in many modern field pH and conductivity meters). Infrared thermometers may also be used. An infrared thermometer is a handheld electronic device that measures the infrared intensity emitted by an object (in this case, a runoff stream) and converts it to a temperature. Infrared thermometers have the advantage that they can be used at a distance of several feet, and do not require field personnel to collect a sample. This can be a safety benefit in areas where physical access to the runoff stream is difficult or precarious.

M.1.2 PH, CONDUCTIVITY, DISSOLVED OXYGEN

pH, conductivity, and dissolved oxygen tests are usually performed using ion-specific electrodes (ISEs). There are several different designs of ISE, but all designs incorporate a transducer that converts the activity of a particular ion in aqueous solution into a voltage. The target ion flows across an ion-specific membrane, generating an electronic potential between two electrodes, and this potential is proportional to the amount of target ion in the sample. This voltage is converted to concentration by the instrument's circuitry.

Many analyses, including pH and conductivity, are temperature-dependent. Most modern ISEs also have the capacity to measure the temperature of the sample and to automatically adjust for temperature when calculating a value. These temperature-compensated ISEs should be used when performing these analyses.

M.1.3 Turbidity

Turbidity is a measure of the cloudiness of water, or, more accurately, the degree to which a water sample becomes less transparent as a result of the presence of suspended matter. The most common cause of turbidity in stormwater is suspended sediment, although other materials such as phytoplankton and algae can also contribute to the turbidity of a stormwater sample.

The instrument used to analyze turbidity is called a nephelometer; the units of a turbidity measurement are nephelometric turbidity units (NTU). Nephelometers are commonly referred to as turbidimeters.

Nephelometers measure turbidity by shining a light of known wavelength into a sample and measuring the light diffracted by the sample. For the methods used to analyze stormwater, a nephelometer uses a tungsten light source and a photoelectric detector placed at a 90° angle from each other. The intensity of light measured by the photoelectric detector is proportional to the turbidity of the sample. Note that turbidity is not a measurement of how much light passes directly through a sample, but of how much light is refracted by a sample at a 90° angle.

M.1.4 Solids

The solid material contained in a stormwater sample is divided into two types: Total Suspended Solids (TSS) and Total Dissolved Solids (TDS). Together, these are referred to as Total Solids.

TSS and TDS are determined by passing a sample through a filter. The suspended matter remains on the filter and the dissolved matter passes through the filter. In order to perform these tests, the laboratory begins by agitating the sample until all of the solids are distributed evenly (a magnetic stir plate is the most common way of doing this). When the sample is homogenized, an aliquot is removed from the sample and filtered using a vacuum filter flask.

The filter is weighted carefully before the test begins. The sample is filtered using the setup pictured in Figure M-1. After filtration, the filter is dried and re-weighed; the difference in the weight of the filter before and after the analysis corresponds to the weight of the solid material trapped during filtration. This is the TSS fraction.

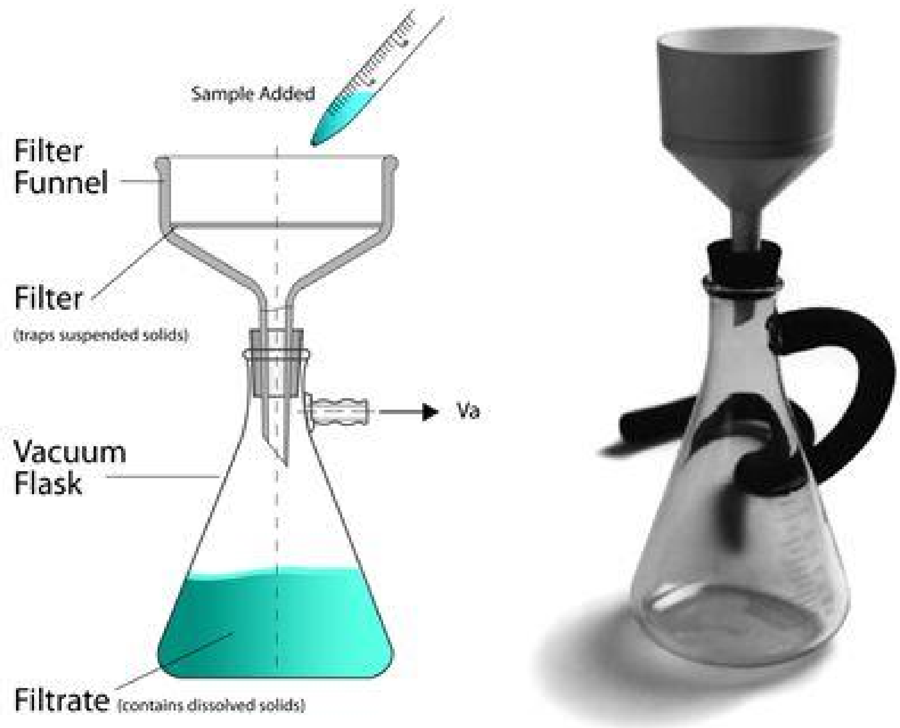

Figure M-1 Suspended and Dissolved Solids Filtration Apparatus

The filtrate is removed from the flask and put into a pre-weighed drying dish, and the sample is evaporated to dryness. The drying dish is then re-weighed; the difference in the weight of the dish before and after the analysis corresponds to the weight of solid material that passed through the filter. This is the TDS fraction.

The filters used in this test are borosilicate glass fiber filters that trap material approximately one to two microns in size and allow everything smaller to pass through.

M.1.5 Hardness

Hardness is a measure of the mineral content of water. Although a number of different minerals may contribute to the hardness of a sample, only calcium and magnesium are important factors in total hardness. Total hardness is generally reported as if it were all the result of dissolved calcium carbonate ($CaCO_3$). For this reason, hardness is commonly expressed as hardness as $CaCO_3$, and the units are often written as mg/L $CaCO_3$.

Hardness has historically been performed using titration. However, the currently preferred method for testing the hardness of surface waters is by measuring the concentrations of calcium and magnesium and then calculating hardness using the following formula:

$$\text{Hardness as } CaCO_3 \text{ [mg/L]} = (\text{Mg [mg/L]} \times 2.497) + (\text{Ca [mg/L]} \times 4.118)$$

Where:

Mg = Magnesium
Ca = Calcium

M.2 Methods for Nutrients

Nutrients that encourage the grown of organisms such as algae and are associated with stormwater usually included nitrate, ammonia, total Kjeldahl nitrogen, total phosphorus, and orthophosphate. Nitrite is also sometimes included, even though it is unusual to find significant amounts of nitrite in surface waters.

M.2.1 Nitrate, Nitrite, and Ammonia

Ammonia is normally analyzed using ion-specific electrodes. Nitrate and nitrite can also be analyzed using ion-specific electrodes but are more commonly analyzed either by means of ion chromatography, or colorimetrically with the use of a spectrophotometer.

Chromatography is the science of separating mixtures into their individual components. Ion chromatography is a form of column chromatography, in which a sample is carried through a tube (or column) by a carrier liquid. Constituents in the sample pass through the column at different rates, so they gradually separate from each other on their way through the column. At the end of the column is a detector that responds to the target analytes as they exit the column. The magnitude of the response is proportional to the concentration of target analyte in the sample.

To analyze for these constituents colorimetrically, chemical reagents are added to the sample that react with the target analyte and turn color. The intensity of the color is proportional to the concentration of the analyte. When the reaction is complete, the sample is placed into a spectrophotometer which reads the intensity of color in the sample and converts it to a concentration.

Laboratories do not usually report the concentrations of nitrate, nitrite, and ammonia directly. Instead, they report the weight of nitrogen that exists in these three forms, and report these results “as nitrogen.” Using this convention, nitrate is reported as nitrate as nitrogen (usually abbreviated NO_3-N), nitrite is reported as nitrite as nitrogen (usually abbreviated NO_2-N), and ammonia is reported as ammonia as nitrogen (usually abbreviated NH_3-N).

M.2.2 Phosphorus and Orthophosphate

There are several forms of phosphorus that can be measured. Total phosphorus (TP) is a measure of all the forms of phosphorus, dissolved or particulate, found in a sample. Soluble reactive phosphorus (SRP) is a measure of orthophosphate, the filterable (soluble, inorganic) fraction of phosphorus, the form directly taken up by plant cells. Total phosphorus and orthophosphate are analyzed colorimetrically using a spectrophotometer, as described earlier. To analyze orthophosphate, the laboratory simply adds chemical reagents to a sample. The reagents react with orthophosphate in the sample and turn color, and the degree of color is measured using a spectrophotometer.

To test for total phosphorus, a digestion step is added before the analysis. The sample is heated with strong oxidizing agents and acid, and this converts all forms of phosphorus in the sample into orthophosphate. The sample is then analyzed for orthophosphate as described above.

Similar to the nitrogen compounds described above, orthophosphate is almost always reported as the weight of phosphorus in the sample that exists in orthophosphate form, not as the actual amount of orthophosphate present in the sample. Using this convention, orthophosphate is reported as orthophosphate as P (usually abbreviated orthophosphate-P).

M.2.3 Total Kjeldahl Nitrogen

Total Kjeldahl nitrogen (TKN) is a measure of all of the nitrogen in a sample that exists in all forms except nitrate and nitrite.

TKN is analyzed by first digesting the sample by heating it with strong chemical reagents and acid. All forms of nitrogen in the sample except nitrate and nitrite are converted into ammonia by this digestion. The total ammonia in the digested sample is then measured either colorimetrically or with an ion-specific electrode.

M.3 Methods for Trace Metals

The analysis of metals in environmental samples is a two-step process. First, the sample is digested, as described in Section 5.3.6. The sample is mixed with strong acid and heated. The digestion process dissolves particulate matter in the sample and drives all metals into the dissolved state. The sample digest is then analyzed using one of the following three instruments:

Absorption Spectroscopy (AAS) – Metals in their elemental form absorb ultraviolet light when excited by heat. Each element absorbs UV light at a unique wavelength. The atomic absorption instrument incorporates a flame with a light source on one side and a photoelectric detector on the other. The instrument introduces some of the sample digest into the flame. As the sample digest enters the flame, the target element in the sample absorbs some of the UV light, reducing its intensity. The detector measures this reduction in intensity and the instrument converts it into a concentration.

AAS is an older technology and is rarely used for modern stormwater monitoring. Although this technology can achieve low reporting limits, AAS instruments are limited to analyzing one metal at a time. A single sample must be analyzed multiple times in order to quantitate multiple metals.

1. Inductively Coupled Plasma/Atomic Emission Spectroscopy (ICP/AES) – Metals emit electromagnetic radiation (light) when excited in a plasma flame. Each element emits a characteristic combination of wavelengths with an intensity that is proportionate to its concentration. The ICP/AES instrument employs an extremely hot (about 7,000° C) plasma flame and an optical spectrometer that can detect the light emitted by metals as they are excited by the flame. The digested sample is introduced into the flame, and the detector converts the emitted wavelengths of light into metals concentrations.
2. ICP/AES instruments can analyze a sample for many metals at the same time. One single analysis is typically enough to produce data for all metals in the project constituent list. The reporting limits achieved with this technology are low, but usually not as low as those achieved using an AAS instrument.
3. Inductively Coupled Plasma/Mass Spectrometry (ICP/MS) – This technology also utilizes a plasma flame to ionize target metals. As the digested sample is introduced into the flame, the metals are ionized. The ions have an electric charge and a specific mass (weight), and each element has a characteristic mass/charge ratio. A strong magnetic field accelerates the ionized metals into a mass spectrometer, where they are separated by their mass/charge ratios. The intensity of each ion is proportional to the concentration in the original sample.

Like ICP/AES technology, an ICP/MS instrument is able to analyze a sample for many different metals at the same time. In addition, the reporting limits achieved by ICP/MS are significantly lower than those achieved by the older AAS technology and usually a full order of magnitude lower than reporting limits achievable by ICP/AES instruments.

Because of this efficiency and ability to reach low reporting limits, ICP/MS is the preferred methodology for analyzing metals in stormwater.

M.4 Methods for Organic Compounds

Organic compounds that typically appear on a stormwater monitoring project constituent list include petroleum hydrocarbons (gasoline, diesel, oil, grease), pesticides (herbicides and insecticides), and heavy compounds usually associated with automobile traffic (polynuclear aromatic hydrocarbons, or PAHs).

The test for oil and grease is performed gravimetrically; that is, by weight. The hydrocarbons that make up oils and greases are extracted from the sample using an organic solvent. The sample is mixed with solvent and agitated vigorously, which causes the target analytes to move from the water phase to the solvent phase. The solvent is then removed from the sample, placed into a pre-weighed drying dish, and evaporated to dryness. The difference in the weight of the dish before and after the analysis corresponds to the content of target hydrocarbons in the sample.

All other organic constituents that typically appear on Caltrans stormwater project constituent lists are analyzed by gas chromatography (GC). Gas chromatography works on the same principle; the sample is introduced into one end of a separatory column and is carried through the column by a carrier fluid (in this case, the carrier is an inert gas). The various constituents in the sample are carried through the column at different speeds, so they separate from each other as they move through the column. The detector at the end of the column responds to the target analytes as they leave the column, and the intensity of the response is proportionate to the amount of analyte present.

There are many kinds of detectors. The chemical characteristics of pesticides and PAHs vary widely, and different kinds of detectors are used to quantify them. The same is true of petroleum products. A particularly reliable GC detector is the mass spectrometer (MS). Methods that use gas chromatography with a mass spectrometer as the detector are called GC/MS methods.

M.5 Methods for Microbiological Constituents

Commonly tested microbiological constituents in stormwater include total coliform, fecal coliform, enterococci, and sometimes E. coli.

Analytical methods for microbiology involve incubating a sample for a specific period of time in a nutrient-rich environment and then counting the bacteria that grow. This is why it is so important that samples be analyzed quickly, usually within sixto eight hours of collection; microbes in the sample must be alive and healthy at the start of the test so they can reproduce in the growth media.

Microbiological analyses are initiated by mixing a specific volume of sample with a liquid growth media that contains nutrients. The mixture is incubated in a warm oven at about 38° C for between one and four days, depending on the test. After the incubation period, the sample/media mixture is checked for bacterial growth. The growth is expressed as the concentration of viable bacteria, or colony-forming units (CFUs), per 100 mL, present in the original sample. The result is reported as CFU/100 mL.

Total and fecal coliform are analyzed by the multiple-tube method, in which sample is added to 15 tubes of growth media at several different dilutions. The amount of growth in each tube is recorded after one to four days of incubation, and the result is determined statistically based on how much growth was observed at each dilution. Because the amount of growth is determined using a statistical calculation, not by direct observation, these results are expressed as a Most Probable Number, or MPN, of colony-forming units present in the original sample. The results of fecal and total coliform testing are reported as MPN/100 mL.

Enterococci and E. coli can also be tested using the multiple-tube method, or by filtering the sample, incubating the filter in the presence of a growth medium, and then visually counting the colonies that grow on the filter. Assay methods also exist for these two constituents, in which the sample is incubated in a nutrient-rich broth and chemical reagents fluoresce in the presence of the target organisms.

Appendix N SPECIFICATIONS FOR PLATFORM INSTALLATIONS

This appendix provides details for installing a monitoring station platform to support stormwater monitoring equipment. Figure N.1 shows two common configurations for constructing pads for stormwater monitoring stations. These details are intended as guidelines and consultants must adhere to any other local and site-specific requirements.

Monitoring station platforms must be made from either wood or concrete. When using wood, only unpainted, untreated wood (fir, redwood, cedar, or pine, cut from sound timber) and stainless-steel fasteners must be used. Materials that could leach chemicals into the surrounding environment must not be used.

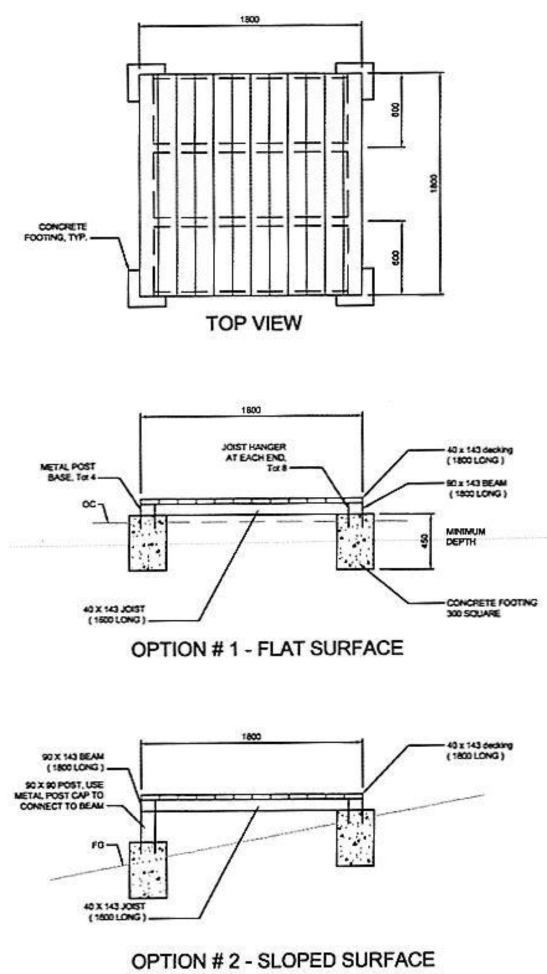

Figure N-1 Common Monitoring Platform Configuration

Appendix O INFORMATION FLOW BETWEEN DATA TOOLS

Caltrans has developed three software tools used by monitoring consultants to process, store, and report stormwater monitoring data. These tools are the Caltrans Post-Storm Technical Memorandum (PSTM) Utility, the Caltrans Hydrologic Utility, and the Caltrans Stormwater Data Archive (SDA).

Post-storm technical memoranda are created using the PSTM Utility. Hydrographs are created using the Caltrans Hydrologic Utility. All Caltrans stormwater monitoring data are stored in the Caltrans SDA.

The following figures illustrate how data flows between these utilities. Figure O.1 shows data flow in and out of the Hydrologic Utility. Figure O-2 shows the data flow associated with the PSTM Utility. Figure O-3 shows how data flow between these tools.

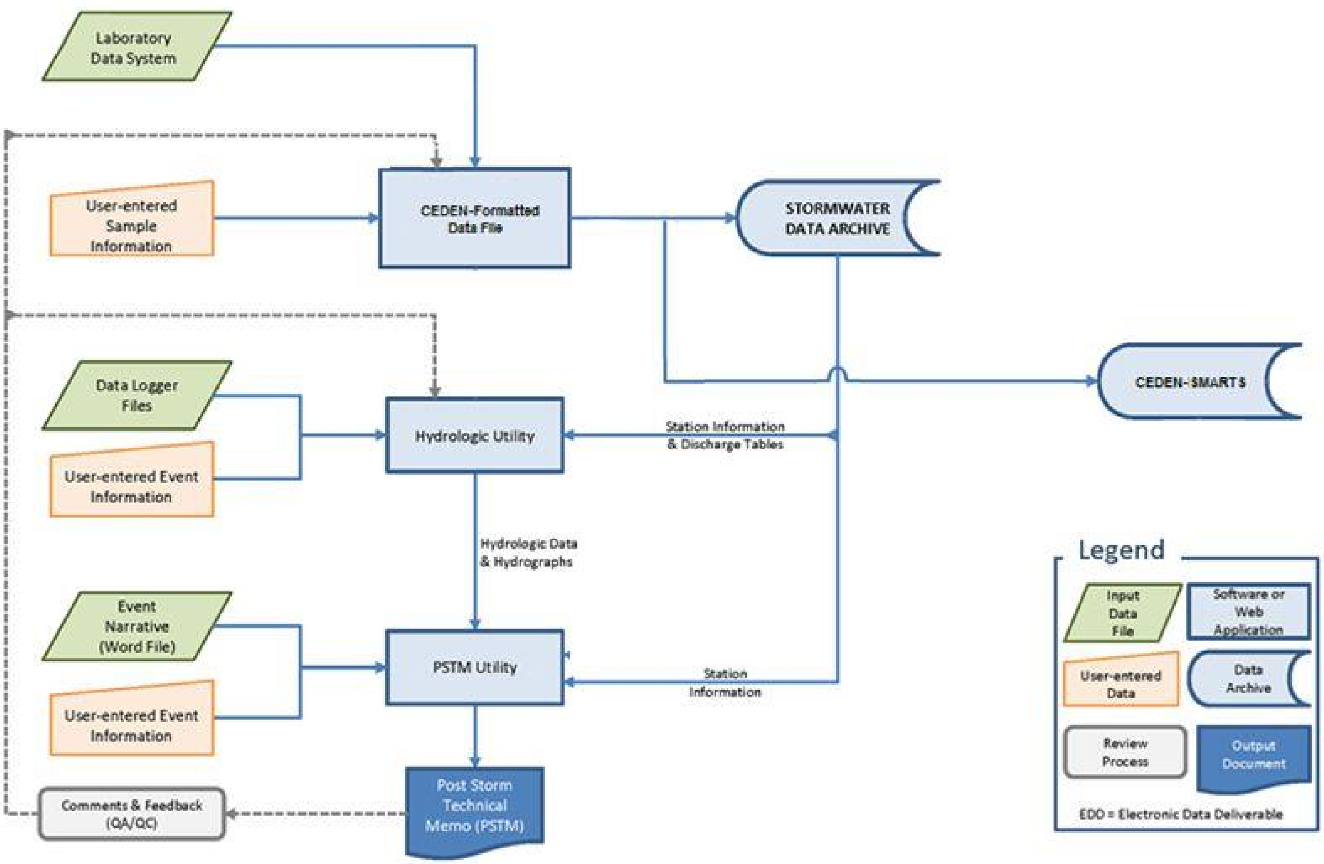

Figure O-1 Data Flow In and Out of the Caltrans Hydrologic Utility

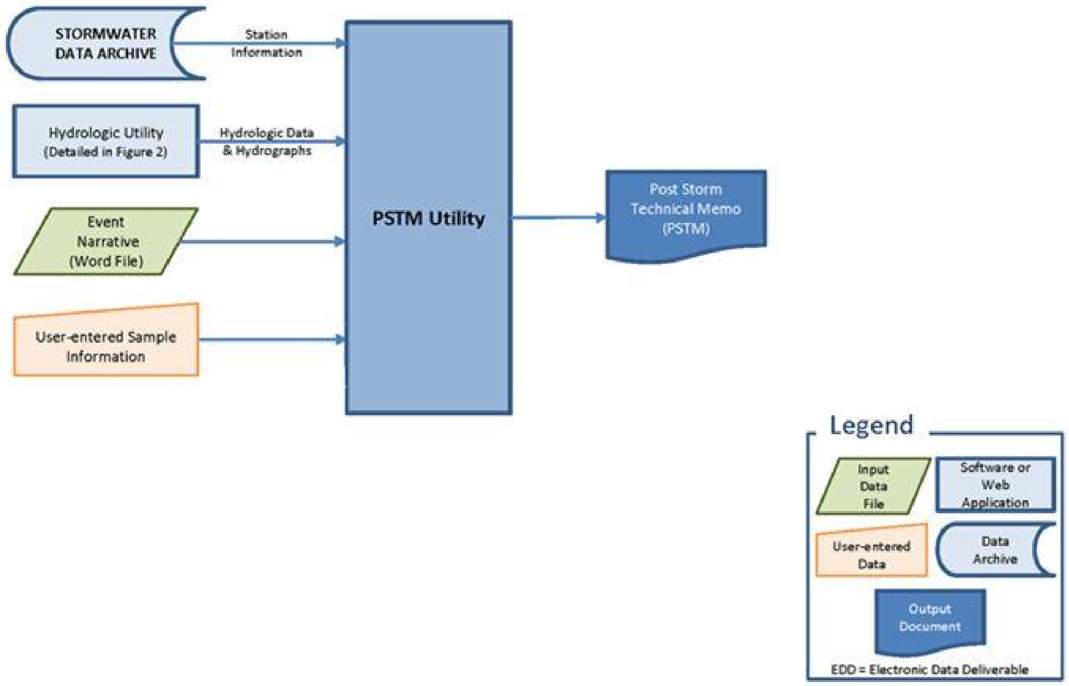

Figure O-2 Data Flow In and Out of the Caltrans PSTM Utility

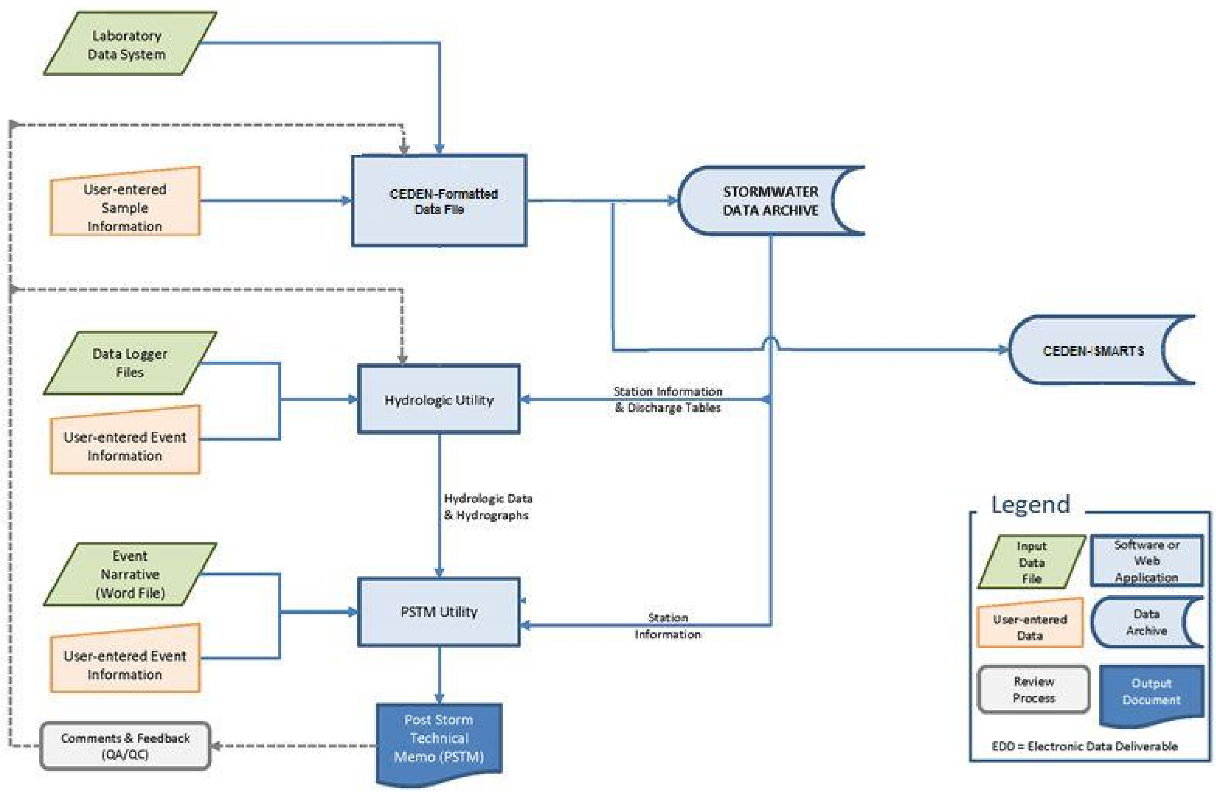

Figure O-3 Data Flow Between the Utilities