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NSTITUENTS OF HIGHWAY RUNOFF

Vol. II. Procedural Manual for Monitoring of Highway Runoff

February 1981

Final Report

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Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
Environmental Division
Washington, D.C. 20590

FOREWORD

This report is composed of six volumes: Volume I documents the constituents of highway stormwater runoff and their pollutional effects; Volume II contains detailed procedures for conducting a monitoring and analysis program for highway runoff pollutant data; Volume III describes a simple predictive procedure for estimating runoff quantity and quality from highway systems; Volume IV is the research report discussing research approach and findings; Volume V contains the computer users manual for a highway runoff data storage program and Volume VI is an executive summary. The report will be of interest to planners, designers and researchers involved in evaluation of highway stormwater runoff contributions to non-point sources of water pollution.

Research in Water Quality Changes due to Highway Operations is included in the Federally Coordinated Program of Highway Research and Development as Task 3 of Project 3E, "Reduction of Environmental Hazards to Water Resources Due to the Highway System." Byron N. Lord is the Project and Task Manager.

Sufficient copies of the report are being distributed to provide a minimum of one copy to each FHWA Regional Office, Division office and State highway agency. Direct distribution is being made to the Division offices.

Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

NOTICE

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16. Abstract

This manual has been prepared for use by highway department personnel to evaluate highway runoff. It contains detailed procedures for establishing and conducting a monitoring program and evaluating the collected data. Step-by-step procedures are delineated and following these steps should help in developing a simple and straight-forward method which will lend itself to use for the design, planning, conduct and evaluation of proposed sampling programs.

The titles of the volumes of this report are:

FHWA-RD-	Subtitle	
81/042	Vol. I	State-of-the-Art Report
81/043	Vol. II	Procedural Manual for Monitoring of Highway Runoff
81/044	Vol. III	Predictive Procedure for Determining Pollutant Characteristics in Highway Runoff
81/045	Vol. IV	Characteristics of Runoff from Operating Highways. Research Report
81/046	Vol. V	Highway Runoff Data Storage Program and Users Manual
81/047	Vol. VI	Executive Summary

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METRIC CONVERSION FACTORS

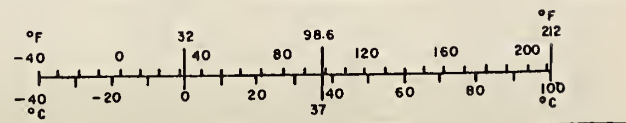
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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ACKNOWLEDGEMENTS

Acknowledgement is given to numerous State highway and U.S. Geological Survey representatives as well as individual experts who provided assistance during the progress of the study and preparation of the final report. It is not possible to name all who participated in this research study and therefore only a few key agencies and persons are listed below.

The following State highway agencies provided technical assistance, sites for field investigations, traffic and maintenance data:

Colorado State Department of Highways
Louisiana Department of Transportation and Development
Pennsylvania Department of Transportation
Tennessee Department of Transportation
Wisconsin Department of Transportation

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Review and assistance in the preparation of the final reports was provided by: Richard Howell, California Department of Transportation and Roderick Moe, Texas State Department of Highways and Public Transportation.

In addition to those agencies and individuals acknowledged above, sincere appreciation is expressed for the work of Frank K. Stovicek, (deceased), FHWA, Office of Research who thoroughly reviewed the final report.

SECTION I
INTRODUCTION

Growing awareness of the threat to the environment by highways and highway drainage systems has brought into focus a pressing need to identify and quantify these effects and to develop measures for the protection of the environment from any adverse effects. The National Environmental Policy Act (NEPA) of 1969, Public Law 91-190 mandates that for all projects affecting the environment, all government agencies shall utilize a systematic, interdisciplinary approach which will insure integrated use of the natural and social sciences and the environmental design arts in planning and decision-making.

Highway systems interact with the nation's water resources in numerous ways. Almost every mile of highway passes through a watershed; therefore, each highway process (planning, location, design, construction, operation and maintenance) has potential for impacting water resources. Pollution from highway sources must be reduced to the maximum extent possible in order to comply with the federal Water Pollution Control Act Amendments of 1972, Public Law 92-500, which sets a national goal of restoring and maintaining the chemical, physical, and biological integrity of our water resources. In addition, many states are in the process of enacting legislation similar to NEPA that may be more stringent than the federal laws in controlling various point and nonpoint discharges.

In order to determine the extent of environmental impact from highway facilities, it is necessary to determine the identity and quantity of substances entering the receiving waters from highway runoff. A number of studies (1)(2)(3)(4) have been done recently to identify the constituents and to provide additional data for refining the predictive procedures for estimating highway runoff quality. The constituents of highway runoff can be quantified by conducting monitoring programs which can vary greatly in sophistication. A simple program may involve monitoring a single runoff event using manual sampling and flow monitoring techniques. A more complex program might involve monitoring events for an entire year or longer using automated equipment. However, the basic monitoring approach is similar enough to make the development of this procedural manual worthwhile. This manual describes how to conduct a monitoring program, and its use by the highway community will ensure compatible results and data.

There are a number of factors affecting the quality of the runoff that must be actively monitored for any site. Primary among these are traffic characteristics, highway operation and maintenance practices, precipitation characteristics, and the accumulation of pollutants on the highway. There are several other factors that must be noted because of their relevance to the quality of runoff: adjacent land usage, right-of-way characteristics, roadway alinement, vertical plane alinement of the highway, pavement conditions, etc. All of these factors should be considered in a study program.

State highway department personnel may be required to determine the effect of highway runoff on the surface water quality of an adjacent body of water. Such study requirements may be for a specific site or may be so general that detailed investigations are required for the selection of a suitable site. The specific details of how to accomplish this usually are not given but are left to sampling personnel to decide. This manual is intended to partially fill this informational gap by providing "hands on information" on how to design and carry out a sampling and monitoring program. It is intended to provide detailed procedures which can be followed by personnel with limited experience in water quality monitoring. Included in this manual are discussions of the information that needs to be collected, the sampling and monitoring equipment needed, specific site selection, and the use of data that is collected. A glossary of terms has been included for those unfamiliar with the technical expressions encountered in environmental monitoring.

One of the first duties of the person responsible for the sampling program (the project director) is to determine how complex a program is needed. This will depend on a number of factors including intended use of the data, regulatory requirements, personnel available, and the most important and often governing factor, available funds. Since this manual covers a wide range of techniques and equipment, the project director must choose those techniques that will provide reliable data within budgetary constraints. The project director must also maintain contact with local, state and federal regulatory authorities responsible for water quality, as they may provide a source of technical assistance, analysis, samples for certain special parameters, possible funding, etc. The cooperation of state and local highway and police departments should be solicited, particularly for those tasks that require access to areas within the highway right-of-way. Their assistance will guarantee compliance with proper procedures and safety considerations. Cooperation with these authorities is strongly recommended as it will facilitate the successful completion of the program.

This manual is designed to help serve the needs of highway department personnel for establishing and conducting a runoff sampling and monitoring program from operating highways. It is not to be considered a water quality manual. For needs pertaining to water quality information, the reader is directed to other published sources, such as the Water Quality Manual Series (Volumes I through V) published by the Federal Highway Administration, U.S. Department of Transportation (5). The ensuing sections of this manual depict the various steps required in establishing a successful monitoring program. These steps are:

1. Selection of a suitable site.
2. Planning a monitoring program.
3. Installing the monitoring equipment.
4. Maintenance and monitoring procedures.
5. Evaluation and application of the results.

Following these steps should help in developing a simple and straightforward procedure for the design, planning, conduct and evaluation of proposed sampling programs.

SECTION II
SITE SELECTION CRITERIA

Selection of a monitoring site is important, since the findings are going to be based upon the data collected from the selected site. Selection of a specific site depends upon the monitoring program objectives. If an assessment of the impact of highway pollutant discharge on the receiving waters is the primary objective, emphasis in site selection should be on larger, isolated highway drainage areas for the end of the pipe type measurements close to the receiving waters. For such studies, it will be desirable to select a site in which drainage from both the paved as well as the unpaved areas of a highway right-of-way are discharged through one outlet. However, if the objectives of the study program require investigation of the sources and migration of pollutants within the highway right of way, site selection emphasis should be towards smaller drainage areas where the runoff from the paved and unpaved areas can be isolated within the selected highway system. If a particular location or highway is specified for monitoring, selection may be limited to finding a suitable "site" for the representative installation of the monitoring equipment.

Possible locations of the monitoring sites are almost unlimited, but the following general criteria may be utilized for site selection for monitoring pollutant discharges from operating highways:

- Right-of-way characteristics
- Adjacent land usage
- Traffic characteristics
- Geographic location, climatological and topographical factors
- Drainage area and highway design characteristics
- Paved (impervious) and unpaved (pervious) area characteristics
- Receiving water characteristics
- Logistical considerations: site accessibility, safety, availability of power, near future planned construction or highway improvement activity, etc.

Adjacent Land Usage

The land use activity near a highway system can have significant influence on the transport of pollutants onto the highway system. Land use activities may be classified under several categories such as: residential, industrial, agricultural, commercial, and suburban or park land, etc. Both rural and urban areas can exhibit peculiar features such as widely varying dustfall contaminants and traffic characteristics in terms of volume, speed, vehicular classification and movement patterns, etc.

Traffic Characteristics

The selected monitoring site should be representative of the average daily traffic (ADT) of the entire stretch of highway under study. If more than one site is to be selected in a study program, the sites should be chosen to represent the range of traffic characteristics of the area under consideration. Generally for operating highways, ADT values below 30,000 may be considered representative of low traffic volume, 30,000 to 100,000 as medium and above 100,000 ADT as high traffic volume. Daily and seasonal traffic variations should be considered. Other traffic characteristics such as vehicular mix, number of exit and entrance ramps, acceleration and braking characteristics, etc., should also be considered for site selection.

Geographic Location, Climatological and Topographical Factors

These factors are generally well defined for the purposes of most monitoring programs unless the objectives of a study require research on this topic. In case of a research study, several sites varying in geographical location, weather conditions, precipitation, wind, temperature and topographical factors (mountainous, flat, open, tunnel, etc) may be desirable depending upon the objectives of the study. The form of precipitation, i.e., rainfall or snow, can have significant effects on highway runoff. The intensity and pattern of precipitation should also be studied to distinguish between rainy and dry seasons.

Drainage Area and Highway Design Characteristics

The drainage area of a monitoring site should be well defined with minimum influence from other land use activities. Larger, isolated highway drainage areas may be desirable for the end of the pipe type measurements for characterizing the overall constituents of highway runoff leaving the highway drainage system. If impact on the receiving waters is the primary objective, then the largest possible site draining through a single outlet close to the receiving water should be selected. Smaller sites may, however, be more suitable for detailed investigative work particularly where separate examination of the runoff from various subareas of the total drainage area may be more critical to the objectives of a study program. However, in all cases the study drainage area should be free of drainage from sources outside the highway right-of-way. A drainage area may be considered small with approximately a one to two acre (0.4- ha) area and stretching over a highway section of less than 1,000 ft (305 m). Large, well defined highway drainage areas are difficult to isolate because of extraneous drainage additions along various points in most of the existing drainage systems. Typical highway drainage areas that may be found for such monitoring studies may be 2,000 to 3,000 ft (610 m to 915 m) long encompassing approximately 8 to 10 acres (3.2 to 4.0 ha).

Consideration should be given to various highway design features to ensure that the selected site will be representative of the highways in the study area. Some of the design features that may be included in such considerations are: vertical alinement of the roadway (elevated, ground level or depressed sections), highway grade or slope and the type of drainage i.e., curb and gutter or flush shoulder. The selected site should also be representative of median barrier characteristics that can have a significant effect on the buildup of pollutants on highways.

If the drainage area of a potential site is located in a depressed section and suitable discharge of runoff cannot be made nearby, the runoff may have to be pumped out of that area to another area. Even though such a site may have other features which are desirable, it should not be used because of the complexity of monitoring the flow rates and obtaining representative water quality samples.

Care should also be taken in selecting a monitoring site that will not be flooded due to water backup from the receiving stream during high water periods.

Paved (Impervious) and Unpaved (Pervious) Area Characteristics

It is important to know the relative degree of pervious and impervious areas within a highway drainage area because of their potential impact on highway runoff. The type of pavement surface i.e., bitumnuous or concrete may again affect the quantity or quality of pollutants discharged from a highway system. The age of pavement and the pavement maintenance practices can have significant effect on the accumulation of pollutants on highways. An average pavement condition may be considered in selecting a typical site.

Similarly, the right-of-way characteristics and the roadway materials of construction should be typical of the highways in the area. Among the right-of-way characteristics the factors needing consideration are: type of cover, type of soil and maintenance practices. If the site area is in a dry region, sprinkler irrigation may be in use that can affect the quantity of runoff produced and in turn the amount of pollutants discharged during stormwater periods.

Receiving Water Characteristics

If field tests are to be conducted to define the magnitude of the impact of highway runoff on the receiving stream, a detailed investigation should be made to obtain existing stream water quality data as well as the effect of other land use activities. Ideally, the monitoring site for highway runoff impact studies should be on a stream where the upstream samples above the highway discharge point are not contaminated by other nonmonitored discharges. In this way, heavy metal loads and other sensitive parameters can be attributed more easily to the highway runoff. Also, the monitored reach of the receiving stream should be free from overland inflows or withdrawals.

Logistical Considerations

These considerations include several miscellaneous items that can be extremely critical in terms of practical difficulties and can greatly influence the final selection of a site that may have most of the other desired features discussed earlier in this section. These considerations are:

a. Accessibility - Site should be accessible to operating personnel both in terms of convenience and safety for installing, as well as monitoring the instrumentation. Monitoring areas should be as vandalism proof as possible. Security measures might include locks on monitoring shed doors, using fenced in areas wherever possible, securing equipment not housed in a protective shed to platforms which are anchored into the ground, and arranging with local law enforcement agencies who normally patrol in the vicinity of the monitoring area to periodically check for vandalism.

b. Power - The availability of line electricity should be considered when automated equipment is to be used because of its convenience and reliability. Certain monitoring equipment, such as the hi-vol air quality samplers, may require 110 volt power for operation and in such cases the availability of power may become a definite prerequisite for site selection. In most other cases, battery power may be used with portable instrumentation and the availability of line electricity will not be so critical.

c. Construction Activity - There should not be any major construction activity planned on the site drainage area or its vicinity during the study period. Such activity can significantly affect the type and level of pollutants discharged from a highway system. This consideration should, of course, be deleted if the data is being collected to assess the environmental damage due to construction itself. Early and frequent contacts with the state or local highway planning and maintenance personnel will be extremely helpful in avoiding any unexpected construction activities during the course of a study.

It is unlikely that a single site will meet all of the above criteria. In such a case the best site should be chosen and modifications made to make the site suitable for monitoring. For example, any tap-ins or drainage channels from outside sources will have to be blocked off, re-routed or monitored.

Typical Site Data

Once a specific site is selected, the pertinent data will merely consist of documenting the physical, traffic and climatological characteristics of the site. Much of the needed information can be obtained from government (public) sources. Information on the roadway and the right-of-way characteristics and maintenance activities should be available from the state and local Highway Departments. The watershed and receiving water characteristics are often available from the state Environmental Protection Agency (or equivalent body such as the Department of Natural Resources, etc) or from a regional 208 planning commission. Topographical maps which delineate the watershed area are usually available from the U.S. Geological Survey and other local agencies. Historic weather information can be obtained from the National Oceanographic and Atmospheric Administration, U.S. Department of Commerce, Asheville, North Carolina.

Much of the data available from these sources should be complimented or confirmed by actual inspections of potential sites with local personnel. Many times certain modifications may be made in the field that may never be represented on the 'As-Built' or available drawings and, therefore, can be uncovered only through site inspections. Typical site characteristics that should be documented are shown in the following example:

Site Characteristic	Typical Site Data
Location:	East-west bound lanes I-794, Milw., WI.
Adjacent land use:	Industrial/commercial.
ADT:	53,000; continuous automatic traffic data available for site.
Vehicular classification:	Mostly passenger cars; <10% trucks
Precipitation:	Total; 30 in./year (76 cm/yr)
Surface type:	Concrete
Number of lanes:	Six
Length:	813 ft (248 m) (approximately between stations 309 and 317)
Vertical alinement:	Elevated bridge deck
Total drainage area:	2.1 acres (0.85 ha)
Highway ROW area:	2.1 acres (0.85 ha)
Paved area:	2.1 acres (0.85 ha)
Unpaved area:	0.0 acres
Off-site drainage area:	0.0 acres

Height of curb or barriers:	Bridge deck (approx. 6 ft or 1.8 m high walls)
Recieving water:	Milwaukee River. All drainage discharges to the river through a separate and isolated storm sewer. Drainage from the elevated section is conveyed to the sewer by means of inlets and downspouts.
Exit or entrance ramps:	None
Availability of power for sampling station:	Can be arranged through local electric company.
Sewer slope or channel grade:	<1%
Monitoring point:	6 ft (1.8 m) deep manhole; 24 in. (0.6 m) sewer
Accessibility to sampling station:	Good accessibility to sampling station; no safety problems for equipment installation or monitoring. A locked shed to house the equipment recommended to make it vandalism proof.
Any planned construction modifications during monitoring period:	None for next two years.
Availability of maintenance data:	Yes. Excellent attitude and cooperation of state personnel in providing such data.
Availability of construction specifications, materials, 'As-Built' drawings, etc.	Yes. Easily accessible through state highway personnel.

In addition to the above data, several other items of information would be pertinent for sites contributing significant runoff from the highway right-of-way such as type of soil, vegetative cover, side slopes and drainage pattern. Background information would also be necessary on roadway alinement (slope, grade, curvature), pavement condition, lane width, shoulder width, and material, curb and barrier types and drainage pattern from road to the monitoring outlet or location.

SECTION III
PLANNING A MONITORING PROGRAM

Once the objectives of the monitoring program have been determined, planning can begin. Thorough planning is essential to the development of an efficient, effective monitoring program. Integration of considerations necessary for proper planning are shown in Figure 1.

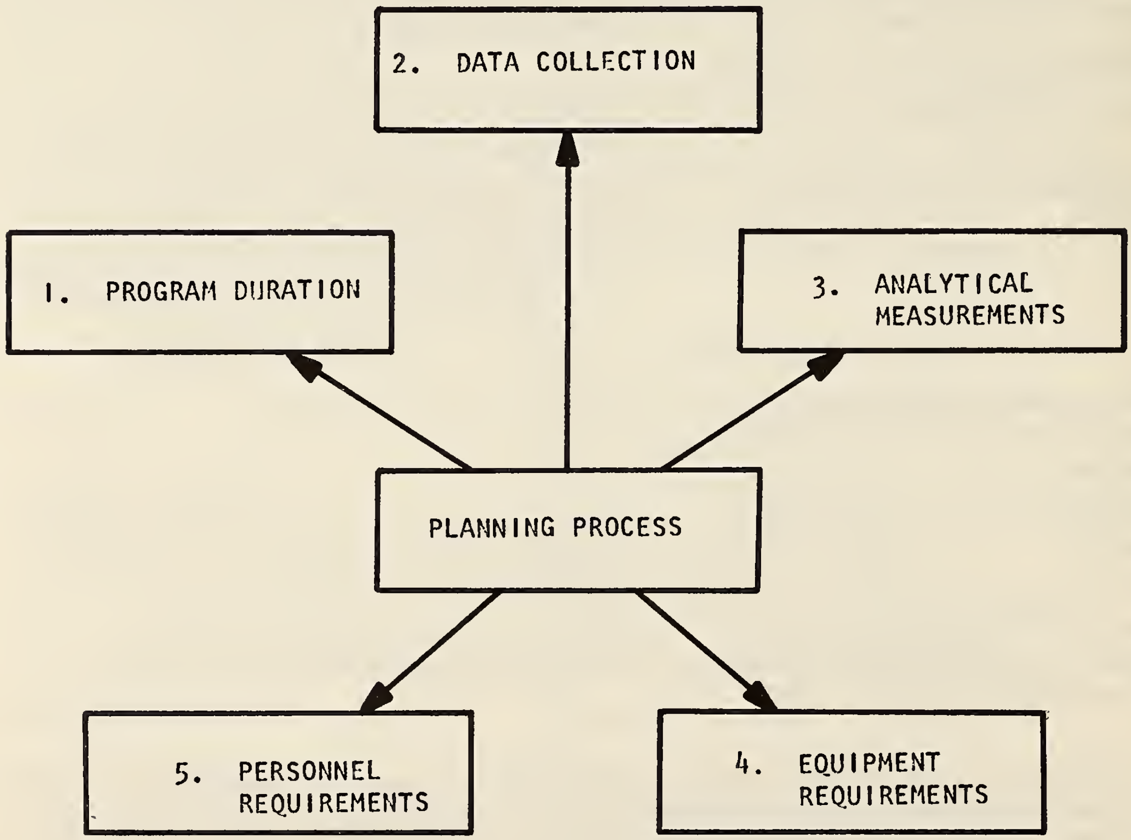


Figure 1. Integration of considerations necessary for proper planning of a monitoring program.

Program Duration

For most types of monitoring programs, it is advantageous to monitor storm events for a 12 month period. This time frame allows for a study of variations in pollutant characteristics due to seasonal changes and will generally provide more than 20 storm events for monitoring (excepting areas with extremely arid climates). A fairly wide variation in rainfall intensities, rainfall durations, and pre-storm conditions (i.e., the number of dry days) should also occur in a 12 month period. Information of this type is necessary to provide statistically reliable data for the prediction of pollutant accumulation rates and washoff efficiency.

If limited resources and/or budgetary constraints make a one year monitoring program impossible, a monitoring program of six months duration, or a minimum of 10 storm events may be established. Monitoring 10 storm events should provide data with some statistical reliability. Also, at least this much data is necessary to permit the prediction of pollutant loadings from a given site. By maintaining close contacts with local weather forecasters and the National Weather Service, it is possible to choose storms of varying intensity and duration. Pre-storm conditions should also be considered in the decision to monitor specific storm events.

Data Collection

This task pertains to the physical quantification of the volume and concentration of pollutants emanating from highways and the adjacent right-of-way. It is also necessary to obtain data on those variables which affect the accumulation of pollutants at the monitoring site.

To accomplish this task the following site background data and monitoring data must be collected:

Site Background Data - Site background data needed includes traffic characteristics and roadway/right-of-way maintenance.

Traffic Characteristics - The collection of traffic counts is important for the correlation of the pollutants in runoff with traffic characteristics. Generally, some ADT and/or vehicular classification data for most highways is available from the state or local highway department. This data may not be current, however, unless a permanent traffic counter is located on or adjacent to the selected site. A temporary automatic traffic counter should, therefore, be installed to collect daily counts for the study site. The local or state highway department should always be consulted on the collection and interpretation of traffic data. It is often the case that only the highway department personnel are authorized to collect such data or a highway department person may be designated to coordinate such data collection. The highway department may also be able to furnish a counter for the duration of the study, thus sparing the expense of purchasing the equipment. If a counter must be purchased, the state or local highway department should again be consulted. They should be able to offer suggestions as to which units are the most dependable, and they may be able to service the units should any problem arise.

In addition to ADT, manual vehicle classification counts should also be obtained at least once every three months to record any changes in vehicular mix due to seasonal variations. This data may be useful as a qualitative means of explaining differences in runoff pollutants between monitoring sites.

Roadway/Right-of-Way Maintenance - All of the necessary highway maintenance data should be available through the local or state highway district responsible for maintaining the study site area. Advance planning is required, however, to ensure that this data is properly recorded on suitable forms by the maintenance personnel and submitted to the study director on a monthly basis. Standard forms for each of the maintenance functions should be developed and given to the maintenance personnel. Figure 2 is an example of a sanding maintenance form. The following data should be recorded throughout the duration of the monitoring program:

- Road sweeping-technique, dates, time, frequency, and duration along with best estimates of the total amount collected.

- Roadside grass mowing and/or weed cutting-technique, dates and time, frequency and duration.

- Herbicide spraying-type of herbicide, application date and method, rate of application and total amount used.

- Sprinkler irrigation frequency, duration, and estimate of the rate of water usage.

- Fertilizer type, spreading frequency, total amount used and dates of application.

- Road sanding/salting data during winter periods - date and time of application, type, mix, and rate of application, number of applications, and total amounts used.

- Any road repair, lane marking, painting or other road improvement items performed in the past month.

- Accident and spill data that may be pertinent to the study.

<u>Monitoring Data</u> - Monitoring data needed includes climatic conditions and runoff monitoring.

SALT/SAND APPLICATION DATA

Test area: I-25 and I-70
Denver, CO

Date: January 8-9, 1977

Time: 2100 - 0400 hours

Number of Passes

VEH. NO.	M.L.N.B.	M.L.S.B.	S.E. #1	S.E. #2	S.W. #1	S.W. #2	M.L.E.B.	
1766								
1350			////	////	////	////		

TOTAL LANE MILES PER RAMP

	2.52	2.52	.85	.14	.70	.15	.90	TOTAL LANE MILES
1766								
1350			3.60	.56	2.80	.60		7.56

			TOTAL TONS PER RAMP					TOTAL RAMP TONS
1766								
1350			.99	.14	.69	.15		1.87
							TOTAL TONS USED	1.87

NO. 1766 - ROLLER SANDER - 238 lb/mi (67 kg/km) - SPOT SAND

NO. 1350 - SPINNER SANDER - 496 lb/mi (139 kg/km) - SPOT SAND

Figure 2. Salting/sanding maintenance form - used in a FHWA study in Denver, Colorado (5).

Climatic Conditions - Accurate measurements of precipitation at the monitoring site are critical to the entire monitoring program. Due to the time variable nature of precipitation events, it is necessary to utilize a recording device that provides a continuous record of rainfall intensity and duration. The precipitation recorder should be located at the monitoring site along with the runoff measuring equipment, or within the immediate vicinity of the site area. Similar raingages located more than one mile apart can have significant variation in recorded rainfall, therefore, monitoring sites with large drainage areas may require more than one raingage. Installation of the precipitation recorder on site will facilitate the "time synchronization" of the rainfall measurements with the flow measurements and sampling equipment. This equipment synchronization is extremely important in determining the lag time from rainfall to runoff and in the determination of pollutant discharge patterns as related to rainfall.

The precipitation gage should be capable of measuring both rainfall and snowfall. A weighing and recording type precipitation gage (either mechanically or electrically driven) having a 6-hour rotation time scale and 4.8 inch (12 cm) dual traverse is recommended for most storm monitoring applications. A mechanically driven precipitation gage should be capable of 7-day operation between windings.

On-site precipitation data may be supplemented by data collected with other gages maintained by city, state, or other private or governmental agencies. Copies of the official local climatological data can be obtained through the National Climatic Center at the following address:

National Climatic Center
National Oceanic and Atmospheric Administration
U.S. Department of Commerce
Asheville, NC 28801

This supplemental data is extremely valuable in times of equipment malfunction.

The official climatological data sheets also provide detailed data on temperature, wind, and other meteorological parameters that can be valuable background information for the study. In any long-term monitoring study, it is important to monitor air and/or runoff temperatures. Generally, the atmospheric temperature information available on the climatological data sheets is sufficient for study purposes if the station where this data was recorded is reasonably close to the study site. If this is not the case, air temperatures should be measured during monitoring events. Probes with recorders can be utilized to record runoff temperature, however, spot checking of runoff temperatures by field personnel may be generally sufficient for study purposes.

Dustfall measurements are a qualitative means of evaluating the effects of land use on the accumulation of pollutants on highway surfaces and right-of-ways. A minimum of three dustfall buckets should be installed at the monitoring site. The actual number of dustfall buckets utilized and the location of these buckets is dependent on the land uses adjacent to the site. Dustfall buckets should be located such that all of the adjacent land uses can be evaluated. The collected dust should then be analyzed once per month or between storm events for total solids. Additional details on the specifications and installation of dustfall buckets and processing of collected samples are discussed in Appendix B of this manual.

Runoff Monitoring - It is important to automate the sampling, flow measurement, and recording equipment. Since monitoring events are precipitation related, an exact prediction of when such an event will occur is difficult. Sampling personnel must be relatively close to the site, otherwise sampling of the beginning of the runoff event may be missed. A sensing device which automatically activates sampling equipment at a certain flow of runoff alleviates this problem. Some flow meters have the capability to generate an electronic flow pulse after sensing a predetermined amount of flow in volumetric units such as cubic feet, gallons, cubic meters, liters, etc. A sample is taken whenever the sampler (set in automatic flow mode) receives a specified number of flow pulses. If the flow meter being used does not have the capability to generate flow pulses, a solenoid can be used to sense a specified flow level and activate a sampler which has been preset to automatically collect samples at a specified time interval.

Synchronization - All the automated monitoring equipment should operate in-phase with each other. As mentioned previously, this synchronization is necessary to accurately determine the lag time from rainfall to runoff and to accurately determine the variations in pollutant loadings. Equipment may become unsynchronized or out-of-phase due to mechanical error (clock drive slippage, etc) or operator error. This may result in an undefined lag between the clocks in the sampling device and the flow recorder, therefore, true flow values corresponding to discrete samples cannot be determined. Pollutant discharge calculations or flow compositing of samples with such data are erroneous.

Event Marker - A simple means to minimize these errors is to carefully synchronize the equipment during routine maintenance. A more efficient method to eliminate these errors is through the use of an "event marker" on the flow recorders. The objective of an event marker is to record on the runoff hydrograph the times at which water quality samples were taken. Figure 3 illustrates a system utilizing an event marker with a bubbler type level recorder in a FHWA study in Milwaukee (5). Basically it consists of activating a normally open solenoid valve each time the sampler pump starts. Upon activation, the solenoid valve closes, thereby

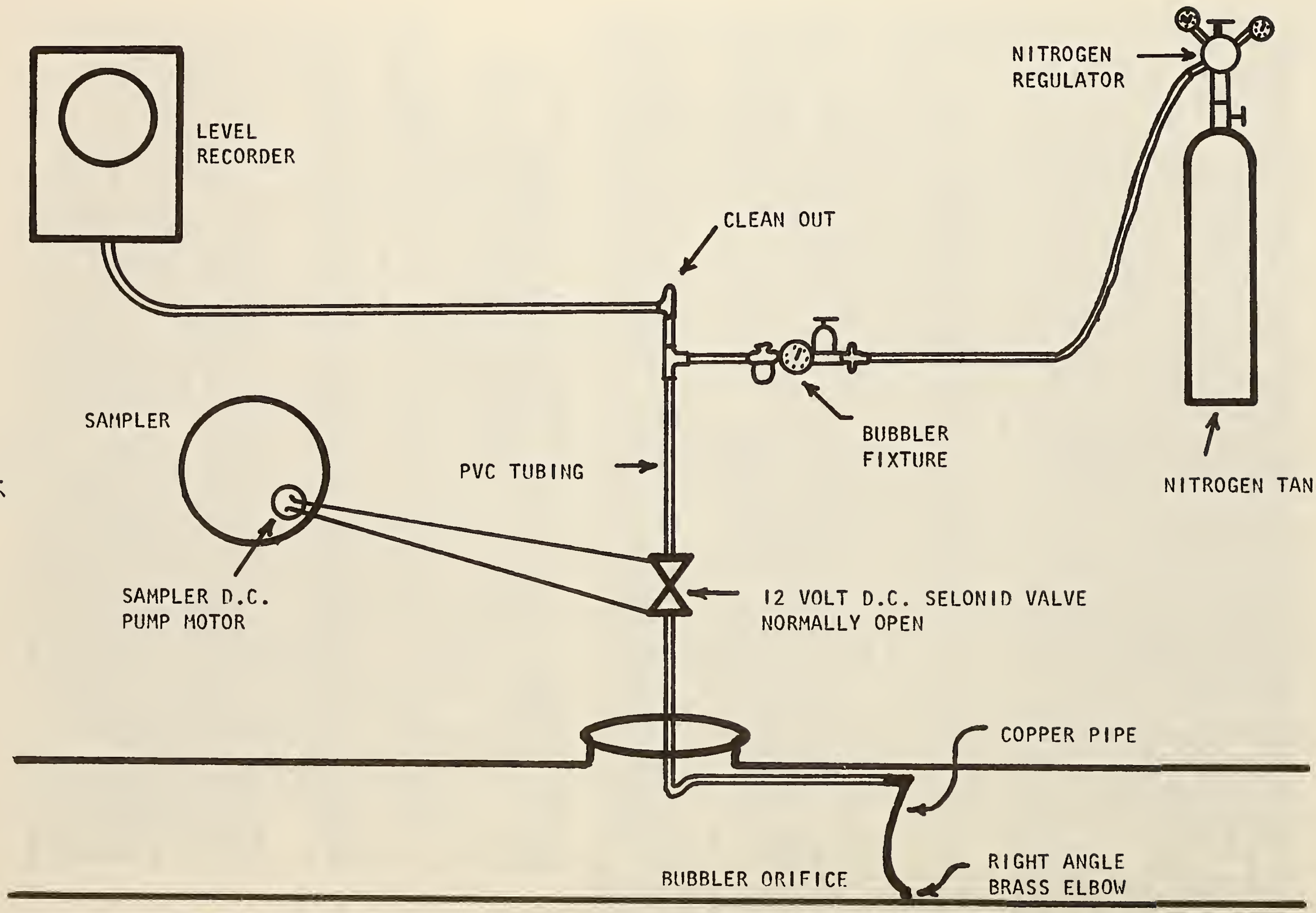


Figure 3. Schematic for an event marker used with a bubbler type level recorder.

blocking air flow to the orifice. This produces a sharp spike on the runoff hydrograph indicating the individual sampling event. Figure 4 is an example of a typical runoff hydrograph with event marker spikes.

In a study entitled "Characteristics of Highway Runoff in Texas" in R. D. Moe, et.al., (6) a different system was utilized for the event marker. A sump pump switch is activated from on to off by a float in a stilling well. This activates the sampling device by interrupting a ground for the sampler pump motor. Each time a sample is pumped, a solenoid is activated which creates a mark on the flow chart.

A separate event marker was also used with a digitalized bubbler flow recorder in an installation in Denver, Colorado (5).

Another type of event marker utilizing a mechanical float type flow recorder was used in a Harrisburg, Pennsylvania installation (5). A sampler pump is connected to a relay switch which is connected to an air pump in the wet well. Each time the sampler pump starts, the relay switch activates the air pump. This causes bubbles in the wet well which increases the buoyancy. The float rises with this increase in buoyancy resulting in a spike on the hydrograph indicating a sampling event.

Alarm System - Regardless of whether funds are available for automated equipment, every study requires some form of an "alarm" system to inform monitoring personnel of the beginning of a runoff event. Use of an alarm system is absolutely essential if automatic monitoring equipment is not being used. Even with the use of automatic equipment, it is highly desirable to use an alarm system to ensure proper equipment operation. Alarm systems can be very convenient if personnel do not live or work close to the monitoring site. They can eliminate many false trips to the site and, therefore, such expense is justifiable for any monitoring study.

Alarm systems can vary in complexity. For example, a signal light at the site can be connected to the sampler circuit. This light turns on whenever the flow recording or sampling equipment is activated. Highway department and/or law enforcement personnel can be requested to alert sampling personnel when the light turns on. Or, an alarm signal can be telemetered to a local police station, highway patrol office, or even a private answering service. Upon receiving the signal, they can telephone monitoring personnel. Arrangements can be made with local or state weather forecasters to inform monitoring personnel of approaching storms.

Paging systems can also be used as an alternative to the above arrangements. A pocket size electronic pager was satisfactorily used during a FHWA study in Milwaukee, WI (5). The pager is carried by the person on storm response call at all times. When precipitation starts, a 24 hour security guard (such as from an

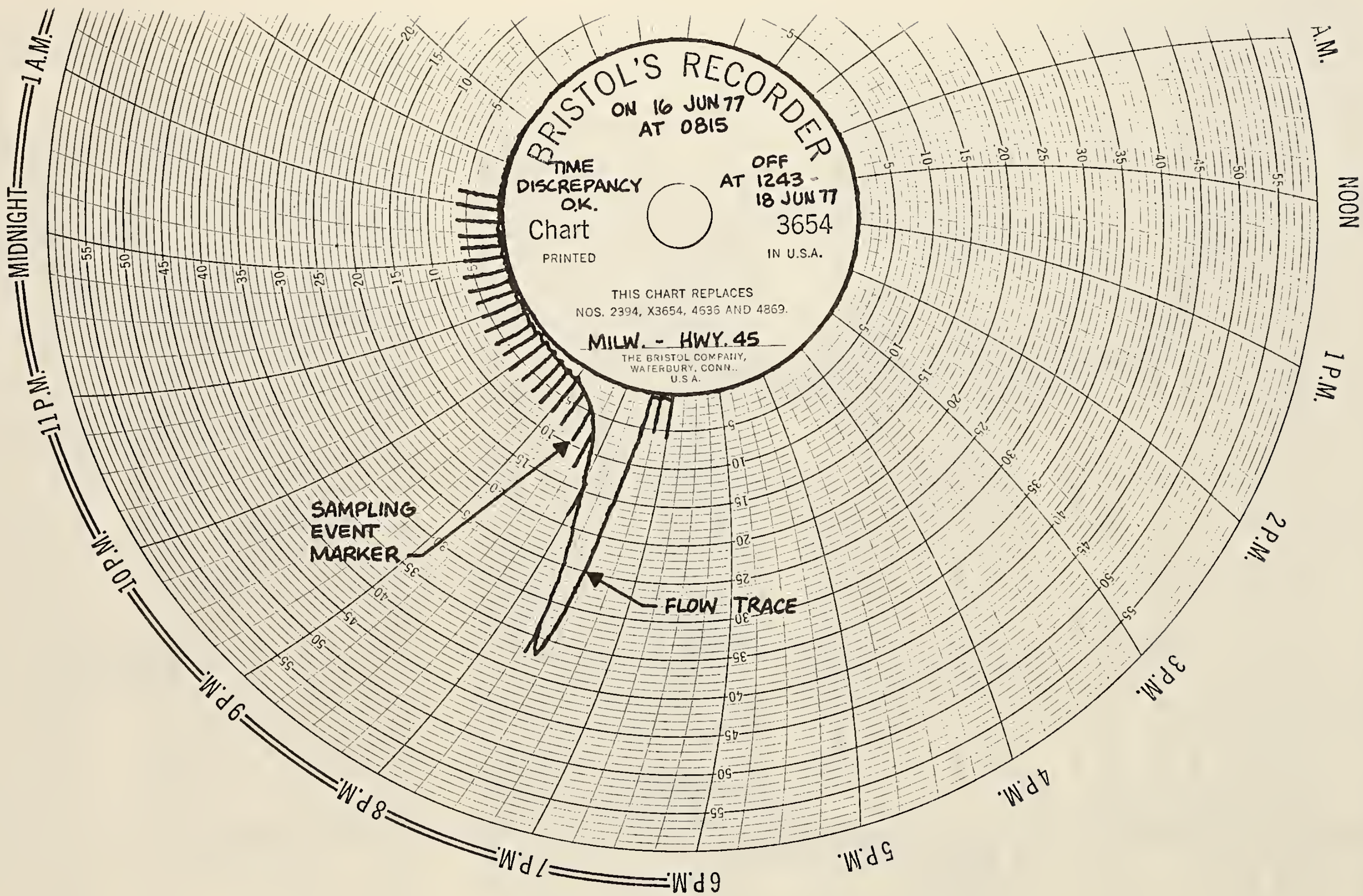


Figure 4. Typical runoff flow chart trace with event marker spikes, FHWA study, Milwaukee, WI (5).

industrial or commercial complex) calls the pager number. A beep tone is then sounded on the pager to alert the person on call of a potential storm event.

Even with the use of an alarm system, however, it is important that monitoring personnel keep in touch with local, state, or national weather service so that they are not surprised by a storm event.

Flow Measurement - Most highway runoff flow measurements are in the category of open channel or gravity flow as opposed to closed conduit pressure systems. For this reason, only gravity flow measurements are considered in this manual.

Two components are generally required to accurately measure gravity flow:

1. A calibrated device which is inserted in a channel such that the resultant water level is directly related to discharge.
2. A level sensing instrument which measures the water level upstream of the calibrated device.

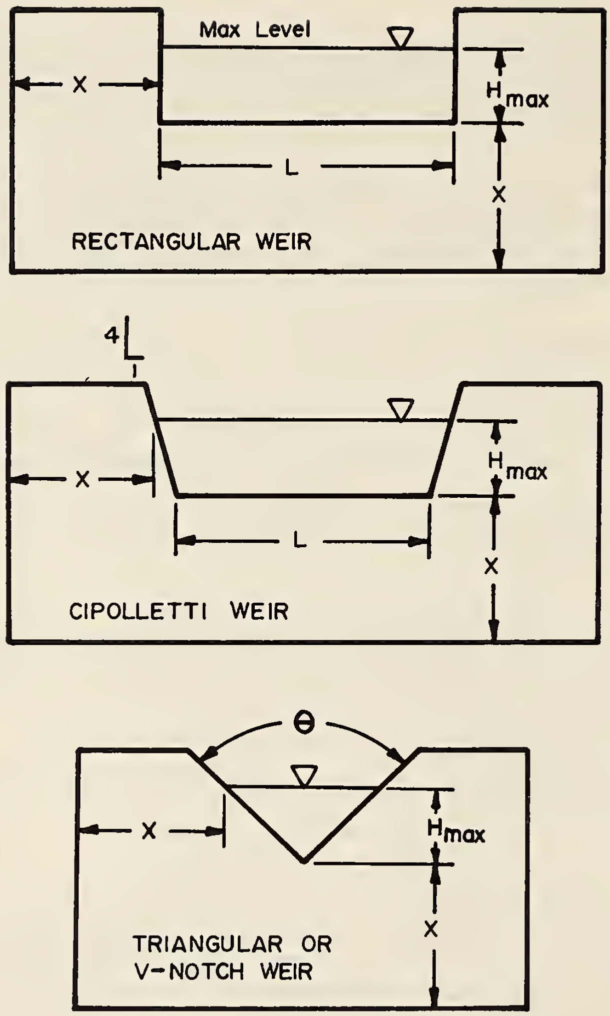
Weirs and flumes are two commonly used calibration devices. For a given type and size of weir or flume, the flow can be calculated using the appropriate formula. Neither device has significant advantages over the other, therefore, it is generally a matter of the preference and experience of the study director that determines whether a weir or a flume is utilized. More sophisticated units having precalibrated cams to provide direct flow measurements can also be utilized in some situations.

Weirs are generally less expensive to install than flumes but require more maintenance. Typical construction materials for weirs are plywood and sheet metal. Flumes have an advantage in that the loss in head in a flume is generally less than in a weir. Concrete and plywood can be used to fabricate flumes. Both weirs and flumes are available in prefabricated fiberglass sections, however, these are considerably more expensive then the previously mentioned materials. Commercially available weirs are generally for sewer sizes up to 48 inches (121.9 cm).

Some typical weirs and a nomagraph for calculating flows through V-notch weirs are shown in Figures 5 and 6. Discharge over a V-notch weir can also be calculated using a simple formula. For example, the discharge over a 90° V-notch weir can be calculated using the following formula:

$$Q = 2.5\ H^{2.5}$$

where Q = discharge in cfs
H = head on the weir in feet



L at least $3H_{max}$
X at least $2H_{max}$

Figure 5. Three common types of sharp-crested weirs (7).

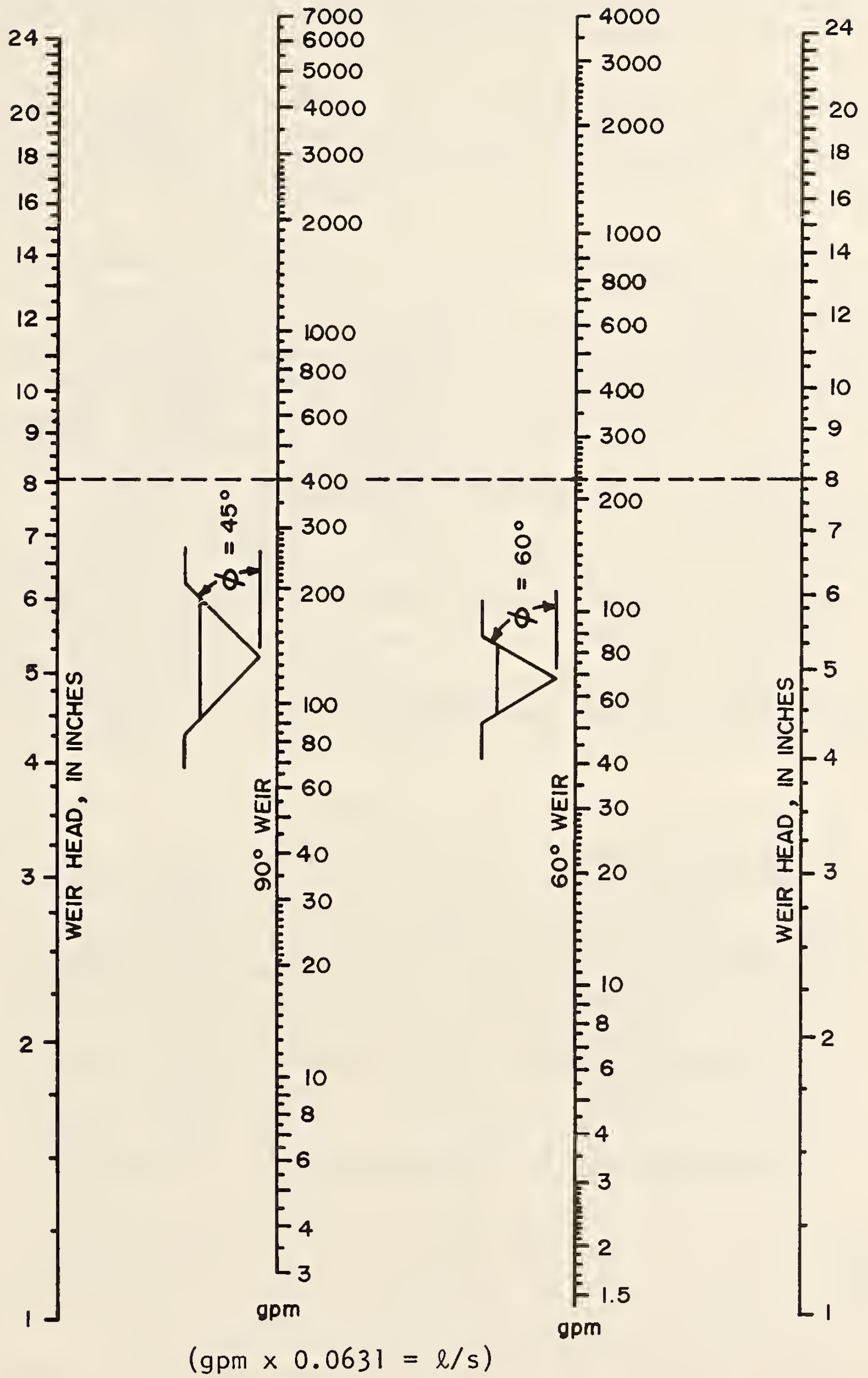


Figure 6. Flow rates in gallons per minute for 60° and 90° V-notch weirs (7).

Additional details on the design, construction, and rating of weirs and flumes can be obtained from references 7, 8, and 9.

Figure 7 illustrates various shapes of Palmer-Bowlus flumes. Details on the design of Palmer-Bowlus flumes are provided in Appendix A. Additional help and information can be obtained by contacting the Madison, Wisconsin Office of the U.S. Geological Survey.

The second component necessary for flow measurement is the level and recording instrumentation. There are a variety of level sensing devices available commercially. There are mechanical surface floats, bubbler tubes, and ultrasonic measurement devices. Reviews of a number of level sensing devices are found in references 10, 11, and 12. Additional details on specific equipment and procurement sources are given later in this section.

Water Quality Sampling - The basis for any pollutional impact program rests upon information obtained by sampling. Thus, all subsequent decisions may be based upon inaccurate data if adequate field sampling techniques are not utilized. The following are important considerations for obtaining good sampling results (7):

1. Ensure that the sample is truly representative of the runoff.
2. Use proper sampling techniques.
3. Preserve samples until analyzed.

These items are discussed in detail in Section V.

Two types of samples are generally used in the characterization of highway runoff. They are discrete and composite samples. A discrete sample is an individual sample that is collected at a particular time, while a composite sample is one that is formed by mixing portions of discrete samples. Discrete samples provide data on the time distribution of pollutant loadings during a runoff event. A composite sample provides data on the average concentration and total load of pollutants during a runoff event. The major value of a composite sample is that it reduces the number of chemical analyses required to determine the total pollutant load.

The most commonly used and recommended method for compositing highway runoff samples is the time constant-volume proportional to flow method. With this method, discrete samples are collected at equal time increments and are composited proportional to the flow rate at the time each sample was collected (Figure 8), This method closely approximates continuous sampling proportional to the flow rate. The smaller the time increment between the discrete samples, the more closely the composite approximates the wastestream. An advantage of this method is that compositing of the discrete samples can be readily accomplished manually.

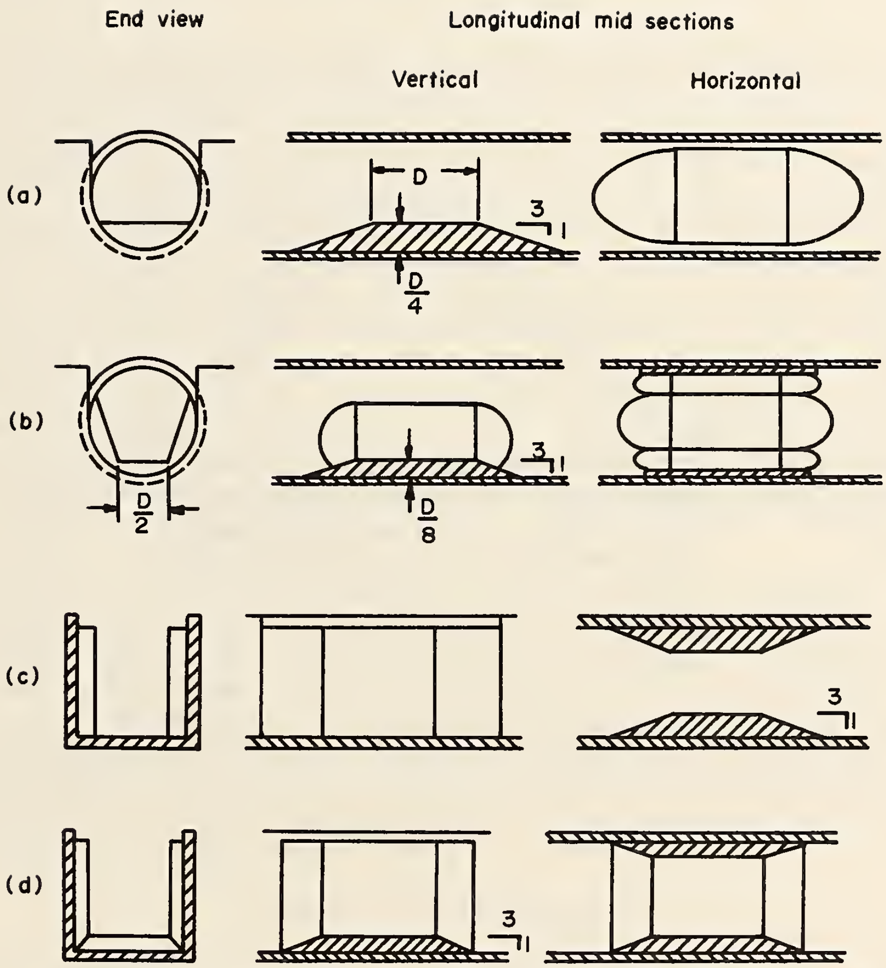


Figure 7. Various shapes of Palmer-Bowlus flumes (7).

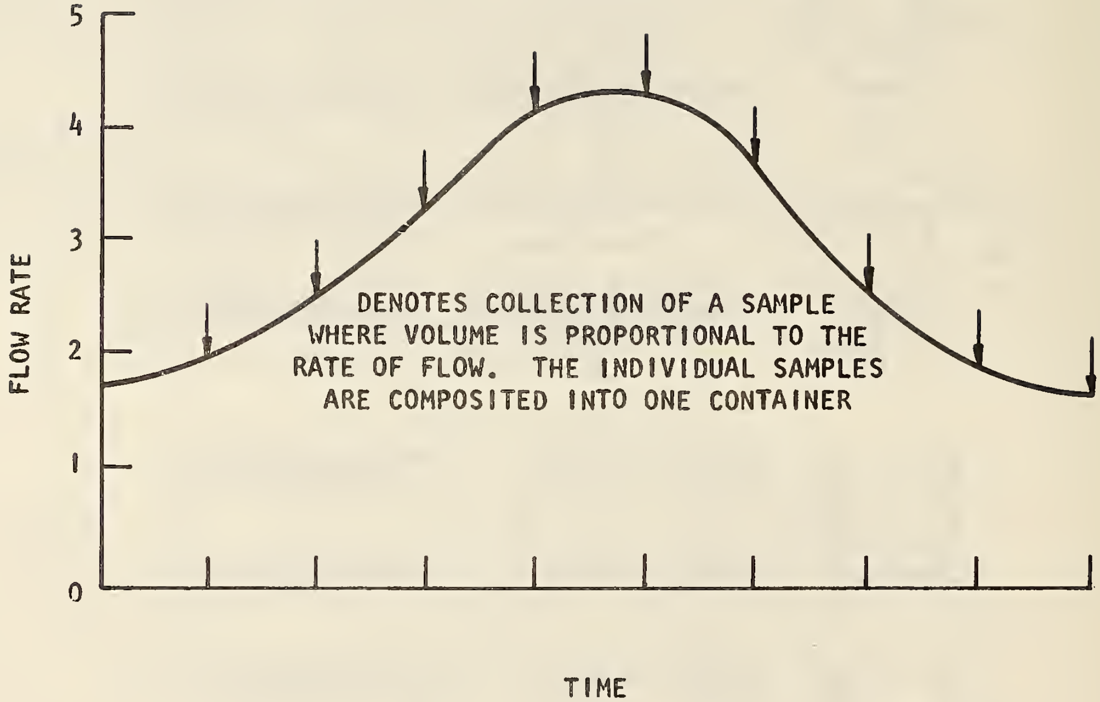


Figure 8. Method for compositing samples proportional to flow rate (13).

An extremely critical factor to having reliable composites is accurate and reliable flow monitoring data. It is in the compositing of samples where an event spike on the runoff hydrograph can be extremely helpful. A more detailed description of compositing samples is presented in Section IV. A detailed discussion of various types of sampling programs for runoff monitoring is found in "Methodology for the Study of Urban Storm Generated Pollution and Runoff" by R. E. Wullschleger, et.al., (13).

Usually, runoff as a result of rainfall has the highest concentrations of pollutants during the first stages of the event (first flush phenomenon). It is necessary to collect discrete samples at more frequent intervals during these periods to properly characterize the time variation in water quality. The proportion of paved area (impervious) versus unpaved area (pervious) in the total drainage area is an important variable in determining the sampling frequency. Drainage areas with a high proportion of paved area require sampling frequencies of 2 to 5 minutes during first flushes, and 15 to 30 minutes thereafter until runoff ceases. Areas which are completely paved may require even more frequent sampling during short duration/high intensity storms. Drainage areas with a high proportion of unpaved area require sampling frequencies of 5 to 15 minutes during first flushes and 15 to 60 minutes thereafter.

Samples for certain parameters require special attention and handling. Bacteriological samples, for example, require sterilized sample bottles and sterile handling techniques to avoid contamination. These samples must therefore be collected manually. Samples for oil and grease, pesticides/herbicides, and PCB's require glass bottles because of possible adsorption of these pollutants by plastic containers. Additional details on the handling and preservation of collected samples are in Section V of this manual and in Reference 14.

Analytical Measurements

In planning a monitoring program, an important decision is which parameters must be measured to fulfill the goals of the study. Water quality is a function of many parameters and can be evaluated on many different levels. For example, water quality can be evaluated from the following broad view points:

Solids
Organics
Metals
Oxygen demand determination
Nutrients
Indicator bacteria
Other

One approach to take in determining which parameters to measure is to first examine a large list of pertinent parameters such as shown in Table I. Examination of all of these parameters for a large number of samples is quite expensive. Normally only selective analytical determinations for the important elements are possible in any study program. Furthermore, limitations on sample volumes put another constraint on the number of analyses that may be performed on any one particular discrete sample. Even for the purposes of a research study, the large list of parameters should be examined only on a preliminary basis. The initial data should then be critically examined to determine the important elements for the remainder of the study.

Examination of the solids is extremely important for all studies of highway runoff. Solids deposit on highways from many sources such as tire and pavement wear, brake shoe drum wear, rust, mud and dirt accumulated on vehicle bodies, car exhaust, sanding/salting for roadway deicing, atmospheric fallout, pavement maintenance, extraneous litter and spilled loads such as sand, gravel, grains, etc. The measurement of total solids provides a total estimate of the total pollutant accumulation on the highway. Also, total solids is an important parameter for the purposes of predictive procedure where it can be used to predict the overall magnitude of pollutant accumulation and washoff from an existing or proposed highway system. The total suspended solids analysis provides information on the amount of total particulate matter contained in highway runoff. An estimate of the dissolved solids can be made by subtracting the total suspended solids from the corresponding total solids analysis. The volatile fraction of the solids gives an estimate of the organic and inert fractions of the solids loadings.

The organic materials measured for a given study are dependent on the purpose of the study, and which organics have been observed to be significant in a preliminary scan of pollutants. Oil and grease, and related petroleum compounds found in highway runoff result from spills or leaks of motor vehicle lubricants, antifreeze, and hydraulic fluids. Some oil and grease may also be contributed by the road bed leachate from asphalt paved highways. Tire wear is the source of traffic related rubber found on roadways (15). The PCB's and specific pesticides and herbicides originate mostly from the highway right-of-way maintenance practices. The significant cost of some of these determinations, especially PCB's and rubber, may be a sufficient deterrent for not measuring these parameters in highway runoff.

Some of the metals listed in Table I can be of major significance on highway surfaces. Much of the lead is deposited principally through the use of leaded fuels and some by tire wear where lead oxide is used as a filter material. Zinc is also used as a filler material in tires and as a stabilizing additive in motor oil. The majority of iron enters the highway drainage system from the rusting of vehicular bodies and other steel (such as guard rails, etc) normally incorporated in the construction of the highway system. Other heavy metals such as copper,

Table 1. Parameters pertinent to studies of highway runoff.

Solids
- Total
- Suspended
- Volatile total
- Volatile suspended

Oxygen Demand Determinations
- 5-day Biochemical oxygen demand
- 20-day Biochemical oxygen demand
- Ultimate oxygen demand
- Chemical oxygen demand
- Total organic carbon

Metals - Total and Soluble
- Chromium
- Copper
- Iron
- Lead
- Zinc
- Cadmium
- Nickel
- Mercury
- Arsenic
- Sodium
- Calcium

Nutrients
- Total nitrogen
- Total kjeldahl nitrogen
- Ammonia and nitrogen
- Nitrite and nitrate
- Total phosphorus
- Ortho-phosphorus

Organics
- Oil and grease
- Rubber
- Pesticides and herbicides
- Polychlorinated biphenyls
- Specific fuels or additives

Bacteria
- Total coliforms
- Fecal coliforms
- Fecal streptococci

Others
- pH
- Chlorides
- Alkalinity
- Sulfates
- Bromides
- Conductivity
- Asbestos

nickel and chromium, although found in much smaller quantities in runoff are present due to the wear of metals from metal plating, bearings, bushings and other moving parts within the engine. Some copper may be deposited as a result of the wear of brake linings which contain copper. Many of the other elements may be present in highway runoff due to specific contaminants being discharged through adjoining land usage (16).

Metals determinations are not very costly and as long as some metals are being measured in a given sample, the added cost to measure a few additional metals is generally minimal. For this reason, there is more freedom in the number of metals which can be measured than with most of the other parameters.

The oxygen demand determinations are not a measure of a specific pollutant, but rather they represent methods to measure the oxygen depletion effects of organics in water. The biological oxygen demand (BOD) is a measure of the oxygen depletion due to the biological oxidation of organic matter (carbonaceous demand) and nitrogen compounds (nitrogenous demand) under aerobic conditions. The chemical oxygen demand (COD) determination provides a measure of that portion of the organic matter in a sample that is susceptible to oxidation by a strong chemical oxidant (dichromate) (16). In the COD test, the carbonaceous portion of nitrogenous compounds can be determined but there is no reduction of the dichromate by ammonia nitrogen. The progressive exertion of the BOD of freshly polluted waters usually can be separated into two stages: a first stage, usually denoted as BOD_5 where the carbonaceous material is largely oxidized in the first five days, and a second stage in which significant amounts of nitrification takes place which are measured by 20-day BOD (BOD_{20}) or ultimate BOD. A COD test has the advantage of providing a quick estimate of the ultimate carbonaceous demand over BOD determinations. However, presence of high concentrations of chlorides can seriously interfere with the COD values (13). Similarly, BOD_5 determination can be seriously affected by the presence of toxic materials such as heavy metal lead in the waste stream (17). Therefore, extreme caution is advised in interpretation of these data.

An additional test that is used to measure the carbonaceous organic material is the total organic carbon (TOC) determination. TOC is a relatively easy test to perform and the results can be correlated with BOD and COD determinations and its results are the most reproducible of the three determinations (16).

Nutrients are important parameters to measure in highway runoff since they may be one of the causes of eutrophication in receiving waters. Total nitrogen is the sum of total kjeldahl nitrogen (organic nitrogen) plus ammonia nitrogen and oxidized nitrogen (nitrite and nitrate). Total phosphorus can be divided into a number of different fractions, however, the only other form which might be of value in a study of highway runoff is inorganic or ortho-phosphorus. Since the total loads of nutrients to receiving waters are of primary interest in most runoff studies, total nitrogen and total phosphorus should be measured.

Coliform bacteria are often of interest in highway runoff studies due to the public health standards for these organisms set for the recreational and consumptive user of receiving water. The presence of a significant concentration of total and fecal coliform in stormwater runoff is widely reported in publications on the subject (4)(15)(16)(17)(18). The origin of these bacteria in stormwater is related to animal excreta, bird droppings, soil, and litter found in most urban and rural environments. Fecal streptococci are also measured in stormwater so as to indicate whether the fecal coliforms are from human or animal sources. A ratio of fecal coliforms to fecal streptococci in excess of 4.0 indicates human sources whereas a ratio less than 0.7 indicates that the pollution is of animal origin (18).

There are a number of additional parameters which can be of value in a specific highway runoff study. Asbestos may be present in runoff due to wear on clutch and brake linings. Chlorides and bromides can be quite significant in areas in which salt is used for deicing road surfaces. Alkalinity is a measure of the capacity of water to neutralize acids. Alkalinity and pH can be extremely valuable parameters for explaining observed variation in other parameters. Conductivity is a measure of the total ions present in water and can be correlated with total dissolved solids.

In most studies, the asbestos analysis cannot be performed on a routine basis due to the significant cost (approximately $300 per sample). There is no approved NPDES technique for measuring asbestos, however, a TEM (transmitting electron microscope) technique is the most advanced at present. Very few laboratories have this capability. There is generally no limitation in measuring alkalinity, pH, or conductivity since these are simple and inexpensive to perform.

Table 2 presents a summary of the above information in terms of parameters which may be measured in a monitoring program.

The methods to be followed for laboratory processing and analysis of the water quality samples should be in accordance with Standard Methods for Examination of Water and Wastewater (19), and EPA's Methods for Chemical Analysis of Water and Wastes (20). It should be noted, however, that special methods may be required for certain special parameters such as asbestos, rubber, etc., and specific guidelines for the same should be obtained from either the specialized laboratories handling such determinations, the EPA, or local regulatory authorities. Additional details on sample handling and preservation techniques are discussed in Section V of this manual.

Table 2. Recommended list of parameters that may be measured in a monitoring program.

Solids	
	Total
	Suspended
	Volatile total
	Volatile suspended
Oxygen Demand Determinations	
	Chemical oxygen demand
	Total oxygen demand
Metals	
	Iron
	Lead
	Zinc
Nutrients	
	Total nitrogen
	Total phosphorus
Organics	
	Oil and grease (selected events)
	Polychlorinated biphenyls (selected events)
	Pesticides and herbicides (selected events)
	Rubber (selected events)
Bacteria	
	Total coliforms
	Fecal coliforms
	Fecal streptococci
Others	
	pH
	Conductivity
	Chlorides (seasonal)
	Asbestos (selected events)

Consideration must be given to the location of the laboratory facilities in relation to the study site. Bacteriological and BOD determinations must begin within 8 to 10 hours of sampling. Samples for the other analyses can generally be preserved and shipped to a suitable laboratory.

Equipment Selection and Procurement

The following discussion details the specifications, procurement, and cost of pertinent sampling/monitoring equipment.

Flow Measurement - As discussed earlier, there are two components of flow measurements;

1. Calibrated flow measuring devices such as a flume or weir , and

2. The recording instrumentation.

If the weir or flume is to be fabricated on-site, refer to Section IV. A V-notch weir constructed of plywood and sheetmetal is shown in Figure 9. If these devices are to be procured commercially, the vendor will need to know the size, location, slope, and other pertinent information for the sewer or the outfall being monitored. If a preference for the type of weir or flume has been established, the same may be specified, otherwise recommendations may be sought from various equipment suppliers. The vendors can generally provide rating curves and other useful literature for prefabricated flumes and weirs in a variety of sizes. Some of the manufacturers handling prefabricated flumes and weirs are listed below.

Plasti-Fab Inc.,
11650 S.W. Ridgeview Terrace
Beaverton, OR 97005

Leupold & Stevens, Inc.
P.O. Box 688
Beaverton, OR 97005

NB Products, Inc.
35 Beulah Road
New Berlin, PA 10901

Fischer and Porter Co.,
Warminster, PA 18974

Singer, American Meter Div.
P.O. Box 13693
Atlanta, GA 30324

For the second component of flow measurement, there are a variety of level sensing devices available. There are three major types of flow measurement recorders:

1. Mechanical float type,
2. Bubbler tube,
3. Ultrasonic type.

Figure 9. A V-notch weir constructed of plywood and sheetmetal, FHWA study Milwaukee, WI (5).

Some desirable features of flow monitoring equipment that can result in better data interpretation and lower maintenance costs are as follows:

Recorder Chart Drive:	Electric (AC current or 12 volt battery) or 8-day spring wound.
Chart Speed:	If available, one revolution per 12 hours is desirable otherwise one revolution per 24 hours is absolutely essential for circular charts; for strip charts, a speed of 9.6 inches per hour (24.4 cm per hour) is recommended. A more accurate hydrograph is obtained if the time scale is large.
Sensitivity:	Vertical scale range should be between 0 and sewer diameter. Desirable sensitivity 0.1 inch (0.25 cm) or better. Minimum required sensitivity 0.5 inch (1.25 cm).
Hi-Lo Alarm:	Should be equipped with dry mechanical contact closure switches that can be utilized for sampler actuation and other desired purposes.

Surface float devices are the most commonly used for level measurement. There are two types of float devices in common use. One is a float attached to a cable with counterweight. This type of float works best in a stilling well outside of the main flow stream. The other type is a float or scow suitable for use in the flow stream without using a stilling well. There are some disadvantages to surface float devices:

1. The stilling well tends to become clogged and silted.
2. An in-stream float can catch debris, rags, etc., which tend to submerge the float and produce erroneous readings.

A typical stilling well with a float type level measurement device was used in Harrisburg, Pennsylvania (5). See Figure 10.

A bubbler tube does not suffer from the previously mentioned clogging disadvantages in that it tends to be self-cleaning. A compressed gas supply and a regulator are necessary. Dry nitrogen in pressure cylinders is recommended. The supply cylinder must be replaced periodically. Figure 11 shows a typical bubbler type flow recorder used in Milwaukee, Wisconsin (5).

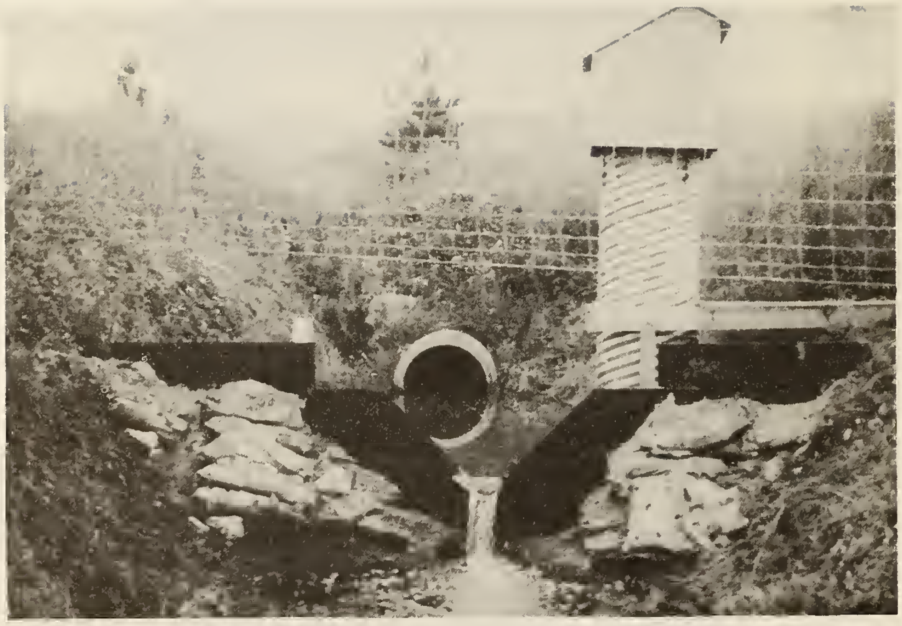


Figure 10. Typical stilling well installation with a float type level recording device, Harrisburg, PA (5).

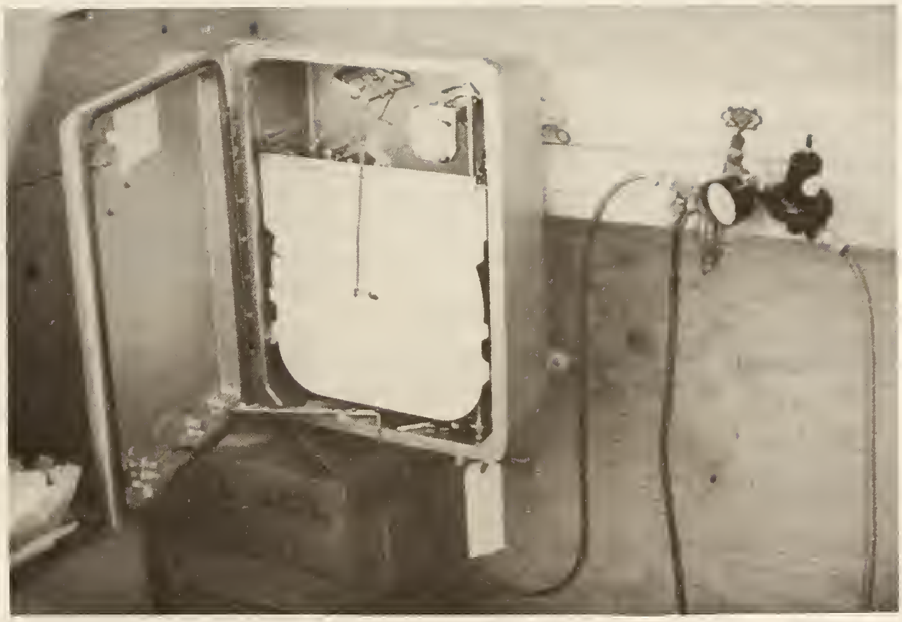


Figure 11. Typical bubbler tube flow recorder, FHWA study, Milwaukee, Wisconsin (5).

Both of the above described level measurement devices were satisfactorily used in highway runoff studies. When equal performance is anticipated from two different instrument types, selections may have to be based upon the familiarity and preferences of operating personnel, available funds, and suitability for installation.

Recently a new type of level recording device has been introduced on the market. It works without any physical contact of the sensor with the material being measured, therefore, it is considered to have good potential for trouble free flow measurements. In operation, the sensor emits high frequency ultrasonic pulses which strike the surface of the material being measured and are reflected back to the sensor. The time delay between sending and receiving is measured electronically and indicated as a precise distance measurement. Signal conditioning to assure maximum accuracy is provided by automatic temperature compensation and built in automatic gain control. Because of their simplicity of operation and maintenance, these devices should find increasing acceptance in flow monitoring. There is, however, little information available as to how well these devices actually perform in the field. Some of the manufacturers handling flow measurement devices are listed below:

Acco, Bristol Industrial Instruments
Waterbury, CO 06720

Badger Meter, Inc., Instrument Div.
4545 W. Brown Deere Road
Milwaukee, WI 53223

BIF Industries
Providence, RI

Drexelbrook Engineering Co.,
205 Keith Valley Road
Harsham, PA 19044

Fischer & Porter Co.
Wariminister, PA 10974

Flow Technology, Inc.
401 S. Hayden Road
Tempe, AZ 05201

Foxboro Company
Neponset Avenue
Foxboro, MA 02035

Simplex Valve & Meter Co.
Lancaster, PA

Leupold & Stevens, Inc.
P.O. Box 600
Beaverton, OR 97005

Meriam Instrument Co.
10920 Madison Avenue
Cleveland, OH 44102

N. B. Products, Inc.
35 Beulah Road
New Brittain, PA 10901

Pamapo Instrument Co.
Bloomingdale, NY 07403

Robertshaw Controls Co.
1013 N. Broadway
Knoxville, TN

Rexnord Instrument Products
30 Great Valley Parkway
Malvern, PA 19355

Wesmar Industrial Systems Div.
905 Dexter Avenue
North Seattle, WA 98109

Singer, American Meter Division
P.O. Box 13693
Atlanta, GA 30324

Tri-Aid Sciences, Inc.
161 Norris Drive
Rochester, NY 14610

Hinde Engineering Co.
P.O. Box 56
Saratoga, CA 95070

Leeds & Northrup Co.
Summerytown Pike
North Wales, PA 19454

The U.S. Geological Survey and state agencies may be able to provide additional information and aid in the procurement of flow measuring equipment.

Water Quality Sampling Equipment - Discrete type samplers are recommended for highway runoff sampling. The collected samples can be analyzed individually and/or they can be composited proportional to flow into a single sample that represents the entire runoff event. Some of the desirable features of automatic sampling equipment are as follows:

Case:	Completely weatherproof, corrosion resistant construction and ability to handle large suspended material.
Type:	Discrete samples, portable, capable of operation with batteries and AC power.
Sample: bottles	Minimum 24 plastic or glass bottles per sampler; minimum sample volume 500 ml, larger sample volumes are desirable but generally requires customizing the sampler.
Sampling: frequency	1 to 120 minutes.
Sampler: actuation	Should be capable of automatic actuation based on a signal from flow or level sensor/recorder. Initial sample should be collected immediately upon actuation or at a set value that can be controlled.
Sample: intake	Optimum intake velocity should be of the order of 2 to 3 feet per sec. (0.61-0.92 m/sec). Suction lines should be either 1/4 or 3/8 in. (6 to 9 mm) ID and

be equipped with weighted strainers to keep rags and other debris from entering the sampler. The sampler should be able to air purge the suction line between samples to minimize contamination and should be capable of lifting against a minimum of 20 ft (6.0 m) head through 20-30 ft of (6.9 m) long suction lines.

A review of different automatic samplers available commercially is found in Water Pollution Assessment: Automatic Sampling and Measurement (21). Following is a listing of some of the automatic sampler manufacturers:

BIF Sanitrol
P.O. Box 41
Largo, FL 33540

Brailsford & Co., Inc.
Milton Road
Rye, NY 10580

Bristol Engineering Co.,
204 South Bridge Street
Box 696
Yorkville, IL 60560

Chicago Pump Division
FMC Corporation
622 Diversey Parkway
Chicago, IL 60614

Infilco Division
Westinghouse Electric Co.,
Box 2118
Richmond, VA 23216

Hydragard Automatic Samplers
850 Kees Street
Lebanon, OR 97355

Hydra-Numatic Sales Co.
65 Hudson Street
Hackensack, NJ 07602

Brandywine Valley Sales Co.
P.O. Box 243
Honey Brook, PA 19344

Instrumentation Specialties Co.,
P.O. Box 5347
Lincoln, NB 68505

Kent Tool Co.
2737 De Hoop S. W.
Grand Rapids, MI 49509

Krofta Manufacturing Div.
The Black Clawson Co.
Fall River, MA

Lakeside Equipment Corporation
2900 East Devon Street
Bartlett, IL 60611

Manning Environmental Corp.
120 Du Bois Street
P.O. Box 1356
Santa Cruz, CA 95061

Markland Specialty Engineering, Ltd.
Box 145
Etobicoke, Ontaria CANADA

Phipps & Bird Inc.
303 South 6th Street
Richmond, VA 23205

Nappe Corporation
Croton Falls Industrial Complex
Route 22
Croton Falls, NY 10519

N-Con Systems Co., Inc.
308 Main Street
New Rochell, NY 10801

Paul Noascono Co.
805 Illinois Avenue
Collinsville, IL 62234

Penberthy Division
Houdaille Industries, Inc.
P.O. Box 112
Prophetstown, IL 61277

Peri Pump Co., Ltd.
180 Clark Drive
Kenmore, NY 14223

Sonford Products Corp.
100 East Broadway
Box B
St. Paul Park, MN 55071

Tri-Aid Sciences, Inc.
161 Norris Drive
Rochester, NY 14601

Pro-Techn, Inc.
Roberts Lane
Malvern, PA 19355

Quality Control Equipment Co.
6139 Fleur Drive
P.O. Box 2706
Des Moines, IA

Rice Barton Corporation
Box 1086
Worchester, MA 01601

Sigmamotor, Inc.
14 Elizabeth Street
Middleport, NY 14105

Sirco Controls Co.
8815 Selkirk Street
Vancouver, British Columbia, Canada

Testing Machines, Inc.
400 Bayview Avenue
Amityville, NY 11701

Samplers supplied by ISCO Co. (Model 1680) were used satisfactorily in the FHWA study (5). This sampler is shown in Figure 12.

Precipitation Measurement - A continuous recording gage should be used so that the time, quantity, and intensity of rainfall or snowfall can be determined. Some of the desirable features of a recording precipitation gage are as follows:

Type: Weighing and recording type, completely weatherproof recording assembly, capable of measuring all forms of precipitation and conforming to U.S. Weather Bureau Specifications.

Chart: drive 8-day spring wound or capable of battery operation, electrical drive when AC power is available at site. Minimum 6 in. (15 cm) wide rectangular chart having a time scale of one revolution per 6-12 hour on a circular chart or a minimum of 9.6 in. (24 cm) per hour on a strip chart. The precipitation chart should be either 4.8 in

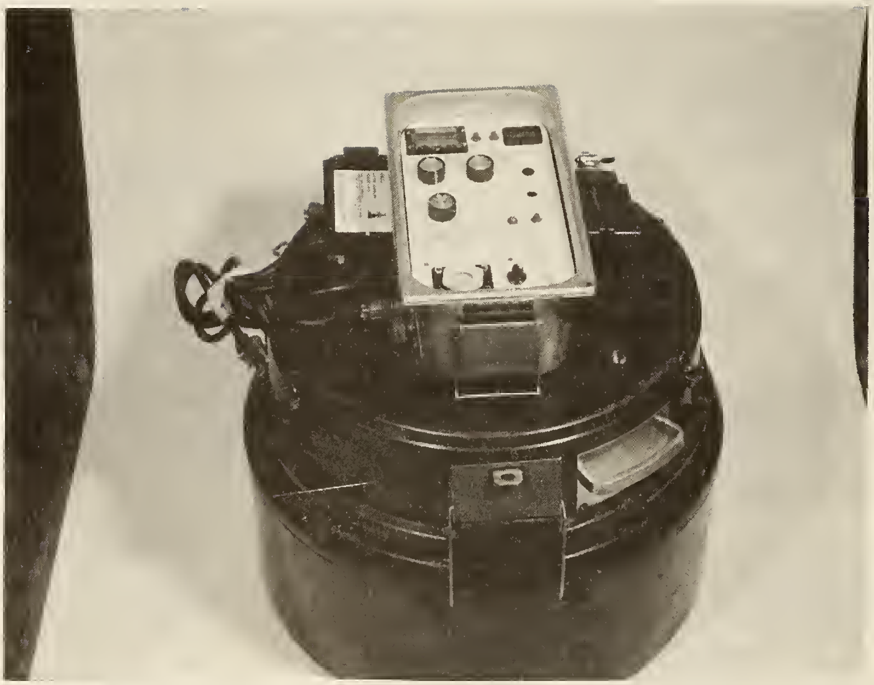


Figure 12. Isco water quality sampler.

(12 cm) dual traverse or 6 in (15 cm) single traverse.

Sensi-: tivity — Not less than 0.5% with a sensitivity of 0.01 in. (0.25mm) of precipitation at a temperature range of -40°F to +125°F.

A combination raingage/flow recorder which records rainfall and flow on the same chart is commercially available. This instrument has the advantage of eliminating synchronization errors between the raingage and flow recorder.

Recording raingage instruments are available from the following manufacturers:

Weather Measure Corp.
P. O. Box 41257
Sacarmento, CA 95841

Belfort Instrument Co.
1600 South Clinton Street
Baltimore, MD 21224

The Bendix Corp.
Environmental Science Division
Dept. 31
1400 Taylor Avenue
Baltimore, MD 21204

The combination flow recorder/raingage is available from:

Leupold and Stevens, Inc.
P.O. Box 688
Beaverton, OR 97005

Precipitation gages from Belfort Instrument Co., were used satisfactorily in highway runoff studies in Milwaukee, Wisconsin (5). See Figure 13.

Dustfall Buckets - The procurement and installation of the dustfall stations should be in accordance with the recommended ASTM specifications and procedures (22). Essentially, the ASTM specifications require that each dustfall station should consist of a standard 8 in (20.3 cm) diameter x 10 in. (24.4 cm) deep tapered jar equipped with a bird-ring support and should be placed a minimum of 8 to 10 ft (2.4-3.0 m) above ground. A copy of the ASTM procedure has been included in the Appendix B. Dustfall stations are available from the following vendors:

Premium Instruments Co.
Alsip Industrial Park
5821 West 117th Place
Worth, IL 60482

Research Appliance Co.
Allison Park, PA 15101

Figure 13. Belfort Instrument Company precipitation gage.

Figure 14 shows a photograph of a typical dustfall station used during the FHWA Highway runoff study (5).

Temperature Recorders - Depending on the type of study, it may be desirable to measure and record air and/or runoff water temperature. Temperature measurements may be particularly appropriate when a monitoring program encompasses more than one season of the year.

Temperature recording instruments are available from numerous sources including the following:

Weather Measure Corp.
P.O. Box 41257
Sacramento, CA 95841

McMaster-Corr Supply Co.
P.O. Box 4355
Chicago, IL 60680

The most important factor in choosing the appropriate equipment for a monitoring program is the suitability of such equipment for the monitoring site. For example, a site with a large proportion of paved area requires a flow recording instrument which can accurately record a large increase in flow over a short duration in time. It is in these types of decisions where the experienced government agencies or research groups which have used certain manufacturer's equipment can be invaluable.

Personnel Requirements

Depending on the size of the program and the availability of outside assistance, personnel with different qualifications may be needed; these people could be called program planning personnel and field personnel.

Persons with a technical background and previous experience with sampling programs should be responsible for planning the sampling effort. These persons would also be involved in assembling and evaluating the data and writing a report of the total monitoring effort. Such persons should have a background in hydraulics, hydrology, environmental and sanitary engineering, and some aquatic biology.

The persons who will actually install and maintain the equipment and collect the samples (the field personnel) should have previous experience in field work especially with scientific instruments and, in general, should have above average mechanical ability and understanding of electrical circuits. Many times people with similar backgrounds can be found within the highway department who with some training can

Figure 14. Typical dustfall bucket station, I-40, Nashville, Tennessee (5).

easily adapt to the needs of such a program.

Formal training for the field personnel is highly desirable. They should become familiar with the procedures to follow and the equipment before actually going into the field. This would include reading pertinent literature on water quality and procedural manuals, orientation to field problems, familiarization with the equipment operation and maintenance manuals. The monitoring personnel can give valuable training by attending short condensed water quality courses, seminars, or FHWA water quality workshops. Many of these workshops are specially designed for highway department personnel or are on assessment of the impact of highway systems on water quality and are sponsored by federal or state agencies or educational institutions (16). The use of common sense is important in any scientific study, especially in obtaining representative samples, avoiding contamination of the samples, and proper preservation and shipment procedures.

Labor Requirements - The labor requirements will depend on the number of sites to be monitored and the extent and duration of the monitoring program. The following man-days are estimated per sampling site using automatic sampling and flow measurement equipment and not including any receiving water monitoring.

Task	Man-days
Preliminary planning of program	5-10
Specific site selection	5-10
Equipment selection and procurement	3-10
Installation of equipment (2 men)	5-20
Collection and handling samples/ event	1-2
Maintenance of equipment/week	1-3

Sources of Assistance - Assistance in planning and conducting the sampling program can be obtained from various agencies including the State and Federal Environmental Protection Agencies. It is a possibility that the laboratory tests can be performed at the State laboratory or at a local sewage treatment plant laboratory. Alternately these people probably can recommend a certified private laboratory. Often the laboratory personnel can answer questions regarding proper sampling and sample handling procedures. There are also a number of helpful references on sampling, flow measurement, and analytical procedures which can be consulted (7)(8)(9)(13)(14)(16)(19)(20)(21).

SECTION IV
INSTALLING THE MONITORING EQUIPMENT

After the monitoring site has been selected and the equipment procured, equipment installation can begin. A flow diagram, Figure 15, summarizes the steps necessary to install the equipment, both at the monitoring point and away from the monitoring point.

Site Preparation

The preparation needed at the site prior to actual equipment installation will vary depending on the site and the type of equipment to be installed. Preliminary activities may involve the following:

Bringing power to the site.
Preparing a foundation for the monitoring shed.
Preparing the runoff channel to allow accurate flow measurement.

Bring Power to the Site - Contact the local electric power utility regarding the possibility of providing electric power at the site. Transformed electric power of 110 V is preferable to the inconvenience and uncertainty of storage batteries. Electric power also permits more complex instrumentation.

If electric power is not available storage batteries will have to be used. Marine batteries have proven more reliable (superior longevity) for this purpose than automotive batteries.

Preparation of Foundation for Monitoring Shed - Preparation for installation of a monitoring shed may involve removal of vegetation and laying of a foundation. The extent of preparation will depend on the nature of the site. The ground at the site may be suitable "as is" for the foundation as long as it is level and well drained. The shed should be anchored for security reasons and for protection against high winds.

Channel Preparation - Channel preparation may be necessary to provide accurate flow measurement. Such preparation might include narrowing the channel to allow placement of the flow measuring device, and possibly paving the channel. However, the channel should be left in its natural condition as much as possible so that the flows measured are those which could be expected to occur under normal drainage and transport conditions. Vegetation, rocks, and other debris should not be removed except when they are not part of the normal landscape or when they might interfere directly with the flow measurement or sampling.

For an earth channel a suitable weir can be made from a piece of metal plate cut in the shape of the cross section of the channel. It should

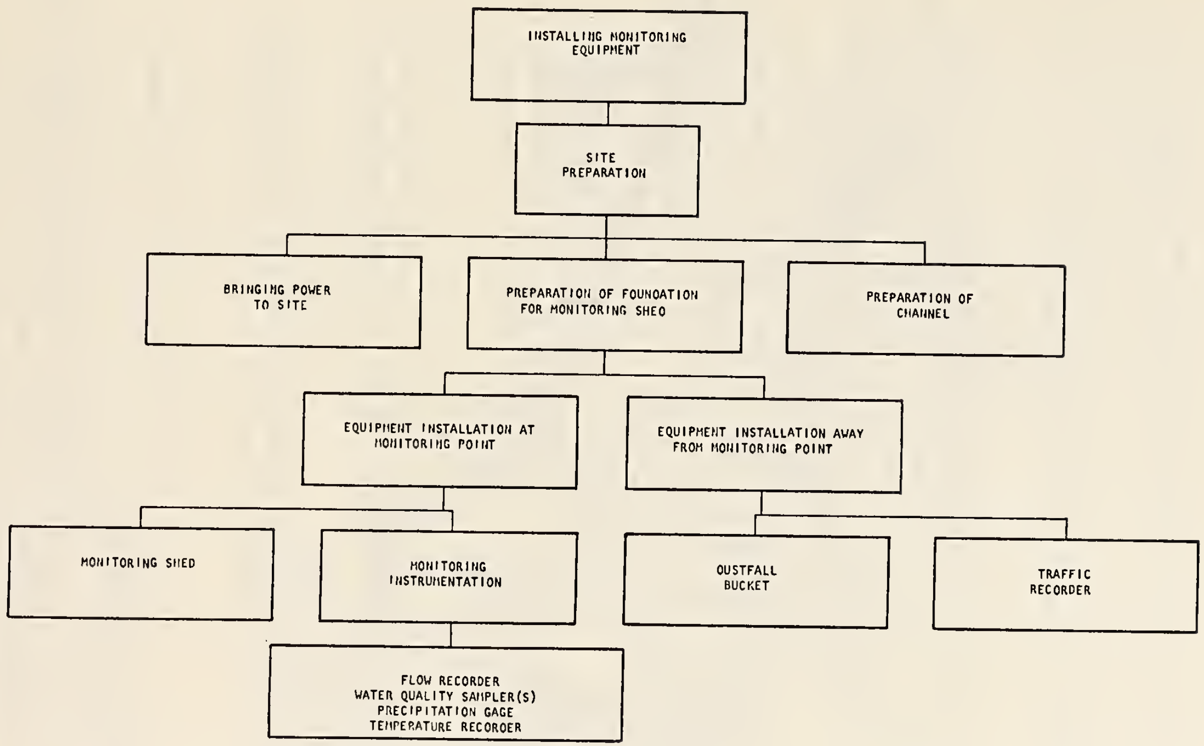


Figure 15. Equipment installation flow diagram.

be cut somewhat larger so that it can be forced into the soft bottom and sides of the channel. Alternately, a bulkhead could be made of lumber, and a metal strip placed on the crest and sides of the weir (see Figure 16). The crest and sides of a notched weir should be carefully cut and sharpened. After the weir has been installed across the channel, the crest should be leveled and the staff gage carefully zeroed. The following guidelines should be followed for accurate flow measurement by sharp crested weirs (7,9):

1. The upstream face of the bulkhead should be smooth and in a vertical plane perpendicular to the axis of the channel.

2. The upstream face of the weir plate should be smooth, straight, and flush with the upstream face of the bulkhead.

3. The entire crest should be a level, plane surface which forms a sharp, right-angled edge where it intersects the upstream face. The thickness of the crest, measured in the direction of flow, should be between 0.03 and 0.08 inch (about 1 to 2 mm). Both side edges of rectangular weirs should be truly vertical and of the same thickness as the crest.

4. The upstream corners of the notch must be sharp. They should be machined or filed perpendicular to the upstream face, free of burrs or scratches, and not smoothed off with abrasive cloth or paper. Knife edges should be avoided because they are difficult to maintain.

5. The downstream edges of the notch should be relieved by chamfering if the plate is thicker than the prescribed crest width. This chamfer should be at an angle of 45° or more to the surface of the crest.

6. The distance from the crest at the notch to the bottom of the approach channel (weir pool) should be at least twice the head on the weir.

7. The distance from the sides of the weir to the sides of the approach channel should be at least twice the head on the weir.

8. The overflow sheet (nappe) should touch only the upstream edges of the crest and sides.

9. Air should circulate freely both under and on the sides of the nappe.

10. The measurement of head on the weir should be taken as the difference in elevation between the crest and the water surface at a point upstream from the weir a distance of four

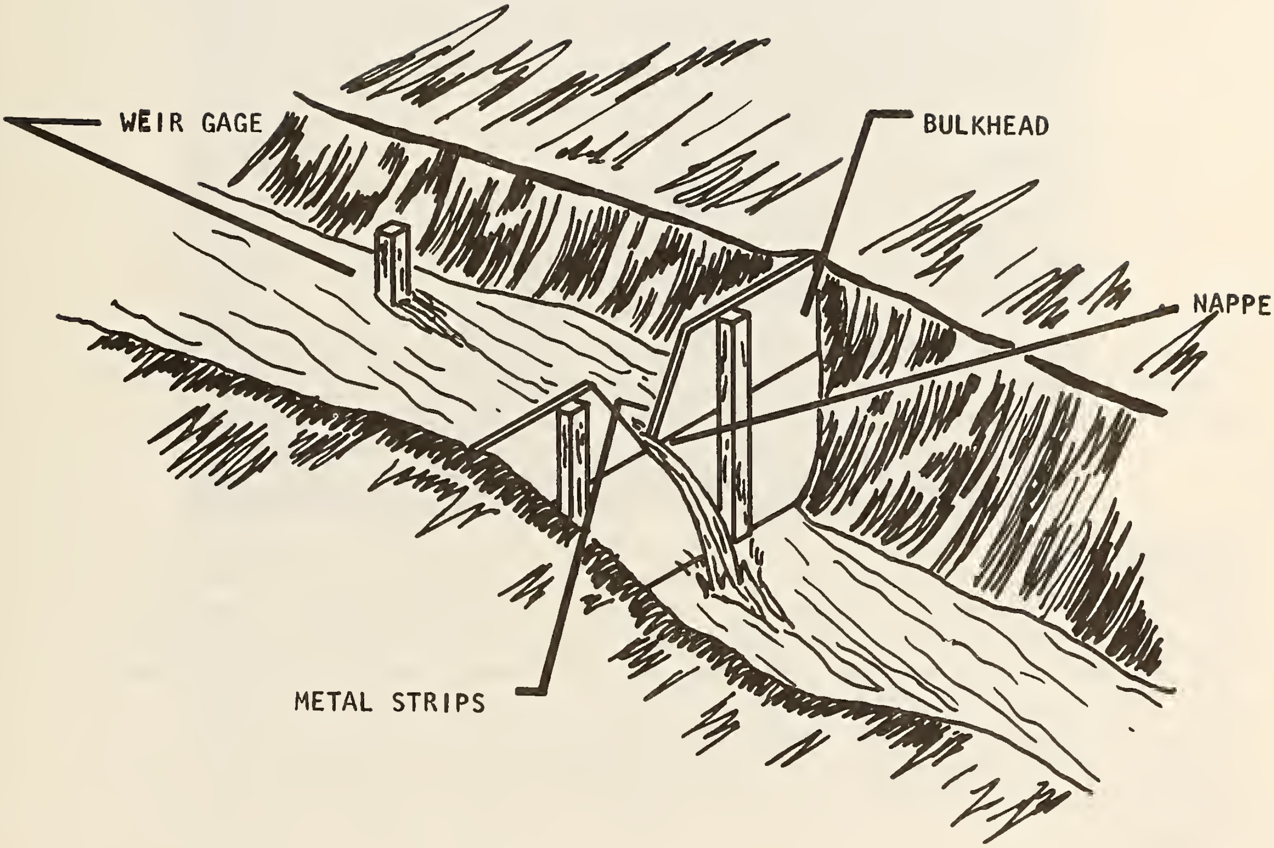


Figure 16. Typical V-notch weir installed in channel.

times the maximum head on the crest.

11. The cross-sectional area of the approach channel should be at least 8 times that of the overflow sheet at the crest for a distance upstream from 15 to 20 times the depth of the sheet.

The conditions for flume installation are in many ways similar to those for weirs. The flume should be installed in a straight section of channel free from turbulence. Careful leveling of the flume and zeroing of the staff gage should also be performed. Figure 17 shows a typical Palmer-Bowlus (P-B) flume configuration (Hwy. 45, Envirex Study, Milwaukee, WI). The following design guidelines are suggested for P-B flume construction (23)(24)(25):

1. Bottom height of throat equal to D/12 (where D is circular diameter of pipe).

2. Base width equal to 5 D/12.

3. Length of throat section at least equal to the pipe diameter.

4. Slope of upstream and downstream transitions at a minimum of one laterally to three longitudinally.

A detailed procedure for design, construction and rating of the P-B flumes is included in Appendix A. The rating is done using the trial-and-error procedure.

Equipment Installation at Monitoring Point

Monitoring Shed - Sampling and flow monitoring equipment should be housed in a locked enclosure to protect the equipment and to reduce the possibility of vandalism. A shed made of sheet metal or lumber may be suitable for this purpose. However, depending upon the weather of the area, an insulated shed may be desirable. During cold weather, the shed should be heated with an electric or gas heater to protect the instrumentation and lines from freezing. Figure 18 shows two typical monitoring sheds. A minimum of 6 x 6 x 6 ft (1.8 x 1.8 x 1.8 m) size shed is recommended for a typical highway runoff monitoring program.

Ample shelf space must be provided for the operator to prepare and label sample bottles, and to record sampling data and observations. Enough storage area is needed for sufficient quantities of sample bottles to handle an "extreme rainfall event". Storage for tools, chart paper, ink, and other supplies will also be necessary. Equipment that could be "tipped" may cause personal injury and/or damage to other equipment and therefore, should be secured. An example would be the nitrogen cylinder which should be fastened, using a strap harness or similar device, to the shed wall. The layout of equipment,

Figure 17. Typical Palmer-Bowlus flume (Hwy. 45, Milwaukee, WI)(5).

Figure 13. Typical monitoring sheds.

storage areas and shelf space should provide maximum ease of mobility for the operator. Figure 19 shows a typical layout for instrumentation and accessories inside a monitoring shed.

The shed should be installed as close as possible to the point of sampling and flow measurements in the drainage channel without risking flooding of the shed.

If the site has electric power, flood lights should be installed to illuminate the area. Also, a light or lights should be installed inside the shed. If the site does not have electric power, battery or fuel powered lanterns will have to be used.

Monitoring Instrumentation - When the weir or flume has been installed and the monitoring shed placed in position, the following instruments should be installed in strict accordance with the manufacturer's instructions.

Level or flow recorder with event marker.
Water quality sampler(s).
Precipitation gage.
Temperature recorders.

Figure 19 shows a recommended arrangement of flow recorder, water quality sampler and nitrogen tank pressure gage. In addition to proper installation, efficient arrangement is also important. During sampling periods (initial flow and peak flow), and emergencies (surcharge event, equipment failure) the operator must be able to perform required duties with a minimum of delay.

If storage batteries are to be used for power, one battery will be needed for each water quality sampler. Keep an additional battery on site as a spare. A voltmeter should also be kept on site to routinely check battery charge.

Location of the precipitation gage is critical if rainfall records which represent the measured flows are to be obtained. In Section III, it was stated that the precipitation recorder should be located either at the monitoring site along with the runoff measuring equipment or within the immediate vicinity. However, at one of the monitoring sites used in a FHWA study (5), storm fronts generally passed through an upper drainage basin located at the foot of a mountain range before entering the lower drainage basin. Initially, both the precipitation gage and flow recorder were located in the lower basin. Because rainfall first fell in the upper basin, flow was usually recorded before rain, making synchronization of flow and rain start times impossible. In one extreme case flow was recorded but rain was not. Calculations of runoff volume to rainfall volume ratios produced extreme variations. The problem was solved by installing a raingage in the upper basin. This new raingage gave rain volumes and

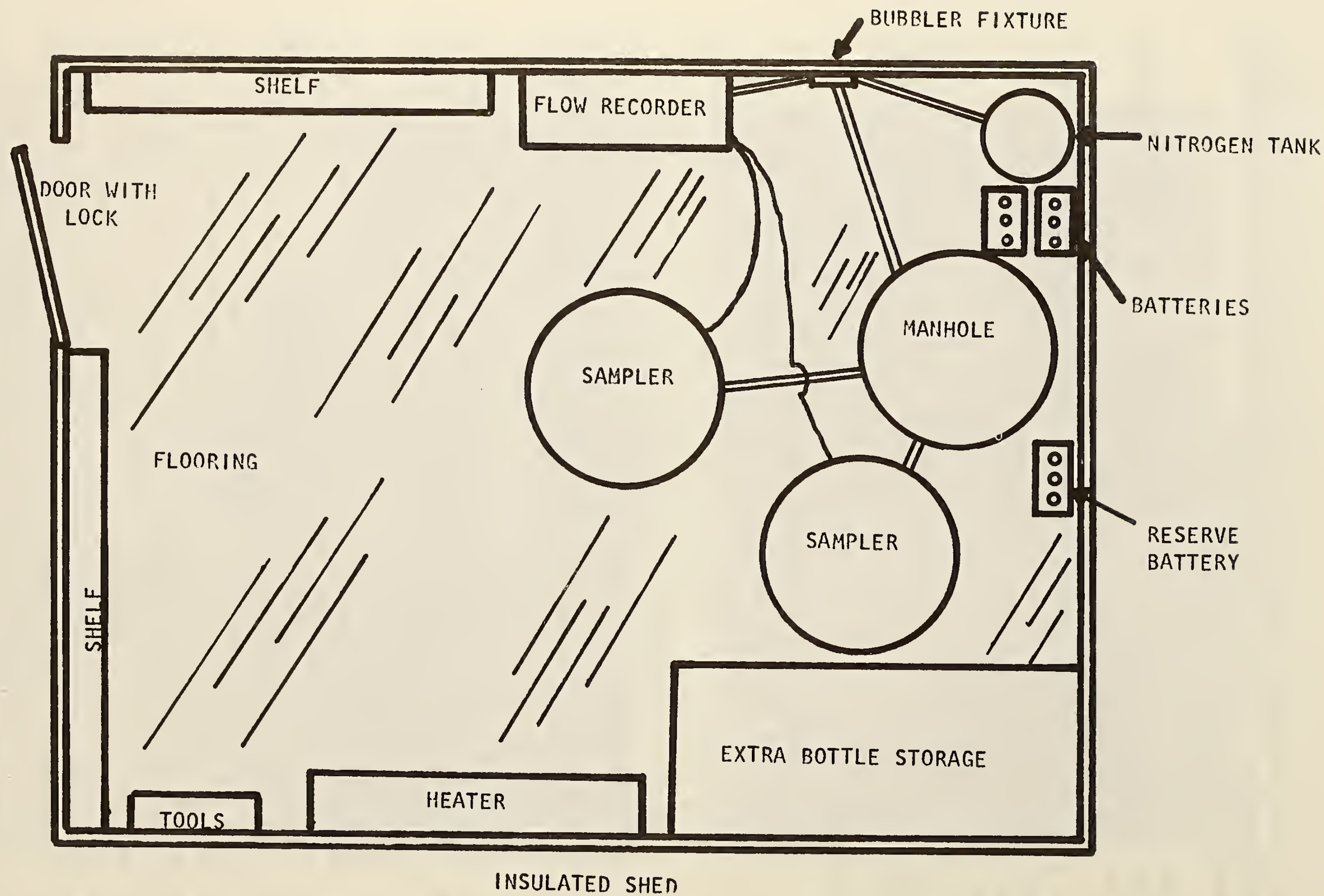


Figure 19. Typical layout for instrumentation and accessories inside a monitoring shed.

rain start times which better represented the measured flows. The flow measurement device should be securely installed in the drainage channel or sewer. Care should be taken to ensure that sides of the device are tight against the bottom and the side banks of the channel.

It is advisable to minimize the length and height of the sampler suction line and air lines. Generally, commercially available samplers are capable of pumping desired sample volumes against heads up to 20 ft (6.1 m) and through approximately 20 ft (6.1 m) long suction lines. Therefore, instrumentation lines should be kept below these head and length limitations as far as possible. Gravity drainage should be provided for the sampler suction line for protection from ice buildup in lines during freezing weather.

Proper installation of sampler intake lines is necessary for procurement of representative samples. A recent EPA study (13) has provided the following guidelines:

1. In sewers and in deep narrow channels, samples should be taken from a point one-third the water depth from the bottom.

2. The velocity of flow at the sample point should, at all times, be sufficient to prevent deposition of solids.

3. Sampling intake location should be such that it allows complete mixing of tributary flows.

4. There should be a straight length of pipe at least seven sewer diameters upstream of the site.

Not all the above conditions can be met at all times but they should be followed as closely as possible. During a FHWA study (5), solids distribution through the depth of flow was ensured by installing a vertical, 2 in. (5 cm) diameter plexiglass tube with 0.25 in. (6 mm) holes at the mouth of the P-B flume. The sampler intake was then placed underneath this tube to obtain representative samples.

For the bubbler type flow recorders, it is important to protect the sampler intake lines and air lines from objects such as wood, branches, rags, etc., contained in the runoff flow, and from the high flow velocities that may be experienced. This can be accomplished by properly anchoring these lines to the sewer or channel walls. Also, tubing should be buried or enclosed in a conduit from the point of exit from the monitoring shed to the point of entrance in the sewer or manhole.

High flow velocities may be experienced at sites with steep slopes. These high velocities at the bubbler orifice cause a drawdown of the recorded stage height and a hydrograph produced under these conditions does not represent actual flows. This drawdown problem can be alleviated by the installation of a static tube over the bubbler gage orifice (Figure 20).

Equipment Installation Away from Monitoring Site

Dustfall buckets and traffic recorders should be located within the site drainage area but not necessarily at the monitoring outfall or the manhole.

Dustfall Buckets - The purpose of the dustfall buckets is to obtain a qualitative estimation of the pollutant fallout from atmosphere within the highway drainage area. The number of these buckets to be placed at a site will be dependent upon the size of the drainage area, as well as the type of adjoining land use activity. A minimum of three dustfall buckets should be strategically located on the highway right-of-way along the length of highway section under study. The installation of the dustfall stations should be in accordance with the recommended ASTM specifications and procedures as discussed in Appendix B.

Traffic Recorders - As mentioned earlier, the highway departments are well versed with the details of obtaining traffic counts and, therefore, no elaborate discussion on this topic has been included in this manual.

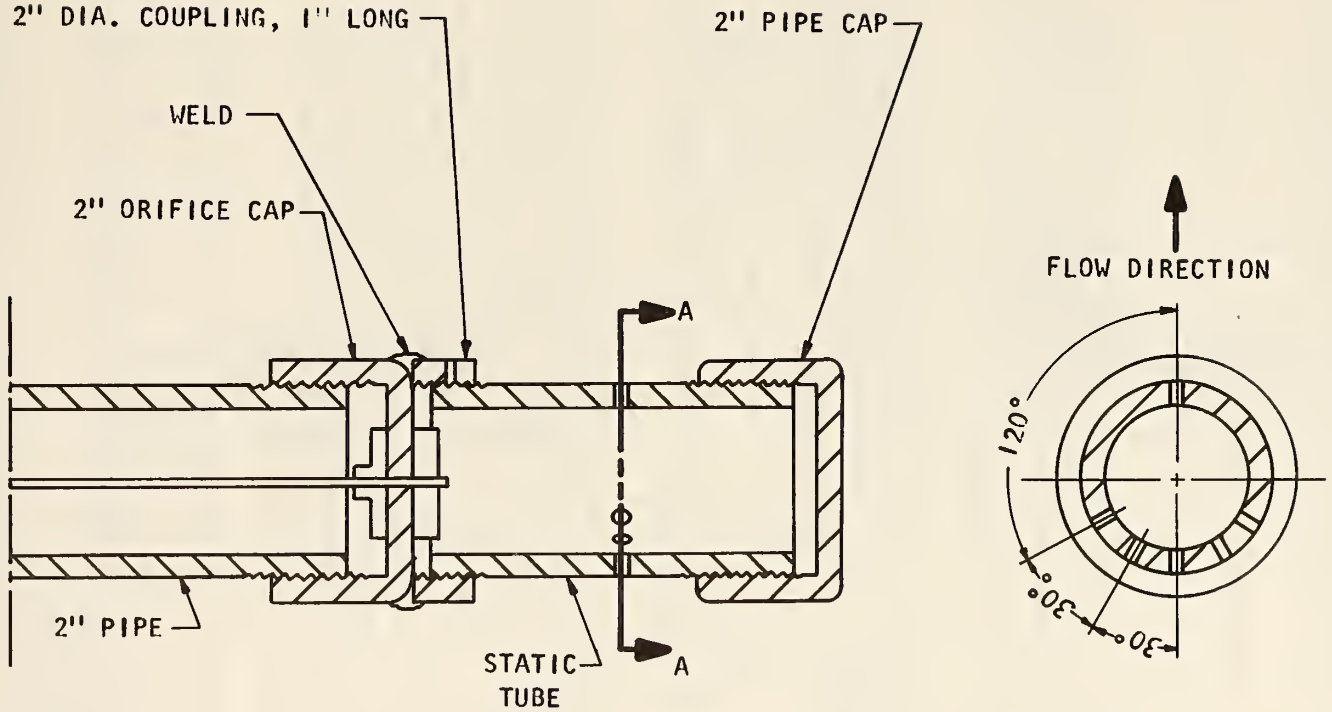


Figure 20. Typical static tube to minimize turbulence over the bubbler gage orifice.

SECTION V
MAINTENANCE AND MONITORING PROCEDURES

Figure 21 presents the various steps involved in routine equipment maintenance along with the sequence of events leading to the monitoring of a storm event.

Maintenance Procedures

Routine maintenance includes such general tasks as:

> Change of charts, clock winding, recorder pen ink fillup and addition of anti-freeze solution (during winter months) to the precipitation gage and liquid level recorder. Inspect storage batteries for charge. The normal frequency for these changes should be <u>once per week</u>.
>
> Collection of dustfall bucket material, in separate containers, and transmission to a water quality analytical laboratory by the field caretaker. The normal frequency of this material collection should be <u>once per month</u> or between storm events.

Specific maintenance tasks for the various monitoring devices are:

<u>Precipitation Gage</u> - The following should be performed <u>weekly</u> or after each rainfall, whichever comes first.

1. The old chart should be removed and replaced with a new chart. "Day and time off" should be recorded on the old chart and "day and time on" on the new chart. Also, the name of field caretaker doing this work should be recorded on both the old and new charts. Care should be taken when putting the new chart on the drum. If chart is crooked or is folded onto the spring clasp incorrectly, the rain trace becomes difficult to follow and can cause errors. Also, the starting point of the recorder pen may be placed at a higher point on the vertical scale to avoid any problems of the recorder pen getting caught on the edge of the chart.

2. The bucket should be emptied of water and debris, and replaced.

3. The clock should be wound and the pen replaced. Any slippage or error between the raingage clock and actual time should be noted and corrected in order to time synchronize it with other instrumentation.

4. The supply of ink to the recorder should be replenished if necessary.

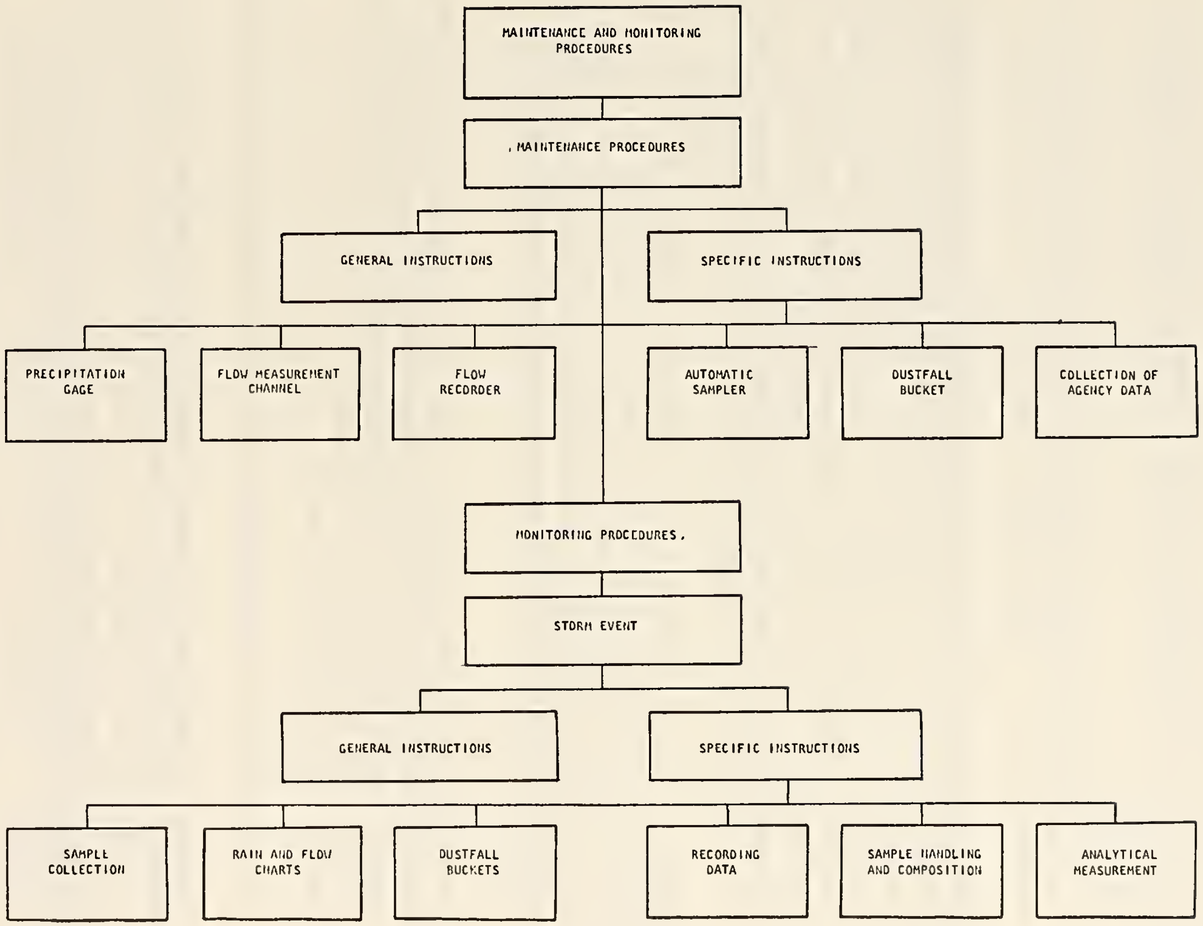


Figure 21. Sequence of events leading to the monitoring of a storm event.

5. The gage should be recalibrated at least once every three months to ensure proper data readings.

Flow Measurement Channel - Inspection should be made weekly.

Weirs

1. The weir and channel should be cleaned of weeds, debris, and sediment.

2. The level of the crest should be checked with reference to the zero of the stage board.

3. Inspection should be made to determine if there is leakage around the weir during runoff conditions.

Flumes

1. The flume should be cleaned of weeds, debris, and sediment.

2. Inspection should be made to determine if any washout has occurred around or under the flume.

Flow Recorder - The recorder should be checked weekly or after each runoff event.

1. The old chart should be removed and a new chart should be put on with similar information as described earlier for the precipitation gage.

2. The clock should be wound if a spring-driven clock is used. Any slippage or error between the flow recorder clock and actual time should be noted and corrected. Again, this will permit time synchronization between instruments, if the charts are running fast or slow.

3. The supply of ink to the recorder pen should be replenished.

4. The level measurement system should be inspected. For example, for a bubble tube device the rate of gas flow should be checked and adjusted if necessary. The orifice should be checked to make sure it is unobstructed. The scale should be recalibrated once every three months to ensure correct readings. Nitrogen cylinder pressure should be checked.

Automatic Sampler - The samplers should be checked weekly for Steps 1, 2, and 3 and all items described below should be performed after each sampling event.

1. Inspect probe and suction lines for accumulation of solids or debris.

2. If battery powered, check charge on battery and replace if necessary.

3. If desiccant cartridge indicator on the sampler shows that it's depleted, replace with a new cartridge and reactivate the old one in the laboratory.

4. Reset the sampler to start automatically at position 1.

5. Replace dirty bottles with clean ones.

<u>Sample Bottle Preparation</u>- These procedures detail the proper methods of cleaning the sample bottles. Compliance with these procedures is necessary to insure the purity of the sample. All new bottles should be prepared as detailed below prior to being used for samples. After samples are taken, new bottle sets should be prepared immediately for the next storm event. This policy will avoid cross-contamination.

Automatic Sampler Bottle Preparation - These bottles should be prepared as follows:

1. Wash all bottles and caps with a nonphosphate soap, hot water, and a stiff bristled brush. Make sure the bottle is completely clean inside and outside. Be careful to clean the grooves where the cap fits and underneath the inside rim of the bottle.

2. Rinse the bottles and caps with clean water until all traces of soap and dirt are completely removed from the bottles and the caps.

3. Rinse the bottles and caps with dilute (1:1) sulfuric acid.

4. Rinse the bottles and caps with deionized water.

5. Turn all bottles and caps upside down and allow them to drain onto a porous material such as paper toweling.

6. When all bottles and caps are completely dry, loosely cap the bottles and store them until they are required for sample collection.

Steps 1 and 2 above are minimum cleaning requirements.

Acid wash is desirable but may be deleted if circumstances indicate so. However, a final distilled water rinse should be provided whenever possible.

Oil and Grease and Pesticide Sample Bottle Preparation - These bottles should be prepared as follows:

1. Glass containers such as canning jars should be used.
2. Wash in soap and water with a stiff bristled brush.
3. Rinse in tap water.
4. Wash with hexane or petroleum ether.
5. Air dry.
6. Cap bottles with an aluminum foil lined cap and store.

Bacteriological Sample Bottle Preparation - These bottles should be prepared as follows:

1. Containers for samples for bacteriological analysis should be suitable for sterilizing prior to use. Glass containers are most commonly used although certain plastic containers may also be suitable.

2. The capped sample containers should be sterilized by an acceptable method (see Standard Methods, Reference 19), and kept sterile until use. This sterilization should follow the preliminary laboratory cleaning of the glassware. Any bottle without a cap or with a loose cap should not be used.

Dustfall Bucket - Dustfall buckets are initially filled with 2 liters of distilled water. During extremely dry periods, additional distilled water may have to be added periodically to the dustfall buckets. Dustfall buckets should be checked during these dry periods once a week.

Collection of Agency Data - In addition to routine maintenance, data from the agencies shown below should be procured on a regular basis.

1. Climatological Data - Monthly climatological data sheet for the site area should be obtained from:

   National Oceanic and Atmospheric Administration (NOAA)
   National Climatic Center
   Federal Building
   Asheville, NC 28801

   These monthly data sheets should have the following information:

   Precipitation data
   Number of dry and wet days
   Wind data
   Temperature data

In addition to the climatological data from NOAA, similar information should be obtained from local sources. City or other local agency raingages especially if located near a monitoring site, can provide useful data for verification of on-site raingage data and in case of on-site raingage failure, provide substitute rain data. Local agencies which often have raingages include:

City Engineer's Office
U.S. Geological Service
The Forestry Department
Colleges or Universities

2. Traffic and Other Maintenance Data - This data should be obtained from the local, state, or federal highway department responsible for such monitoring in the area of the study site:

   a. Traffic Count - Daily traffic counts and quarterly vehicular classification counts should be obtained throughout the study period. In addition, traffic data for at least a 4 to 6 week period prior to the first storm event should be obtained to relate the pollutant buildup and wash off at the start of the study.

   b. Maintenance Data - Monthly data sheets covering the following areas pertinent to the site.

      -Road sweeping - technique, dates and time frequency and duration.

      -Roadside grass mowing and/or weed cutting - technique, dates, time, frequency, and duration.

      -Any highway right-of-way sprinkling data, if irrigation is practiced on site.

      -Herbicide spraying - type of herbicide, application date and method, rate of application and total amount used.

      -Road salting data during winter periods - date and time of application, type, mix, and rate of application, number of applications and total amounts used.

      -Any road repair, land marking, painting, or other road improvement items performed in the past month.

      -Any accident or spill data pertinent to the study.

Monitoring Procedures

Storm Event - Every effort should be made by operating personnel to reach the site prior to the start of a storm event. However, within practical limitations, it is suggested that an operator should reach the site within 10 to 15 minutes of the start of a storm event. Upon arriving at the site, the operator should proceed as follows:

1. Make sure equipment is functioning properly and that all control settings and chart times are correct.

2. As flow begins, initiate manual sampling for oil and grease, coliforms, PCB and pesticides if so planned for that storm event. If the runoff event has already started, inspect flow trace on flow recorder and initiate manual sampling only if the flow peak has not been reached. For the manual samples, care must be taken to avoid sample contamination. Each sample must be obtained directly from the flow in-lieu-of obtaining one large sample and transferring an aliquote into each of the specially prepared bottles.

3. Ensure proper sample collection and equipment operation through the duration of the storm event. During the major portion of the runoff event, usually the first hour of flow or less, both manual and automatic samples should be obtained frequently (5 to 10 minutes) to adequately characterize the "first flush effect". If the storm is expected to last for a long duration (more than one hour) the sampling frequency should be adjusted (15 to 30 minutes or longer) for the latter portion of the runoff event.

4. At the end of the storm event, fill out the pertinent data sheets and record all observations about the storm. Collect all necessary samples and label them per procedures outlined later in this section and in accordance with any special instructions for that storm event. Empty out the precipitation collection bucket, replace used sampling bottles, replace charts as necessary, and set the instrumentation in proper order for monitoring the next storm event.

All samples, rain and flow charts, field notes and completed data forms should be brought in from the field. Rain and flow charts should then be inspected to determine if the storm event is to be utilized for flow quality analysis. Criteria for selecting a storm event for quality analysis might include the following:

1. Was the storm event "significant"? A storm event may be classified as "significant" for a minimum rainfall intensity of at least 0.5 inches per hour (1.25 cm/hour).

2. Is the storm needed to characterize prevailing seasonal conditions?

3. Is the storm needed to meet a particular study objective?

Rain and Flow Charts - Figure 4 shows a typical flow chart. Spikes coming off the flow trace represent sampling events by an automatic sampler. In preparation for the next storm event, both the flow chart and the rain chart should be removed as soon as possible after a monitored storm event. Multiple storm tracings on a chart make them difficult to read, especially flow charts, where it is possible to overlay storm events.

When removing rain and flow charts, the site operator should make sure that the following information is present on the charts:

1. Site name.
2. Date and time chart was put on.
3. Date and time chart was shut off.
4. Time discrepancy between actual time and time shown in the chart, if any.

When new charts are put on after a storm event, the clock mechanism should be wound and the ink reservoir checked and refilled if necessary.

Dustfall Buckets - The dustfall bucket should be emptied and the sample collected, sent, or taken along with the runoff samples to a laboratory for analysis. The dustfall bucket should be rinsed with approximately 500 milliliters (about 1 pint) distilled water and the rinsings transferred to the sample bottle. This should be done in a way to ensure that all the dust particles are transferred to the sample bottle. Additional details of the recommended ASTM procedure are included in Appendix B. The dustfall bucket data record form (Figure 22) should be completed by filling in the site name, bucket locations, and all appropriate dates. Sample bottles should be marked for each identification, including laboratory I.D. numbers, before being sent to the laboratory for analysis.

Recording of Data

In any scientific study, the recording of data in an understandable and orderly manner is extremely important. Instead of relying on his memory, the person responsible for the sampling should write down the specifics as soon as possible. Keeping thorough records will make the job easier in the long run and particularly for the report preparation at the end of the project. Three log books are recommended in this regard.

A maintenance log book (Figure 23) should be maintained to include all routine maintenance and any observations concerning activities in the site area which may affect data results. Such activities might

Dustfall Data

Site: Hwy. 45, Milwaukee, Wisconsin

Date results reported: 6/20/77

Buckets 'UP' since: 6/12/77, storm event no. 24

Buckets 'OFF' since: 6/17/77, storm event no. 25

Number of days buckets were up: 4

Date samples received: 6/18/77

Bucket locations or number	Lab no.	Volume of sample, ml	Total solids, mg/l
1. Wisconsin Avenue	25291	970	78
2. Mayfair Road	25290	520	113
3. Watertown Plank Road	25289	560	109

Figure 22. Typical dustfall bucket data record form.

include construction, road maintenance, herbicide or pesticide application to vegetation, etc. The maintenance log book should be kept on-site at each site. This provides maintenance personnel with a running record of maintenance performed, observations on equipment status, and quantities of supplies on hand. Because trends can be observed with a running record, it helps to prevent equipment malfunctions by indicating what parts may need replacing or servicing. It helps to pinpoint causes of equipment malfunctions if they do occur, and aids in time synchronization between precipitation gage, flow recorder and sampler clocks.

A field log book (Figure 24) should be maintained to keep special notes with reference to climatology, the physical condition of the roadway and right-of-way, and the details of sample collections. In addition, notes should be written to describe what was done. Any equipment malfunctions or breakdowns should be noted to explain missing data. The field log book is best kept in the office for reference during sample compositing and data analysis. During sampling events, notes can be written down on the data collection form or in a field notebook and immediately transferred to the permanent field log book.

A log book with laboratory sample identification numbers should also be kept (Figure 25). This log book should include; method of sampling (automatic samplers or manual "grab" samples), the time samples

TITLE HWY 45 PROJECT NO. 27
BOOK NO.

14 JUNE 77 1000 to 1100 HRS

RAIN GAGE: PUT ON NEW CHART - CHART TIME O.K.
WOUND CLOCK MECHANISM
REFILLED INK RESERVOIR
INK BOTTLE GETTING LOW

FLOW RECORDER: PUT ON NEW CHART - CHART WAS 10 MINUTES SLOW
WOUND CLOCK MECHANISM
REFILLED INK RESERVOIR
NITROGEN CYLINDER PRESSURE O.K. - 1800 PSI
CHECKED FOR LEAKS ON GAS LINES AND FITTINGS - OK

ISCO SAMPLERS: CHECKED TIME INTERVALS FOR AUTOMATIC SAMPLING - BOTH ISCO'S FUNCTIONING
CHANGED DESICANT ON 1379 AND 1680
CHECKED FUSES - O.K.
CHECKED BATTERIES WITH VOLT METER
- 1379 - O.K.
- 1680 - LOW - TOOK BACK FOR RECHARGE
- AUXILLARY - O.K. - HOOKED UP TO 1680

BOTTLE SUPPLY - WELL STOCKED

LEFT NEW SUPPLY OF FELT TIP PENS, MASKING TAPE AND PAPER TOWELS
FLASH LIGHTS ALL IN WORKING ORDER

DUST BUCKETS - PUT 1000 ML OF DISTILLED WATER INTO EACH DUSTFALL BUCKET

CITY WORKERS ARE SPRAYING TREES IN PARK NORTH OF INSTRUMENTATION SHED

SCIENTIFIC BINDERY PRODUCTS CHICAGO 60605

SIGNATURE Nicholas P. [illegible] DATE 6/14/77

DISCLOSED TO AND UNDERSTOOD BY DATE WITNESS DATE

Figure 23. Typical information in routine maintenance log book.

TITLE Hwy 45 PROJECT NO. BOOK NO. 74

17 JUNE 77

1850 - ARRIVED AT SITE
- RAINING LIGHTLY, GROUND WET, BUT NO FLOW RECORDED
- CHART TIME OK

1900 - TOOK PRESTORM MANUAL GRABS FOR OIL AND GREASE, AND PESTICIDES

1910 - RAINING HARDER - NO FLOW YET
- STORM FRONT LOOKS SEVERE TO THE NORTHWEST
- DISCONNECTED ISCO'S FROM FLOW RECORDER AND PUT THEM IN AUTOMATIC SAMPLING MODE
- 1680 BLEW A FUSE WHEN I DISCONNECTED LEAD FROM FLOW RECORDER - REPLACED FUSE - 1680 SEEMS TO BE IN WORKING ORDER
- DESICANT INDICATOR FOR 1379 AND 1680 SHOWS DESICANT GOOD
- NITROGEN GAS PRESSURE GOOD

1925 - FLOW STARTING TO RISE ON FLOW CHART
- TOOK FIRST SAMPLE ON 1680 AND 1379, ALSO TOOK MANUAL GRABS FOR PESTICIDES, OIL AND GREASE AND FECAL COLIFORMS
- 1680 WILL NOT AUTOMATICALLY ADVANCE SAMPLES - WILL HAVE TO DO THIS MANUALLY

2000 - CHECKE FLOW CHART TIME - O.K.

2010 - RAINING ONLY LIGHTLY

2020 - RAIN STOPPED

2300 - PUT A NEW SET OF BOTTLES INTO BOTH ISCO'S - WILL LEAVE ISCO'S IN AUTOMATIC MODE
- AM LEAVING NOW - TAKING WHAT SAMPLES I HAVE BACK TO ENVIREX

SCIENTIFIC BINDERY PRODUCTS CHICAGO 60603

SIGNATURE Nicholas P. Holmes DATE 6/17/77

DISCLOSED TO AND UNDERSTOOD BY DATE WITNESS DATE

Figure 24. Typical information in field log book.

TITLE Hwy 45

PROJECT NO.

BOOK NO.

26

STORM # 30 - 17 JUNE 1977

SAMPLES RECEIVED - 18 JUNE 1977

1392 - 15 MIN

#	ESD #	TIME
1	25681	1900
2	25682	1915
3	25683	1930
4	25684	1945
5	25685	2000
6	25686	2015
7	25687	2030
8	25688	2045
9	25689	2100
10	25690	2115
11	25691	2130
12	25692	2145
13	25693	2200
14	25694	2215
15	25695	2230
16	25696	2245
17	25697	2300
18	25698	2315
19	25699	2330
20	25700	2345
21	25701	2400
22	25702	0015
23	25703	0030
24	25704	0045
25	25705	0100
26	25706	0115

1680 - 5 MIN

#	ESD #	TIME
1	25707	1925
2	25708	1930
3	25709	1935
4	25710	1940
5	25711	1945
6	25712	1950
7	25713	1955
8	25714	2000
9	25715	2005
10	25716	2010
11	25717	2015
12	25718	2020
13	25719	2025
14	25720	2030
15	25721	2035
16	25722	2040
17	25723	2045
18	25724	2050
19	25725	2055
20	25726	2100

MANUAL GRAB - GALLON

#		ESD #	TIME
1	(Pest)	25206	1900
2	(O & G)	25207	1900

MANUAL GRAB - OIL AND GREASE

#	ESD #	TIME
3	25208	1925
4	25209	1935
5	25210	1945
6	25211	1955
7	25212	2005
8	25213	2015
9	25214	2025
10	25215	2035
11	25216	2045
12	25217	2055

MANUAL GRAB - COLIFORM

#	ESD #	TIME
3	25196	1925
4	25197	1935
5	25198	1945
6	25199	1955
7	25200	2005
8	25201	2015
9	25202	2025
10	25203	2035
11	25204	2045
12	25205	2055

COMPOSITE SAMPLE - ESD # 25218

SCIENTIFIC BINDERY PRODUCTS CHICAGO 60605

SIGNATURE [illegible] DATE 6/18/77

DISCLOSED TO AND UNDERSTOOD BY | DATE | WITNESS | DATE

NOTE: ESD# IS THE LABORATORY IDENTIFICATION NUMBER.

Figure 25. Typical log book page showing sample identification numbers.

were taken, and the date that samples were received. If a sample identification log is maintained, questions on data received from the laboratory can speedily be obtained with a minimum of confusion. This is especially true if a large time lag exists between sample analysis and questions. If the laboratory is a part of the monitoring agency, this log book is easy to maintain. If the laboratory is independent from the monitoring agency, special arrangements may have to be made.

When recording data in the log book, it is a good idea to follow a standard procedure especially when more than one person is involved:

1. All entries should be made in ball point pen to insure the permanency of the record and the legibility of the carbon copy (if used).

2. All data must be filled in accurately, completely, and as quickly as possible with emphasis placed on correct date and time.

3. All pages of the log should be utilized in ascending order. The event occurring first, chronologically, will be recorded on page 1 (one). The second event will be recorded on page 2 (two), etc. If a page is rendered unusable, it should be marked "VOID".

4. All sheets should be signed by the individual performing the maintenance or sampling the event upon completion of all entries to the log.

Event Record Sheets - Standard record sheets can be prepared and used to record the data from each event. Space should be left at the bottom of the record sheet for the site operator to make comments and observations about the monitored event. These notes can later be transferred to the field log book as a permanent record. Figure 26 shows a typical sampling record sheet that was utilized in Milwaukee, Wisconsin during a FHWA study (5). Notice that time is a particularly important factor.

Sample Handling and Composition

Sample Identification - The proper handling of samples is important in developing reliable data. To allow easy identification in the field and laboratory, each sample should be assigned a unique identification number. In this regard, it is recommended that pre-numbered stickers be used to assign sample identification numbers. These sample I.D. numbers should be related to the location of sampling and date and time of collection in the sample I.D. book. These numbers should also be specified on the sample analysis request form and data sheet(s). The analysis request form should be included each time samples are submitted to the laboratory for analysis. A copy of the form should

Site: Hwy. 45

Storm event no.: 30

Date: 6/17/77

Operator: D. Gruber

Descrepency between chart time & actual time: None

Time storm started: 1920

Time storm ended: 1945

Sampling duration: 1900-0115

Sampler #1-1392		Sampler #2-1680		Manual grabs		
Time	Sample number	Time	Sample number	Time	Sample number	Temperature °F
1900	1	1925	1	1900	1	69
1915	2	1930	2	1900	2	69
1930	3	1935	3	1925	3	70
1945	4	1940	4	1935	4	70
2000	5	1945	5	1945	5	71
2015	6	1950	6	1955	6	71
2030	7	1955	7	2005	7	73
2045	8	2000	8	2015	8	72
2100	9	2005	9	2025	9	72
2115	10	2010	10	2035	10	71
2130	11	2015	11	2045	11	71
2145	12	2020	12	2055	12	71
2200	13	2025	13			
2215	14	2030	14			
2230	15	2035	15			
2245	16	2040	16			
2300	17	2045	17			
2315	18	2050	18			
2330	19	2055	19			
2345	20	2100	20			
2400	21					
0015	22					
0030	23					
0045	24					
0100	25					
0115	26					

Comments and Observations

1850 - Flow chart time ok
1910 - Blew fuse on ISCO
1925 - Flow started
- Automatic advance on 1680 did not work

2000 - Flow chart time ok
2020 - Rain stopped
2300 - Left monitoring site

Figure 26. Typical storm event data collection form.

be kept by the person responsible for sampling for his records. Typical analytical determination request forms and results forms are shown in Figures 27 and 28, respectively.

The data sheet or sheets should be used to organize and summarize all the data collected for a given runoff event. These sheets should be completed and given to the person who will be responsible for evaluating the data. The evaluation and use of the data after it is collected is discussed in Section VI.

Sample Composition - The details of the method of sample composition can be recorded as shown in Figure 29. This form is set up for the flow-proportional method of compositing. The following procedure was used for flow-proportional sample compositing during Envirex's study. Sample lab I.D. number 25707 at time 1925 (Figure 29) will be used as a sample calculation problem:

1. Using the storm event data collection form (Figure 26) and storm event hydrograph chart (Figure 4), transfer data for site sample numbers and corresponding times of sample, and gage height information in appropriate columns (no. 1, 3, 4, respectively) on the flow compositing data form (Figure 29).

2. Calculate corresponding flow values using appropriate calibration curves (Table 3) for the flume or weir use. Transfer this information to appropriate column (no. 6).

   a. Gage height at 1925 = 0.5 in.(1.27 cm) - from column 4.

   b. Using rating table (Table 3) convert gage height to flow: 0.5 in. = 0.1 cfs (1.27 cm = 0.0028 m^3/s) to enter in column 6.

3. Calculate the time interval between successive samples from data shown in column 3 and record in column no. 5. The first number in column 5 will have to be calculated from the storm hydrograph trace (Figure 4) as the time difference between the times when flow started increasing to the time the first sample was taken.

   a. Flow start time = 1924 hrs.

   b. Time of first sample = 1925 hrs - from column 3.

   c. Time interval between flow start time and time of first sample: 1925 - 1924 = 1 minute - enter in column 5.

4. Multiply column 5 and 6 and record values in column 7. The first and last numbers in this column should be divided by 2 to reflect areas under a triangle representative of the beginning and end of storm event.

Storm event number: 30
Site: Hwy. 45
Time & date of storm: 6/17/77 120-2315

Project number: FG 40333 32-01
Results reported to: M. Gupta
Time & date samples received: 11:00 am 6/18/77

Sample lab no.	Site sample number	Time of sampling	Type of sample	pH	TS	SS	TVS	VSS	Pb	Zn	Fe	Cr	Cu	Cd	Hg
			Flow composite	x	x	x	x	x	x	x	x	x	x	x	x

Ni	COD	BOD5	BOD20	TOC	Total PO4	TKN	NO3 NO2	Cl
x	x	x	x	x	x	x	x	x

Sample lab no.	Site sample number	Time of sampling	Automatic sampler	pH	TS	SS	VSS	Pb	Zn	Fe	Manual Grab Samples: Oil and grease	Manual Grab Samples: Coliform analysis
14150	1-1680	1900	Discrete	x	x	x	x	x	x	x	x	x
14151	2-1680	1930	Discrete	x	x	x	x	x	x	x	x	x
14152	3-1680	1935	Discrete	x	x	x	x	x	x	x	x	x
14181	4-1392	1940	Discrete	x	x	x	x	x	x	x	x	x
14182	5-1392	2000	Discrete	x	x	x	x	x	x	x	x	x
14185	8-1392	2045	Discrete	x	x	x	x	x	x	x	x	x
14195	18-1392	2315	Discrete	x	x	x	x	x	x	x	x	x

Figure 27. Typical laboratory analysis request form.

Storm event number: 30	Time and date of storm: 6/17/77 1920-1945	Time and date samples received: 11:00 am 6/18/77
Site: Hwy. 45	Project number: FG 40333 32-01	
Date of data report: 6/29/77	Results report to: M. Gupta	

Lab no.	Site sample no.	Time of sampling	Type of sample	pH	SS	VSS	TOC	Pb	Zn	Fe	COD	Total PO_4	TKN	NO_3,NO_2	Cl	Cr	Cu	TS	Cd	Hg	BOD	Ni
25218	--	--	Flow composite	7.30	579	510	4.3	0.9	0:38	18.1	105	0.72	3.8	0.97	105	0.03	0.09	1944	0.05	0.03 μg/l	11	0.1

Lab no.	Site sample no.	Time of sampling	Automatic sprinkler	pH	SS	VSS	TS	Pb	Zn	Fe	Manual grab samples: Time	Lab no.	Oil & grease	Time	Lab no.	Total coliform	Fecal coliform
25681	Back-ground	1900	Discrete	7.85	30	150	5430	0.2	0.39	0.27	1900	25207	8	1925	25196	72,000	4,200
25708	2-1680	1930	Discrete	6.95	529	98	1740	1.8	0.92	12.7	1925	25208	8	1935	25197	140,000	8,700
25709	3-1680	1935	Discrete	6.83	561	300	2520	1.8	0.53	17.9	1935	25209	14	1945	25198	47,000	6,600
25710	4-1680	1940	Discrete	7.25	788		1310	1.3	0.49	20.7	1945	25210	7	2025	25202	6,800	1,500
25711	5-1680	2000	Discrete	7.50	803	297	1360	1.4	0.44	26.9	2055	25217	9	2055	25205	5,400	2,100
25688	8-1392	2045	Discrete	7.60	1376	176	2180	0.9	0.46	49.5							
25698	18-1392	2315	Discrete	7.01	182		1840			4.93							

Figure 28. Typical laboratory results form.

Site: Hwy. 45
Storm event number: 30
Time and date of storm: 6/17/77

Temperature of samples: 20°C
Flow composited by: T. Meinholz
Approved by: M. Gupta

Time and date samples received and composited: 6/18/77

Site sample number	Lab no.	Time of sample, hrs.	Gage height, inches	Time interval between samples, minutes	Flow, cfs	Flox x time int., cfs x min.	Proportionate volume, %	Sample volume to make 2 liters composite, ml
1-1680	25707	1925	0.5	1	0.1	0.05	0.004	0.1
2-1680	25708	1930	7.0	5	4.7	21.0	1.69	33.7
3-1680	25709	1935	35.0	5	59.3	296.5	23.81	476.2
4-1680	25710	1940	35.0	5	59.3	296.5	23.81	476.2
5-1680	25711	1945	26.0	5	34.8	174.0	13.97	279.5
6-1680	25712	1950	21.0	5	24.2	121.0	9.72	194.4
7-1680	25713	1955	18.0	5	18.8	94.0	7.55	151.0
8-1680	25714	2000	14.0	5	12.4	62.0	4.98	99.6
9-1680	25715	2005	11.0	5	8.3	42.5	3.41	68.3
10-1680	25716	2010	8.0	5	5.2	26.0	2.09	41.8
11-1680	25717	2015	7.0	5	4.2	21.0	1.69	33.7
12-1680	25718	2020	5.5	5	2.9	14.5	1.16	23.3
13-1680	25719	2025	4.5	5	2.15	10.75	0.80	17.3
14-1680	25720	2030	4.0	5	1.8	4.0	0.72	14.5
15-1680	25721	2035	3.5	5	1.5	7.5	0.60	12.1
16-1680	25722	2040	3.0	5	1.2	6.0	0.48	9.6
17-1680	25723	2045	2.8	5	1.09	5.45	0.44	8.8
18-1680	25724	2050	2.5	5	0.93	4.63	0.27	7.4
19-1680	25725	2055	2.3	5	0.82	4.08	0.33	6.6
20-1680	25726	2100	2.0	5	0.065	3.25	0.26	5.2
10-1392	25690	2115	1.9	15	0.61	9.15	0.73	14.7
11-1392	25691	2130	1.5	15	0.45	6.75	0.54	10.8
12-1392	25092	2145	1.1	15	0.29	4.35	0.35	7.0
13-1392	25693	2200	1.0	15	0.25	3.75	0.30	6.0
17-1392	25697	2300	0.1	60	0.05	1.50	0.20	2.4

in. x 2.54 = cm
cfs x 0.028 = m^3/s

Figure 29. Typical flow compositing form.

Table 3, Rating table for Milwaukee-
Hwy. 45 site - Palmer - Bowlus flume(5).

Gage height, in.	Discharge, cfs	Gage height, in.	Discharge, cfs	Gage height, in.	Discharge cfs
0.1	0.05	3.5	1.50	27.0	37.2
0.2	0.05	4.0	1.80	28.0	39.7
0.3	0.08	4.5	2.15	29.0	42.3
0.4	0.10	5.0	2.50	30.0	44.9
0.5	0.10	5.5	2.90	31.0	47.6
0.6	0.15	6.0	3.30	32.0	50.4
0.7	0.18	6.5	3.75	33.0	53.3
0.8	0.20	7.0	4.2	34.0	56.3
0.9	0.22	7.5	4.7	35.0	59.3
1.0	0.25	8.0	5.20	36.0	62.3
1.1	0.29	8.5	5.70	37.0	65.4
1.2	0.33	9.0	6.20	38.0	68.6
1.3	0.37	9.5	6.75	39.0	71.9
1.4	0.41	10.0	7.3	40.0	75.3
1.5	0.45	11.0	8.5	41.0	78.8
1.6	0.49	12.0	9.7	42.0	82.3
1.7	0.53	13.0	11.0	43.0	85.9
1.8	0.57	14.0	12.4	44.0	89.6
1.9	0.61	15.0	13.9	45.0	93.3
2.0	0.65	16.0	15.5	46.0	97.0
2.1	0.71	17.0	17.1	47.0	101.0
2.2	0.76	18.0	18.8	48.0	106.0
2.3	0.82	19.0	20.5	49.0	121.0
2.4	0.87	20.0	22.3	50.0	122.0
2.5	0.93	21.0	24.3		
2.6	0.98	22.0	26.2		
2.7	1.04	23.0	28.2		
2.8	1.09	24.0	30.3		
2.9	1.15	25.0	32.5		
3.0	1.20	26.0	34.8		

in. x 2.54 = cm
cfs x 0.028 = m^3/s

1 minute x 0.1 cfs ÷ 2 (first sample) = 0.05
enter in column 7.

5. Calculate sum of all the numbers in column 7.

6. Calculate proportionate fraction percentage of each sample by dividing individual values in column 7 to the sum of values calculated in Step 5. Record this data in column 8

   0.05 (column 7) ÷ 1245.2 (sum of column 7) = 0.004%

7. Multiply individual values in column 8 by the desired total volume of composite sample to arrive at individual sample volumes.

   0.00004 x 2000 ml (volume of composite sample) = 0.08 or 0.1 ml.

8. Vigorously shake each individual sample bottle to obtain a representative sample before transferring the measured sample volumes (column 9) to the separate composite sample container. Composite sample container should have a laboratory I.D. number and this should be logged into sample I.D. logbook. Composite sample is now ready for laboratory analyses.

Sample Volume Preservation - Preservation techniques are recommended by parameter in Table 4. The volume given is the minimum volume required by the laboratory for each analysis.

Analytical Measurement - A listing of the important analytical parameters was made in Section III of this manual. Selection of specific parameters for analysis should be made by the program director based upon the study objectives and budgetary constraints. Furthermore, only a few parameters such as pH, solids, organics, selected heavy metals such as lead, zinc, and iron and chlorides need be analyzed on several discrete samples to study their variation with time during a storm event. More detailed analyses should be conducted on the flow composited sample to obtain total pollutant loadings for the storm event in question. However, flexibility should be maintained in the number and type of analyses to be performed for any storm event. Table 5 shows a listing of the parameters that were analyzed during a FHWA study (5) for various discrete and composite samples. Among the listing shown in Table 5, pH, BOD, and coliform analyses are the most critical ones that need to be analyzed immediately. Chlorides should be run on discrete samples only for those storm events when road salting for deicing is used. PCB's and selected pesticides/herbicides need be run only in those seasons when application of such materials is made on the highway system. Any special analyses such as asbestos, rubber, paraffins, etc., may be run on a cursory basis to evaluate their level of significance.

Table 4. Recommended sampling and preservation techniques (20).

Parameter	Volume ml	Preservation	Time for which samples can be kept without analysis
BOD	1,000	Ice	6 Hrs.
COD	50		
Chloride	50	None required	7 Days
Metals	100	Ice or HNO_3 to pH <2	6 Mos.
Kjeldahl nitrogen	500	Ice or H_2SO_4 to pH <2	24 Hrs.
Oil and grease	1,000	Ice or H_2SO_4 to pH <2	24 Hrs.
Organic carbon	25	Ice or H_2SO_4 to pH <2	24 Hrs.
pH	25	Ice	6 Hrs.
Total phosphorus	50	Ice	24 Hrs.
Total residue (solids)	100	Ice	7 Days
Filterable residue (and volatile filterable residue)	100	Ice	7 Days

Table 5. Parameters analyzed during a FHWA study (5).

Composite	Discrete, auto	Discrete, manual
Total solids	Total solids	(selective events only)
Suspended solids	Suspended solids	Oil and grease
Volatile suspended solids	TOC	
BOD_5	Lead	Total coliform
TOC	Zinc	Fecal coliform
COD	Iron	Fecal strep
Total PO_4	Chloride	
Kjeldahl nitrogen	pH	PCB's
$NO_3 + NO_2$		Pesticide/herbicide
Lead		
Zinc		
Iron		
Copper		
Chromium		
Cadmium		
Mercury		
Chloride		
pH		
Asbestos (selective events)		

SECTION VI
DATA EVALUATION AND USE

State highway personnel will have varying degrees of responsibility for evaluating and applying the monitoring data. In some cases their responsibility may end with the collection of the raw data and the delivery of the data sheets to the appropriate agency. In other cases the responsibility will extend beyond the collection of the raw data to include evaluation techniques. These techniques which may vary in complexity, are applied to determine what conclusions can be drawn from the data base. The following approach can be used to evaluate single or multiple site data.

Evaluation Techniques

The evaluation of rainfall, runoff and constituent quality data requires the transformation of the raw data into various units and combinations in order to normalize the data. The normalized data can then be used to compare the results of various runoff events from single or multiple sites. The procedure to be followed consists of the following techniques.

Rainfall-Runoff Data - The rainfall data obtained from the monitoring site raingages must be converted into three parameters corresponding to:

$$R = \text{total rainfall in inches}$$
$$TR = \text{rainfall duration}$$
$$RI = \text{average rainfall intensity} = R/TR \qquad \text{Eq. (1)}$$

The total rainfall is the amount of rain that contributes to the monitored runoff event. It must include only that rainfall associated with the runoff hydrograph.

The runoff data must also be transformed into a different units of volume which allows normalization of the data. The total volume of runoff from a drainage area of A acres, as measured at the outfall can be used to produce the following:

$$Q = \text{total volume of runoff in inches}$$
$$= (\text{total cubic feet of runoff})*\left(\frac{2.75 \times 10^{-4}}{A}\right) \qquad \text{Eq. (2)}$$
$$= (\text{total gallons of runoff})*\left(\frac{3.67 \times 10^{-5}}{A}\right) \qquad \text{Eq. (3)}$$

Equation 2 is derived in the following manner:

cubic feet of runoff (ft^3) is divided by the square feet of drainage area A (acres x 43,560 ft^2/acre) which is:

$$\frac{1\ ft^3}{A(43{,}560\ ft^2)} = \frac{2.29 \times 10^{-5}}{A}\ ft$$

converting feet to inches

$$\frac{2.29 \times 10^{-5}\ ft}{A} \left(12\ \frac{inches}{ft}\right) = \frac{2.75 \times 10^{-4}\ inches}{Acre}$$

The same analysis holds for equation 3.

Q is expressed as the inches of runoff resulting from the A acres of drainage area contributing to the monitoring point. Thus, the following example illustrates the methodology for determining the value of Q:

Example 1

A 40 acre drainage area produces 1.36 million gallons of runoff during a storm event. Using equation 3, the inches of runoff can be calculated as:

$$Q = 1.36 \times 10^6 \text{ gallons} * \frac{3.67 \times 10^{-5}}{A}$$

$$= 1.36 \times 10^6 * \frac{3.67 \times 10^{-5}}{40}$$

$$= 1.25 \text{ inches}$$

The duration of the runoff is the total time from the start of the arriving flow to the end of the runoff event. The runoff duration is specified as TQ and can be expressed in hours or minutes. TQ is also used to determine the average runoff intensity RI:

RI = average runoff intensity; inches/hour or inches/min.
= total runoff volume /duration
= Q/TQ

Eq. (4) or RI = Q/TQ

The categorization of rainfall and runoff data according to the above discussions provides the basic parameters necessary for more detailed comparisons. In addition to a simple listing of both the Q and R parameters, the ratio of Q/R is also determined to provide insight into the response of the study area to various rainfall events.

Table 6 provides sample data for a typical site comprised of approximately 30% paved area and the remainder being grassy.

Table 6. Rainfall runoff values

Event	Date	Rainfall-R, inches		Runoff-Q ft^3	Runoff-Q inches		Q/R	
1	3/26	(1)	1.56	346,302	(1)	0.90	(2)	0.58
2	3/29	(7)	0.22	73,108	(4)	0.19	(1)	0.86
3	6/18	(3)	0.66	103,891	(2)	0.27	(3)	0.41
4	7/28	(5)	0.33	23,087	(7)	0.06	(8)	0.18
5	7/30	(2)	1.14	88,499	(3)	0.23	(7)	0.20
6	8/5	(8)	0.04	5,268	(8)	0.01	(5)	0.25
7	8/14	(6)	0.31	30,782	(6)	0.08	(4)	0.26
8	8/25	(4)	0.37	34,630	(5)	0.09	(6)	0.24

(1) = Ranking in. x 2.54 = cm
ft^3 x 0.028 = m^3

The data listed for the eight monitoring events presents a wide range of rainfall and runoff values. Evaluation of the data is greatly simplified by converting the runoff volumes in cubic feet to inches. The Q/R ratio then provides indications as to the amount of runoff produced for each unit of rainfall. For events 1 and 2, the Q/R ratio is significantly higher than any of the other values for the period. The dates of these events indicate that the ground surface may have been partially frozen or some snowmelt occurred at this site and therefore the amount of runoff from the grassy areas was significantly greater than that expected from the rainfall.

Table 6 also provides a ranking of individual columns within the table. For example, the R values are ranked from 1 to 8 based on a highest to lowest numerical value. Comparison of the rank in the R column with that of Q column or Q/R column provides an easy method of evaluating each expression. Thus, event number 1 had the highest R and Q value and the second highest Q/R value.

The expected Q/R ratio for nonwinter conditions for any site can be approximated by assuming 85% of the paved area percentage and 5% of the grassy area percentage which contributes to the volume of runoff. Thus, for the above site the expected Q/R ratio would be roughly;

$$85\% (0.30) + 5\% (0.70) = 0.29$$

Using the nonwinter events (numbers 3-8) the average Q/R value is approximately 0.26 which is close to the expected value. Different sites having steeply sloped grassy areas or high percentage paved areas may exhibit significant variations in the expected Q/R ratio. As an example, an all paved, elevated site comprised of 2.1 acres of area has an average Q/R ratio of 0.87 with the range of values between 0.8 and 1.0. An all grassy site produced an average Q/R of 0.20 and the range of values between 0.001 and 0.53. Wide variations in the measured Q/R ratio for the grassy portion of the drainage area reflect soil saturation, slope and other conditions.

The evaluation of the runoff data from individual or multiple sites is greately simplified by the production of Q/R ratios. Runoff events producing ratios close to the paved percentage of the site indicate little, if any, contribution from the nonpaved areas. High Q/R ratios indicate runoff from the nonpaved areas or a large percentage of the drainage area is impervious.

Evaluating the data of Table 6 will provide an example of how the variations in the ratio can be explained. As previously mentioned, the first two events occur during winter conditions which accounts for the high ratios. Event number 3 also exhibits a significantly higher ratio than anticipated for this site even though it occurred during the summer. A check of the rainfall record at this site indicates a number of storms occurred within five days previous to this event, but were not monitored because of an equipment malfunction. A large storm one day prior to an event could have saturated the pervious area to such an extent that during event number 3 this area contributed more runoff than expected. The remainder of the Q/R data is reasonably consistant for this 30 percent paved site.

The lowest Q/R ratio for the data of Table 6 was 0.18 for event number 4 which resulted from a storm that occurred after more than three weeks of dry weather. This dry period had the opposite effect of event number 3 in that the pervious area most likely contributed very little flow to the total runoff volume. These examples provide a brief idea of the utility of the Q/R ratio in evaluating the hydraulic response of single or multiple monitoring locations.

Quality Data - The analysis of discrete and composite quality results is difficult when individual concentrations of each parameter are viewed on a storm by storm basis. In order to evaluate this type of data, the following approach using the composite concentration values can be used to normalize the data for different storms or sites.

$$\text{composite concentration in mg/l} \times 2.205 \times 10^{-6} \ \frac{\text{pounds}}{\text{mg}} = \text{pounds/liter}$$

$$\text{pounds/liter} \times 3.531 \times 10^{-2} \ \frac{\text{liter}}{\text{cu ft}} \times \text{cubic feet} = \text{pounds}$$

Simplifying this expression for a runoff event that produced a composite concentration equal to C and a total volume equal to V, the following equation results:

$$\text{Eq. (5)} \qquad C(\text{mg/l}) \times 6.37 \times 10^{-5} \times V\ (\text{ft}^3) = \text{total pounds}$$

For V in inches of runoff

$$\text{Eq. (6)} \qquad C\ (\text{mg/l}) \times 24.510 \times V\ (\text{in.}) = \text{total pounds}$$

Typical composite data from the same runoff events as previously described is listed in Table 7. Using equations 5 and 6 the conversion of the suspended solids concentrations into the total pounds of pollutant discharged can be determined. Using the runoff volume in cubic feet or inches produces a pounds loading which when calculated for each unit of volume, may vary because of the round-off error in the inches of runoff values.

The pounds of suspended solids for each event of Table 7 provide an indication of the impact of each runoff event. Thus, although event number 3 has the highest composite concentration, event number 1 produced the greatest loading. Other relationships using the pounds loading and total volume of runoff indicate that although event number 7 had less than half the flow of event number 2, the former produced almost 20% more load than the latter.

The ranking of the volume of runoff, concentration and pound columns provides other interesting relationships.

Additional insight into the suspended solids loads can be gained through the conversion of the pounds loading of Table 7 into pounds per inch of runoff (lb/in.). This expression is another form of a concentration except it relates pounds to the total volume of runoff while mg/l relates an average load (mg) to an average volume (liter). Thus, the lb/in column of Table 7 shows similar relationships to the mg/l column as seen in the ranking column, for example event number 3 shows the highest concentration (mg/l) and lb/in. value with the other events having about the same ranking.

The relationship between the pounds of pollutant discharged and the average intensity of runoff can be determined by using runoff volume and duration to produce an in./hr value and dividing this value into the pounds load. The final column of Table 7 presents these values. Note that event number 7 has the lowest ranking while event number 3 has the highest. An interesting point using this method can be seen for event number 3 which previously ranked 1 or 2 in the concentration, pounds and pounds per inch columns. When this event is expressed on a pounds per inch per hour basis, it is ranked last out of the 8 events. This is due to the extremely high runoff intensity of 0.27 in./hr producing only a small loading for this event. Other similar trends can be found for the remaining events.

The use of the discrete concentration values for determining the distribution of the total load being discharged will be briefly discussed in the following paragraphs. In general, discrete samples are analyzed to determine maximum concentrations or the time location of any flush

Table 7. Composite concentrations and loadings.

		Runoff			Suspended solids			
		Volume		Duration,			Pounds/	Pounds/
Event	Date	ft^3	in.	hr	mg/l	Pounds	in.	(in./hr)
1	3/26	346,302	0.90^{1}	1.75	470^{2}	$10,194^{1}$	$11,327^{3}$	$19,833^{7}$
2	3/29	73,108	0.19^{4}	9.75	151^{8}	682^{5}	$3,589^{8}$	$34,997^{4}$
3	6/18	103,891	0.27^{2}	10.00	646^{1}	$4,306^{2}$	$15,948^{1}$	$15,948^{8}$
4	7/28	23,087	0.06^{7}	4.75	362^{5}	518^{7}	$8,634^{5}$	$41,008^{3}$
5	7/30	88,499	0.23^{3}	5.25	234^{7}	$1,290^{3}$	$5,608^{7}$	$29,446^{5}$
6	8/5	5,268	0.01^{8}	1.83	386^{4}	127^{8}	$12,700^{2}$	$23,241^{6}$
7	8/14	30,782	0.08^{6}	8.41	395^{3}	805^{4}	$10,062^{4}$	$84,626^{1}$
8	8/25	34,630	0.09^{5}	7.5	270^{6}	601^{6}	$6,678^{6}$	$50,083^{2}$

Note: Superscript numbers indicate ranking.

$ft^3 \times 0.0283 = m^3$
in. x 2.54 = cm
lb x 453.6 = g

phenomenon, if present. One additional technique which can be used is the determination of what percentage of the total load, an individual sample produces. This percentage can be calculated by multiplying the flow rate at the time a discrete sample is obtained times the concentration and duration that the sample covers. A description of the compositing procedure as discussed in Section V will provide the methodology for this calculation. Once the pounds of pollutant discharged for a discrete sample is determined, the percentage of the total pounds can be produced by dividing the discrete pounds by the total pounds.

Data Interpretation

The use of the rainfall, runoff, composite and discrete quality data to produce different parameters to normalize the data base must also rely on other relationships which follow more general guidelines for full data interpretation. Examples include prestorm history and site characteristics.

Prestorm History - The production of runoff and quality parameters at a site for multiple events shows a large variation in magnitude even after extensive normalization. These variations are due, in part, to the climatological conditions present at a site before the runoff event under consideration. The number of days of dry weather, or days in which rainfall events less than a critical amount occur will have a significant effect on the monitored values. Thus, as previously mentioned, event number 3 had an unusually high Q/R ratio in Table 7. Upon investigating the prestorm history it was found that a large amount of rain fell a few days before and possibly saturated the pervious area. The same event produced the highest pounds per inch of runoff as listed in Table 7 . Again, the contribution of the pervious area could account for this high load. Other effects which have occurred for various storms include the wash-off of most of the available pollutants prior to a monitored storm resulting in little, if any, load from the monitored event. This is especially true for sites containing paved area as a large portion of the drainage area. For these types of sites the accumulation and wash-off of pollutants is strictly dependent on the prestorm history.

Site Characteristics - When data from different sites is compared, it is important to include some quantification of a site characteristic to assist in the analysis. For example, the pounds per inch of runoff from a site of 90 percent paved area is significantly higher than for a site of only 30 percent paved. Other site characteristics such as traffic volume, type of barrier or curb also enter into the evaluation.

Statistical Applications

Throughout this section of the report, very little reference to statistical methods was included. In general, the use of average and standard deviation was assumed to be a first cut analysis which would be followed by Q/R ratios and pounds determinations. Average Q/R ratios and other normalized parameters are also assumed to be calculated in order to determine the typical value under investigation.

Over and above these simple statistics, one analysis which should be discussed is the correlation analysis which is available on most desk-top and some hand-held calculators (TI-58, HP-25).

When determining if a functional relationship or correlation exists between two or more variables, it is assumed that one variable is dependent and the other(s) is independent. The independent variables control or affect the dependent variable. As an example, the quality of the runoff (dependent variable) might be found to be highly correlated with runoff intensity, prestorm history, and rainfall intensity and duration (independent variables). These independent variables may in turn be found to be dependent on other variables. For example, runoff intensity may be a function of drainage area, area grade or cross slope.

There are two types of correlation, simple and multiple correlation. In simple correlation two variables are involved. One is independent and the other dependent. In multiple correlation more than two variables are involved, one independent and two or more dependent. For both types of correlation, the relationship may be linear or nonlinear. For a linear relationship the change in the dependent variable is at a constant ratio to the independent variable. If the values for the dependent variable (y) were plotted against the independent variable (x), a straight line approximation (the line of regression) would be obtained (see Figure 30). This line can be expressed by an equation of a straight line:

Eq. (7) $$y = a + bx$$

where

a = y axis intercept

b = slope of the line

The values for a and b are determined using the Least Square Technique discussed later in this section.

For a nonlinear relationship the change in the dependent variable is not at a constant ratio, but at an increasing or decreasing ratio. For example, the relationship could be of a logarithmic form (see Figure 31).

When a linear relationship cannot be established, the usual approach is to attempt to perform a transformation to linearize the relationship and then to proceed as for the linear case using the Least Square Technique.

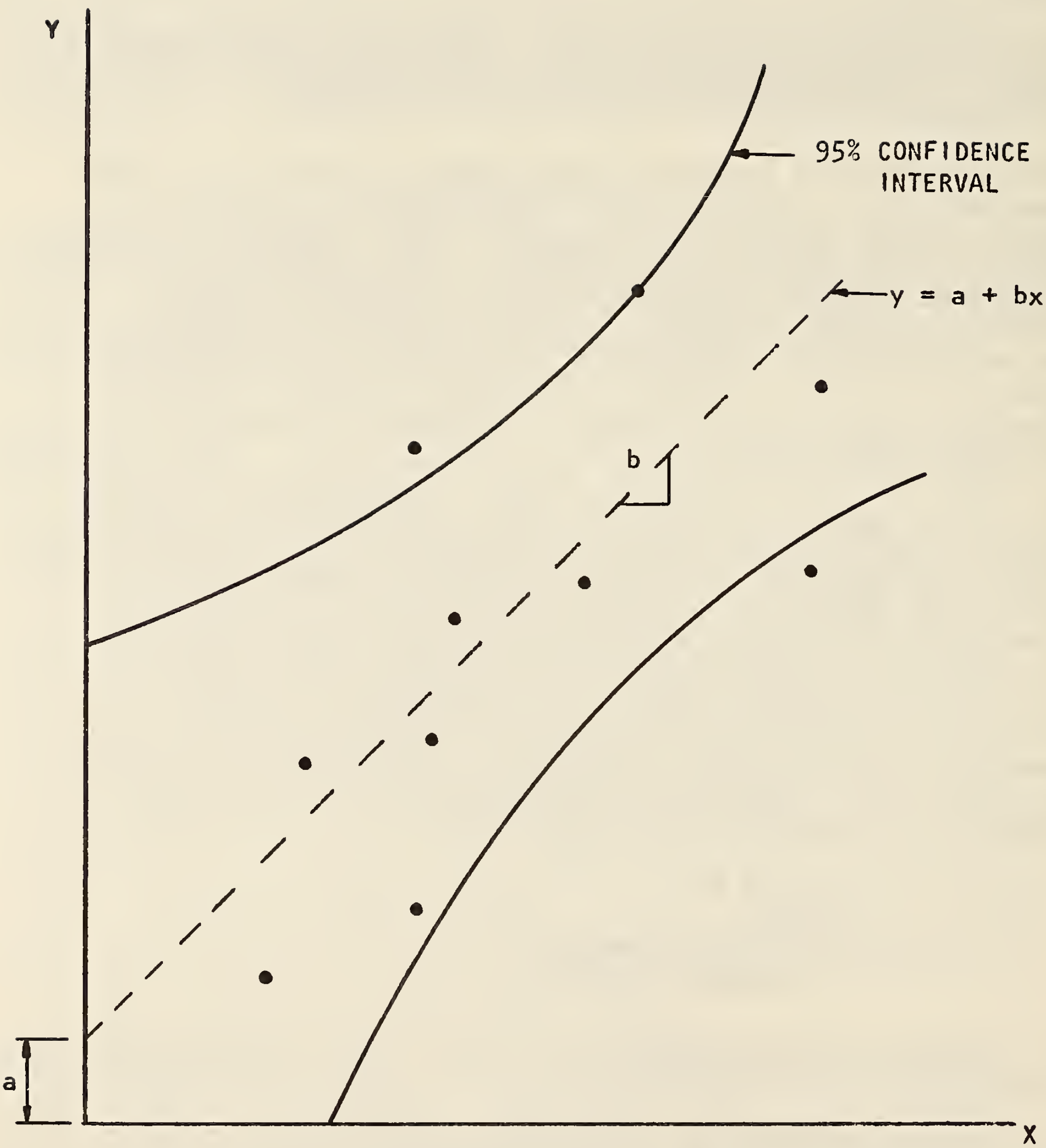


Figure 30. Scatter plot of experimental data indicates a linear regression line gives "best fit".

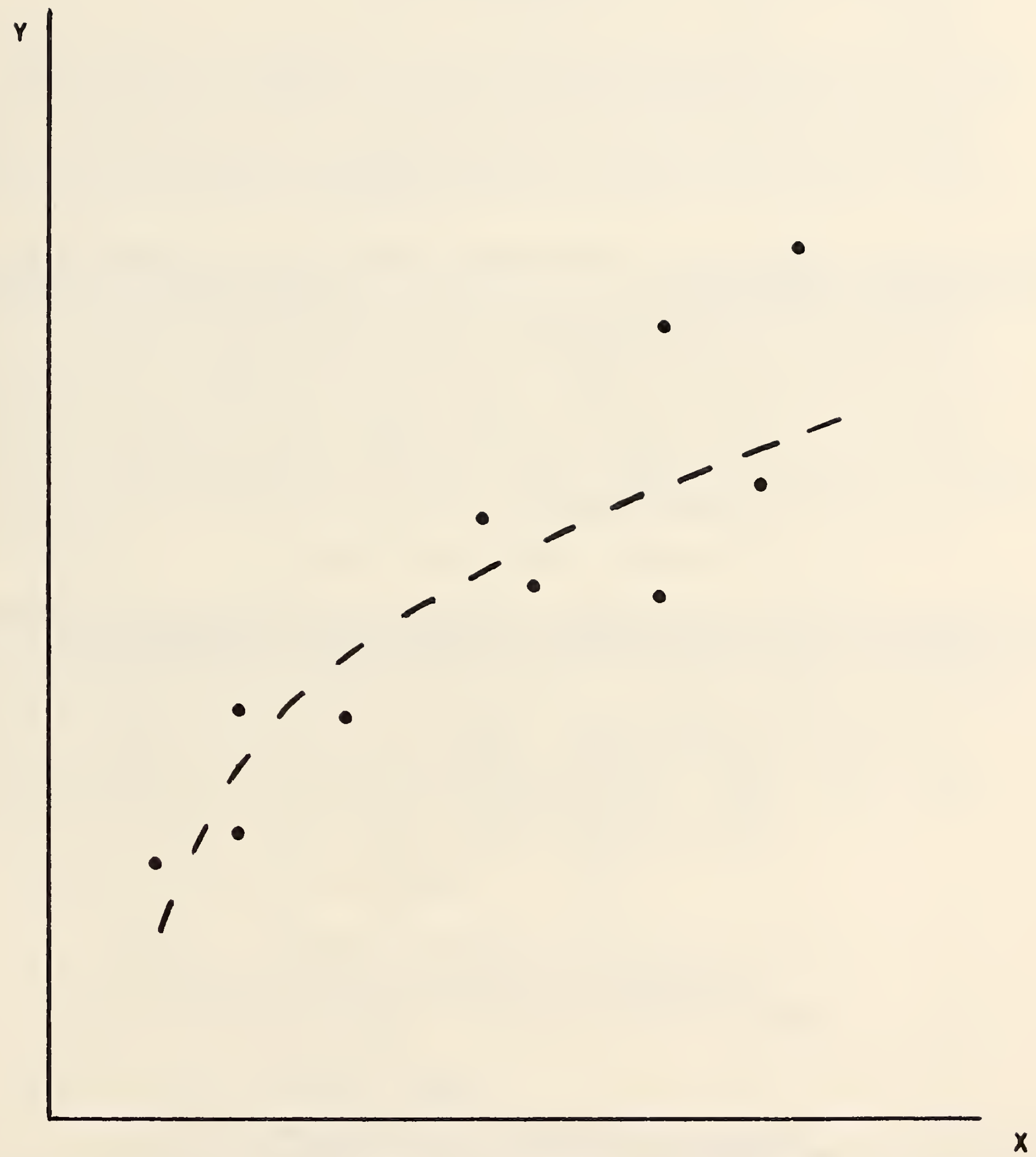


Figure 31. Scatter plot of experimental data indicates a non-linear regression line gives "best fit".

Least Square Technique - The details of this technique can be found in most texts on statistics including references (26)(27)(28)(29). The values of a and b in equation (1) can be obtained by solving the following two equations simultaneously:

Eq. (8) $$\sum_{1}^{N} Y = Na + b \sum_{1}^{N} X_i$$

Eq. (9) $$\sum_{1}^{N} X_i Y_i = a \sum_{1}^{N} X_i + b \sum_{1}^{N} X_i^2$$

The degree of correlation is estimated by the value r, the coefficient of correlation, defined as:

Eq. (10) $$r = \sqrt{1 - \left(\frac{S_{yx}}{S_y}\right)^2}$$

where

S_y = standard deviation

S_{yx} = standard error of the estimate

The standard error of the estimate is a measure of the variation of the scatter of the observed points about the line of regression

Eq. (11) $$S_{yx} = \sqrt{\frac{\sum_{1}^{N} (Y_i - Y_{comp})}{N}}$$

where

Y_i = observed value of Y

Y_{comp} = computed value of Y on the regression line

The value of r can vary from -1 to +1. As r approaches ±1, the correlation and degree of linearity increases. A value of 0 indicates no correlation. The sign of the coefficient indicates whether the relationship (slope of the regression line) is positive or negative.

The use of correlation analyses between two monitored pollutants provides an example of the utility of this method. Thus, it has been found that the linear correlation of iron and total solids is always significant which leads to the possibility of the iron being associated with the solids. Correlation of nutrients, however, with total solids is usually not significant. This relationship tends to indicate that the nutrients may be washed off as a soluble portion while the solids, of course, are particulate.

Predictive Model

Another use of the data generated in a monitoring program is as input to the predictive procedure or model developed under the same project as this manual (U.S. Dept. of Transportation Contract No. DOT-FH-11-8600). The predictive procedure has three separate components which are related to hydraulic determinations, accumulation of pollutants, and the wash-off of pollutants.

Hydraulic Determinations - The determination of the total volume of runoff in the model is based upon the user supplying the total rainfall under consideration, the duration and a description of the drainage area. Factors used to describe the drainage area include the percent paved and the associated average grade and shoulder type, the side slope and type of cover on the nonpaved area. Use of the data in the predictive procedure produces the total volume of runoff in inches and the duration of runoff. Various graphs and tables are used to help the user in selecting proper coefficients and model input parameters.

Accumulation of Pollutants - The second component of the procedure is the pollutant buildup function which predicts the pounds of pollutant on the surface prior to a rainfall event. The unit within the predictive procedure is designated K_1 which is the pounds of pollutant per mile of highway per day of dry weather. The selection of the K_1 value is based on average daily traffic (ADT) and other site characteristics. Using the K_1 value, the user is able to determine the initial surface load using the following equation:

Eq. (12) $$P = P_o + (K_1 x HL x T)$$

where P = pounds on surface

K_1 = selected build-up rate lbs/mi/day

T = dry days

HL = highway length

P_o = residual on surface prior to time t

Pollutant Wash-off - The pounds of pollutant on the surface of the drainage area is removed as a function of the rainfall runoff process in the wash-off component of the model. The constant K_2 is selected by the model user based on site characteristics and the method of evaluating the rainfall runoff process. The equation relating pounds washed-off to total surface load is:

Eq. (13) $$P_D = P_{\_} \; (1-e^{-K_2 r})$$

where

P_D = pounds washed-off

$P_{\_}$ = pounds on surface (from equation (12)

K_2 = washoff constant

r = average runoff intensity (in/hr)

A series of graphs and tables are then utilized by the user to select the appropriate constant.

The use of the model is related to predicting the loads of various pollutants from a highway system. For example, the heavy metals discharged from a highway as predicted by the model can be compared to the urban runoff loads from an equal area near the highway. In this way the relative impact of highway systems, whether actual or proposed, can be evaluated. Other uses of the model such as the effects of selected rainfall events can also be evaluated in terms of the pollution impact on nearby streams or lakes. Further discussions of the model application and use are provided in a separate report (30).

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APPENDIX A

Design of Palmer-Bowlus Flumes (23)(24)(25)

The design procedure comprises of the following steps:

1. Selecting the P-B flume shape or proportions.
2. Rating the flumes.

The following letter symbols are used in this procedure description:

A = area of flow section (A_n, A_u, A_c), in square feet;

b = base width of throat, in feet;

B_c = width of water surface in throat, in feet;

d = depth of flow, in feet;

d_c = critical depth of flow in throat, in feet;

d_{cp} = critical depth of flow in sewer, in feet;

d_n = normal depth of flow in sewer, in feet;

d_u = depth of flow in sewer upstream from throat, in feet;

D = diameter of sewer, in feet;

E = energy of flow (E_c, E_u) in feet;

h_v = velocity head (h_{uv}, h_{vc}) in feet;

m = slope of side of throat;

p = slope of bottom sill transition;

Q = flow, in cubic feet per second;

t = height of bottom sill, in feet;

V = velocity of flow, in feet per second.

<u>Flume Description</u> - As illustrated in Figure 32, the P-B flume comprises a control section or throat, plus upstream and downstream transition sections. The restriction caused by the control section results in backup above the flume so that the depth of flow immediately above the flume, d_u, is greater than the normal depth, d_n. The upstream depth, d_u, is the depth actually measured, and the problem of calibrating the flume amounts to correlating values of d_u and Q.

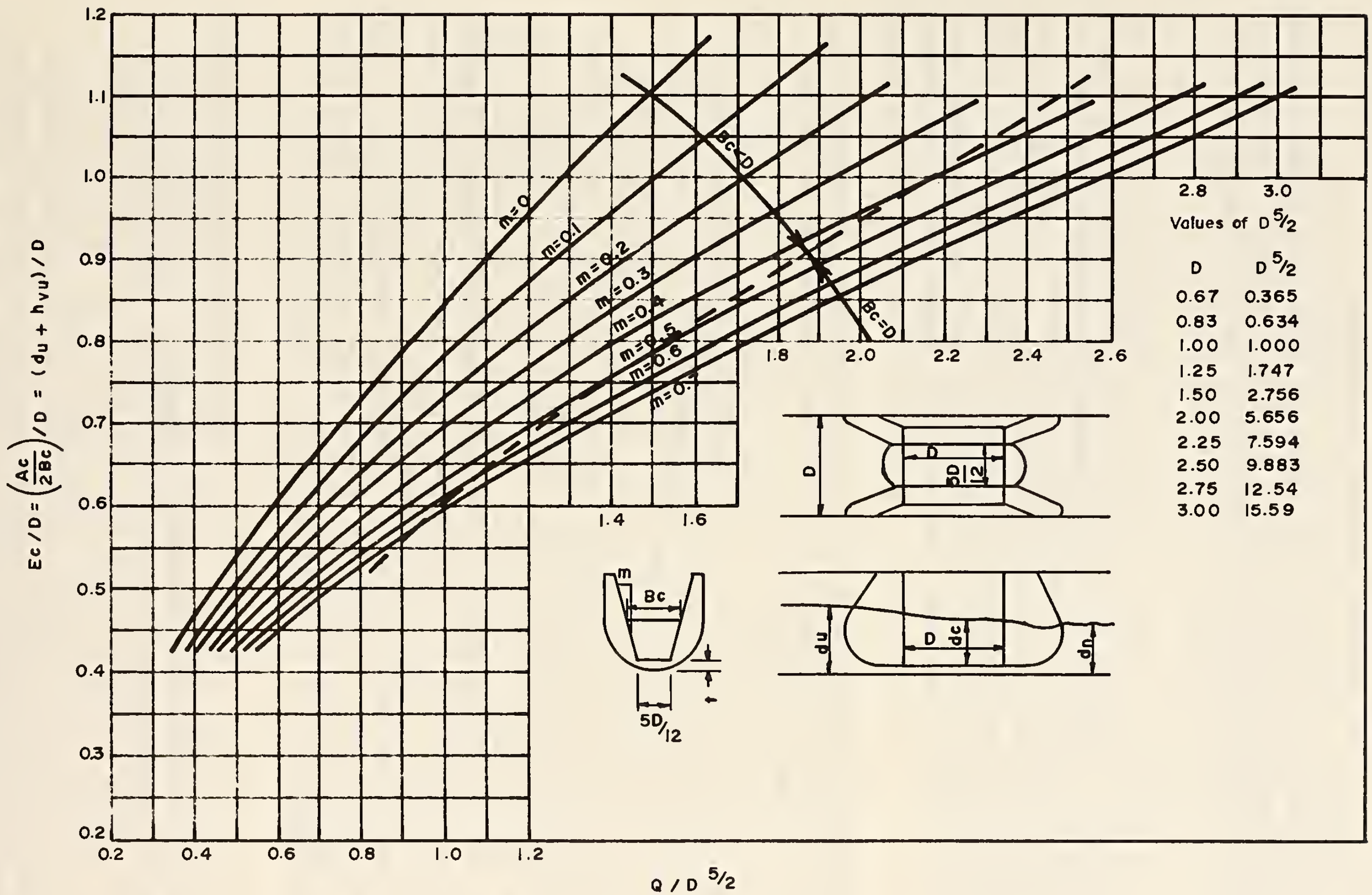

Figure 32. Discharge-total energy curves for flow in trapezoidal channels of varying side slope (23) (24).

1. <u>Factors Controlling Design</u> - The depth and velocity of flow are the factors which determine the applicability of the flume to an existing sewer; that is, they limit the proportions or shapes which may be selected for the control section as follows:

a. When the velocity of flow in the sewer is no more than enough to transport the suspended solids (i.e., 2.0 to 2.5 ft per sec), the design should allow some back-up of flow in order to maintain as high a velocity as possible, upstream from the flume.

b. When the velocity of flow in the sewer is greater than 2.5 ft. per sec., the proportioning could be determined by the conditions stated in (a) above; however, a greater restriction can be provided without causing deposition, and in most instances this will be desirable. In these cases the maximum upstream depth is limited to a value such that (1) the minimum upstream velocity is not less than 1.8 to 2.0 ft. per sec., or (2) the upstream depth is not greater than some depth above which undesirable flow conditions result and measurement becomes uncertain. This limit has been set at 0.85D in the discussion to follow.

2. <u>Limiting Cases for Flume Use</u> - The limiting range of usefulness of <u>a P-B flume i.e., the measurable</u> maximum discharge, depends on the normal depth of flow as follows:

a. Palmer and Bowlus state that for proper operation of the flume such that possible backwater conditions downstream from the throat (due to channel irregularities) are not projected upstream so as to affect the rating qualities of the flume, the depth downstream from the flume should not be greater than 0.90 d_u. However, where conditions will allow, it is advisable to allow more drop in the water surface than this minimum amount, say a drop of $d_u/6$ which results in a downstream depth equal to 0.833 d_u. If the depth upstream from the flume is limited to a maximum of 0.85D, as stipulated in above item Ib, and the drop allowed through the flume is $d_u/6$, then d_n may not exceed 0.833 x 0.85D = 0.71D. For a downstream depth of 90 percent of the upstream depth, the normal flow in the pipe may not exceed 0.90 x 0.85D = 0.76D. When the normal flow depth in the sewer exceeds these limits, special provisions must be made in order for a P-B flume to measure such extreme flows.

b. In the usual flow condition encountered, velocities are relatively low and the normal depth of flow is above the critical depth of flow for the quantity of flow and pipe size involved. In all cases where depth of flow is above critical depth, the maximum normal depth is limited as discussed in above item IIa. However, in sewers laid on steep slopes, "shooting flow" may occur, that is, the normal depth of flow may be less than the critical depth. In this case, the flume restriction must be sufficient to cause a hydraulic jump to form far enough upstream from the flume so that the turbulence due to the jump is damped to the extent that tranquil flow conditions are attained immediately upstream from the flume. When this problem is encountered, the design procedure must be modified.

3. Shape of Control Section - The selection of the shape of the throat section is governed by practical considerations involved in the installation of the flume, as well as by the depth-velocity relationships. Palmer and Bowlus recommend a trapezoidal section, which may be varied as to bottom width, side slope, and the height of the bottom above the pipe invert.

The best method of installation for small flumes is to prefabricate the entire throat and transition sections of sheet metal. The prefabricated flume is then grouted into the sewer section. This technique ensures accurate construction of the flume; the only important field precaution is to install the flume with the bottom of the throat section level transversely and with the desired bottom height. Following is a summary of the design consideration that should be followed for P-B flume design:

a. With low velocity in sewer (2.0 to 2.5 ft/sec) design should result in minimum back-up to sewer.

b. Maximum upstream depth such that minimum upstream velocity is not less than 1.8 ft/sec.

c. Generally upstream depth should be limited to 0.85D where D is pipe diameter.

d. For best conditions it is advisable to allow a drop in water surface of about $d_u/6$ where d_u is upstream water depth.

e. Experience indicates that slab thickness "t" should be between D/8 and D/12 and base width at throat should be about 5D/12.

f. Length of throat should be at least equal to the pipe diameter.

g. Upstream and downstream transitions should be sloped a minimum of approximately one laterally to three longitudinally.

4. Selection of Throat Section

a. For the given sewer diameter, slope, and design or maximum discharge, determine V_n, A_n, and d_n. King's "Handbook of Hydraulics" (8) can be used to make these determinations.

b. Determine the value of $Q/D^{5/2}$.

c. Determine the value of $Ec/D = (du + h_{vu})/D$ for one of the following conditions:

1. When V_n <2.0 to 2.5 ft. per sec, determine $d_u = 1.20\ d_n$ and the corresponding values of Au, Vu, and h_{vu} for the maximum Q.

2. When V_n > 2.0 to 2.5 ft. per sec, determine d_{cp} for the given Q and D. If $d_n > d_{cp}$ proceed as in (1) above, or determine the value of d_u for a desired minimum upstream velocity (usually 1.8 to 2.0 ft. per sec) or a maximum upstream depth of 0.85D. For the chosen value of d_u determine the corresponding values of Au, Vu, and h_{vu} for the design Q. If $d_n < d_{cp}$ special consideration must be given to insure a hydraulic jump upstream from the flume. Design criteria for this condition are not presented.

d. With the computed values of $Q/D^{5/2}$ and E_c/D enter Figure 32 and select the proper value of m.

Rating the P-B Flume

After the flume has been installed, the physical measurements of the control section (specifically, b, m, and t) must be taken. The flume is then rated using these dimensions, which of course may vary slightly from the design. See Figure 33 for the nomenclature used in rating of the P-B flume. First set up a 9 column table (Table 8) such as given below:

Table 8. Initial computation table for the rating of Palmer-Bowlus flume.

1	2	3	4	5	6	7	8	9
dc	d_t (dc t)	$b + \frac{dc}{m}$	$\frac{4\ dc}{m}$	Ac (1)x(3)	2Bc (2b+(4))	$V^2/2g$ ((5)÷(6))	Water depth	Wetted area

Each of the above is derived as follows (all dimensions are in ft).

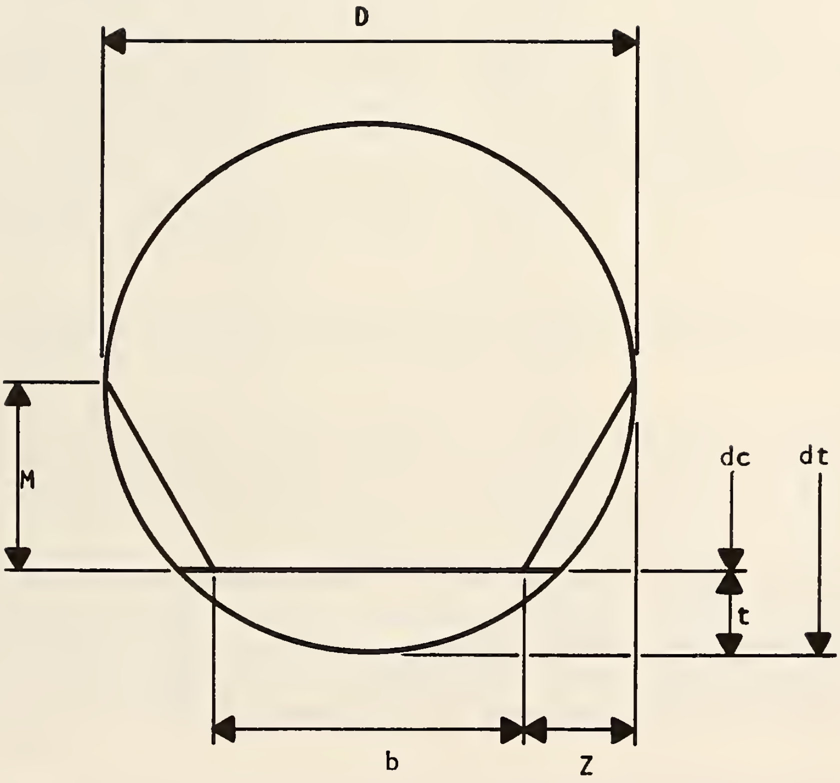

Figure 33. P-B flume design nomenclature.

Column number	Designation	Derivation
1	d_c	Depth of water over floor of flume in feet.
2	d_t	This is the same as dc+t and is a measurement from the bottom invert of the sewer to the surface of the water which is flowing through that sewer.
3	$b + \frac{dc}{m}$	Bottom width of flume plus the water depth divided by m where m is the ratio of the vertical dimension (M) of the flume to the horizontal dimension (Z).
4	$\frac{4\ dc}{m}$	This is 4 times the depth of flow over the flume divided by m.
5	Ac	Column 1 times Column 3.
6	$2\ B_c$	2b plus Column 4.
7	$V^2/2g$	Column 5 divided by Column 6.
8	Water depth	This is the same as d_t.
9	Wetted area	This is the area of a circle segment having a height of d_t and the respective cord of the diameter of the sewer being monitored.

The next thing to be done is to set up a graph known as an Arredi diagram which has one x axis and two y axis (see Figure 34 below). Figure 34 shows a completed Arredi diagram. The x axis is the area (Ac), the positive y axis is $V^2/2g$ from the Table 9 and the negative y axis consists of d_t values from the same table.

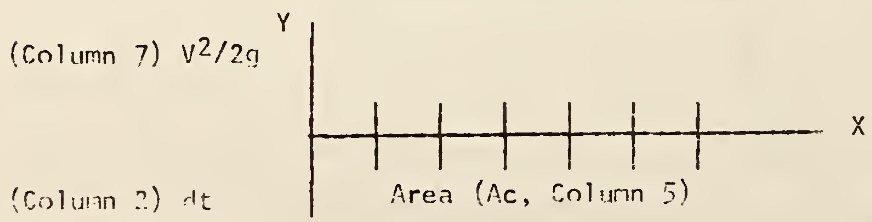

Figure 34. Form of Areddi diagram.

The Areddi diagram is a group of curves each of which is a plot of the identity for a particular value of Q, i.e., for a given value of Q, plot values of $V^2/2g$ vs. values of A. On the Areddi diagram (Figure 35), first plot the following:

i Flow in throat i.e., $V^2/2g$ vs. Ac (column 7 vs. column 5)

ii And depth vs. area (column 2 vs. column 5)

iii Flow in pipe i.e., depth vs. area (column 8 vs. column 9).

The second group of curves (intersecting the throat curve) representing various values of Q as shown in the positive XY quadrant of the Areddi diagram (Figure 35) is plotted by a trial and error procedure as follows:

Set up a table with arbitrary values of Q, $V^2/2g$ and other calculated values as shown in Table 9. The values in column 1 for Q are selected arbitrarily but within the range of flows expected for the given application. The values of Q^2 are then calculated and inserted in column 2 as shown. The values of $V^2/2g$ in column 3 are again selected arbitrarily but so as to fall on either side of the throat curve ($V^2/2g$ vs. area curve plotted earlier) in the Areddi diagram. It is important to note that several low values of $V^2/2g$ should be selected so that full range of the particular Q value curve may be plotted below the throat curve approaching zero.

Column 4 is simply a multiplication of column 3 by 2g or 64.4. Column 5 is column 2 divided by column 4. Column 6 represents the square root of column 5 values.

From the upper part of the Areddi diagram, locate intersection points of throat curve ($V^2/2g$ vs. area curve) for various values of Q as shown in Figure 35. The ordinate E_t represents the total energy in the throat i.e., $d_t + V^2/2g$ for the corresponding value of Q. Depth of flow in the pipe is found by locating an ordinate E_p such that $E_p = E_t$, and such that the upper end of E_p ordinate lies on the Areddi diagram for that particular value of Q and the lower end lies on the pipe-depth-area curve (column 8 vs. column 9 curve). The lower point then represents the depth of flow in the pipe for that value of Q. This information provides one point for plotting the rating curve for the P-B flume.

Now, obtain other depth of flow points corresponding to various values of Q in order to prepare the flume rating curve. Plot the flow depth points with respect to the bottom of pipe as ordinate and corresponding discharge Q values as abscissae to complete the depth-discharge rating curve (Figure 36).

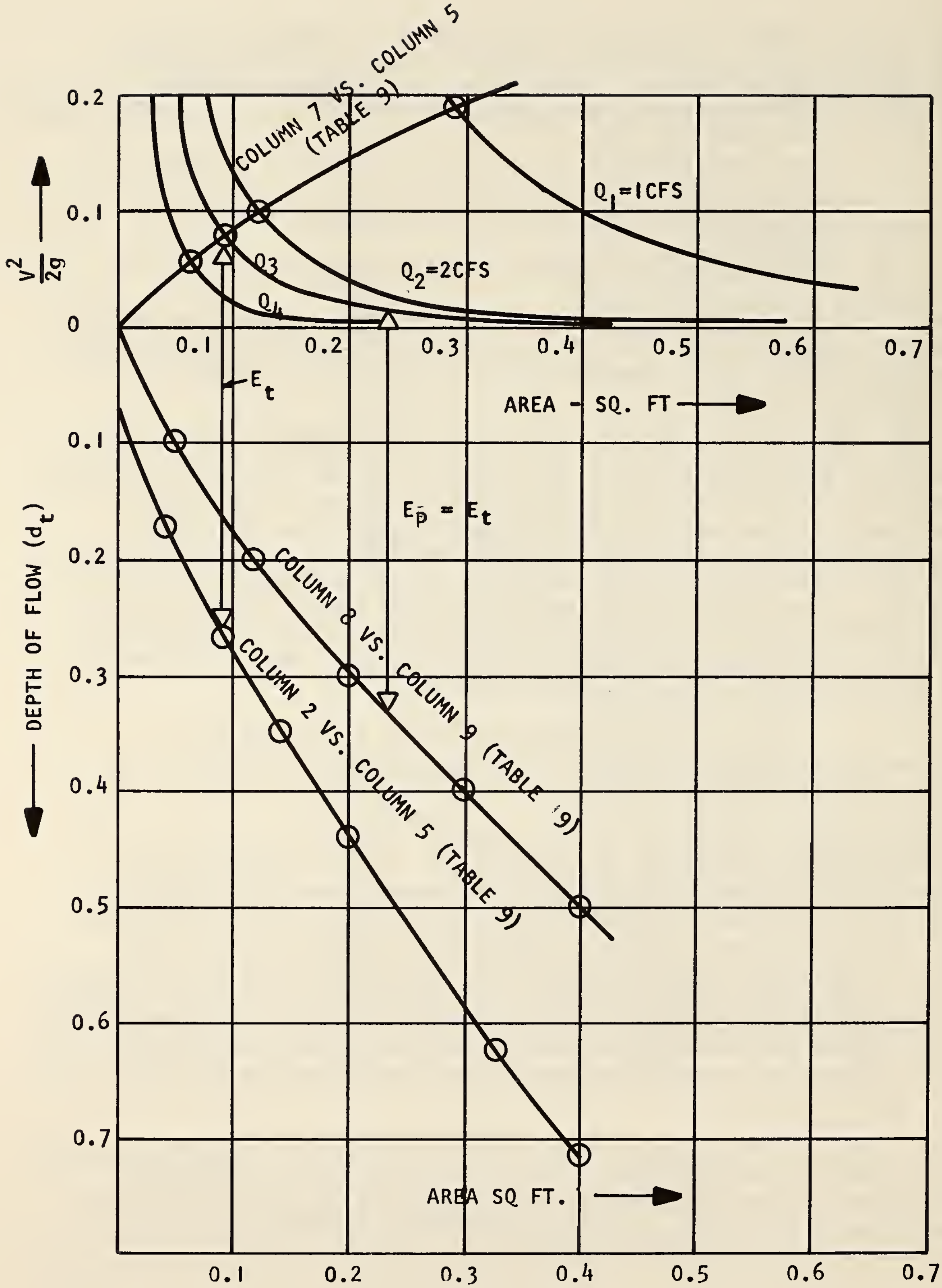

Figure 35. Areddi diagram for design of P-B flume.

Table 9. Trial and error calculations for developing Q family of curves on the Areddi diagram.

Q	Q^2	$V^2/2g$	$V^2/2g \cdot 2g$	$A^2 = \frac{\text{col. 2}}{\text{col. 4}}$	A
1	1	2.00	128.8	0.0078	0.088
	1	1.50	96.6	0.0104	0.1017
	1	1.00	64.4	0.01557	0.1246
	1	0.50	32.2	0.0311	0.1762
	1	0.20	12.88	0.07714	0.2781
	1	0.10	6.44	0.1553	0.3941
	1	0.05	3.22	0.3013	0.5488
	1	0.025	1.61	0.6211	0.7881
2	4	0.200	12.88	0.3106	0.5572
	4	0.100	6.44	0.6211	0.7881
	4	0.050	3.22	1.2422	1.1146
	4	0.025	1.61	2.4845	1.5762
	4	0.0125	0.805	4.9689	2.2291
	4	0.006	0.3864	10.3520	3.2174
3	9	0.200	12.88	0.6988	0.8359
	9	0.100	6.44	1.3975	1.1822
	9	0.050	3.22	2.7950	1.6718
	9	0.025	1.61	5.5900	2.3643
	9	0.025	0.805		
4	16	0.30	19.32	0.8282	0.9100
	16	0.25	16.10	0.9938	0.9919
	16	0.20	12.88	1.2422	1.1146
	16	0.15	9.66	1.6563	1.2870
	16	0.10	6.44	2.4845	1.5622
	16	0.05	3.22	4.9689	2.2291
	16	0.025	1.61	9.9379	3.1524

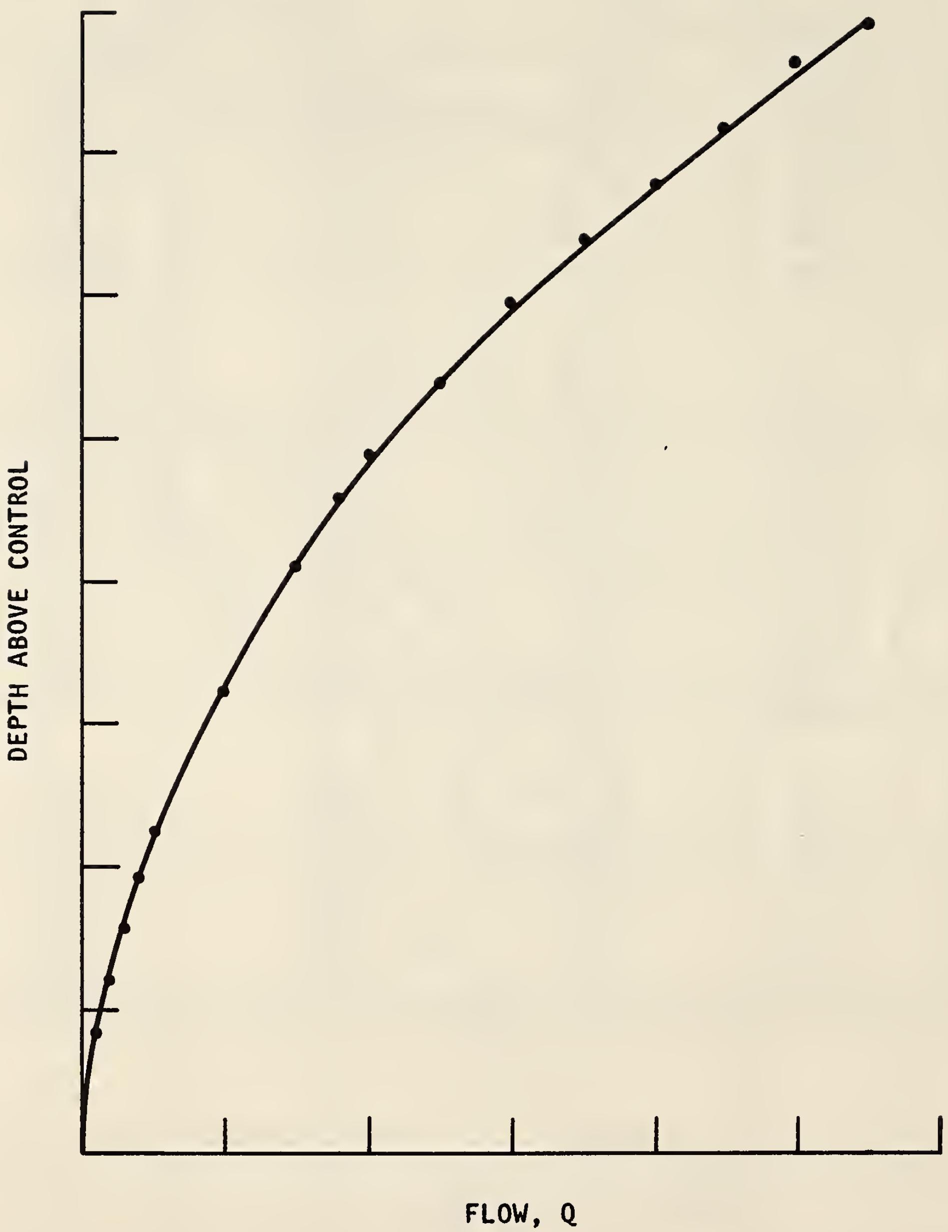

Figure 36. Typical Palmer-Bowlus flume depth-discharge rating curve.

APPENDIX B

ASTM Method for Dustfall Bucket Installation and Analysis (22)

Principle of the Method - Large particulate matter, which becomes suspended in the atmosphere by wind forces or mechanical means, and other particulate matter cleansed from the atmosphere by rain or agglomeration, is measured using an open mouth container exposed for a period of approximately one month. This static measurement technique is simple but the results are strongly dependent on the design and placement (especially the height) of the container. In cases where settleable dust is generated by local sources, the inherent dustfall rate is widely variable. Reported data indicate that dustfall measurement is not precise. In most situations this may be less important than the inherent variability in dustfall rate at any given location (31)(32)(33)(34)

Following collection, samples can be analyzed in many ways to suit the needs of specific situations. The gross measurement of soluble and insoluble fractions is normally undertaken. Further physical analyses can be performed on the insoluble dustfall, e.g., particle size distribution, specific gravity. Chemical analysis can be performed on either fraction to determine the elemental composition, or to determine compounds of specific interest in local situations.

Range and Sensitivity - The lower limit of measurement is approximately 0.2 g/m^2/month. The upper limit is dependent upon the ratio of the depth to the diameter of the collector and is not likely to be reached.

Interferences - The major interferences in the method are algae, fungi, bird droppings, and insects. Any of these four can be present in the container after the period of exposure to such a degree that they overwhelm the analysis. Because of the unattended nature of the sampling device, tampering has frequently been observed. The container is frequently a target for rocks, snowballs, and fire arms.

Precision and Accuracy - Replicate samples by various investigators indicate that a precision of plus or minus 15 percent is attainable for any given combination of collecting element and retention fluid. Results of greater than 2 to 1 variation have been found with replicate samples taken by different methods. No information on accuracy is available.

Apparatus - Collector. The collector of choice is a polyethylene container with a tapered cylinder and a sealable lid. The dimensions are 7-3/8" diameter x 8-1/4" high. A suitable holder for the collector should allow convenient changing of the samples, adequate support, and a bird ring approximately 1.5 x the diameter of the collector and positioned so it is approximately 3" higher than the top of the collecting jar. A chemically inert 20 - mesh screen shall be used to remove extraneous material, e.g., leaves, insects, etc., prior to analysis.

Filtering Apparatus - The use of gooch crucibles, alundum crucibles, filter paper, or membrane filters is acceptable to separate the insoluble fraction from the soluble fraction. The choice of method is frequently based on the further analysis which is planned.

Reagents - Distilled Water. Water conforming to specifications for reagent water (ASTM designation D 1193).

Algacide - In those areas where algae or fungus growth is found not to occur, it is recommended that no chemical be added to the collecting liquid.

When secure control of the dustfall collectors is assured, the addition of 0.01 g of reagent grade mercuric chloride is recommended. This will act as both an algacide and fungicide. In instances where there is the possibility that the collecting fluid may be consumed by humans or animals, 0.01 g of copper sulfate pentahydrate shall be used as an algae inhibitor. This has no fungicidal properties. The addition of any foreign material will complicate the analytical procedures.

Procedure - Sampling Site. Freedom from tampering and accessibility to the operator changing the samples are prime considerations in site selection. The most common locations for dustfall sampling sites are on the roof of low buildings or on utility poles. When a number of dustfall samples are collected concurrently for the purpose of a survey, it is important that all collectors should be located consistently. The following general recommendations should be observed.

a. The top of the dustfall container shall be a minimum of 8 ft and a maximum of 50 ft above the ground or 4 ft minimum above any other surface such as a roof. Higher objects such as parapets, signs, penthouses, and the like must not be more than 30° from the horizontal, i.e., a line drawn from the sampling jar to the nearest edge of the highest point on any building should form not more than a 30° angle with the horizontal.

b. Public buildings such as schools, fire stations, libraries, etc., are most favorable to public agencies because of their accessibility and security.

c. The influence of a source close to the collecting jar can dominate the results. When selecting the site, detailed notes should be made on the direction and distance of stacks, parking lots, material storage piles, roads, or other sources likely to make a significant contribution to dustfall as measured at the location.

d. The support for the collecting jar should be mechanically stable and firm enough to prevent tipping or swaying from the wind.

Collection of Sample - Prior to exposure, 200-1,000 ml of liquid should be added to the collection jar as dictated by expected evaporation rate over the exposure period. This liquid may be distilled water, algacide or fungicide as deemed necessary. The cover should be placed on the jar, and it should not be exposed until it is placed in its holder at the sampling location. Following the collection period, which is normally 30 days, ± 3 days, the cover shall be placed on the collecting jar prior to removal from its support stand and transported to the laboratory with the cover.

Analysis - The first step in analysis is the transfer of the sample from the collecting jar to laboratory glassware. The sample should be screened through a 20-mesh screen to remove extraneous material. The inside of the collecting jar shall be scrubbed or policed to remove all adhering materials. In the event that the collection jar is dry or that only a small amount of water remains, make up the volume to at least 200 ml before the next step in the analysis. If the collection jar contained more than 200 ml of liquid at the time of its collection, proceed to the filtration step. If the volume must be made up to 200 ml, the sample should stand for a period of 24 hours at room temperature to allow the soluble material to dissolve. The filtration step shall be carried out according to routine laboratory procedures and the weight of insoluble material determined. For determination of the soluble material, the entire filtrate portion or suitable aliquot shall be evaporated to dryness and the total weight of soluble material in the sample shall be reported.

Calibration and Standards - There is no calibration procedure available for dustfall, and standards do not exist.

Calculations - Calculate the dustfall rate in terms of grams per square meter per month (30-day basis) as follows:

$$\text{Dustfall} = \frac{W}{a} \times \frac{30}{t}$$

Where dustfall equals grams per square meter per month, W = weight analyzed, grams; a = open area of sampling container at top, 0.0275 square meters; t = time of exposure, days.

Effect of Storage - The major effect of storage of samples following collection and prior to analysis is the growth of algae or the chemical breakdown of organic material. It is recommended that the samples be analyzed within one week following their collection.

APPENDIX C

Glossary of Terms Commonly Used in Environmental Monitoring

Aerobic - Requiring, or not destroyed by, the presence of free elemental oxygen.

Algae - Primitive plants, one- or many-celled, usually aquatic, and capable of elaborating their foodstuffs by photosynthesis.

Anaerobic - Requiring, or not destroyed by, the absence of air or free oxygen.

Benthic animals - Animals living at the bottom of a body of water.

Bioassay - (1) An assay method using a change in biological activity as a qualitative or quantitative means of analyzing a material's response to biological treatment. (2) A method of determining toxic effects of industrial wastes and other wastewaters by using viable organisms or live fish as test organisms.

Biochemical oxygen demand (BOD) - The quantity of oxygen, in mg/l, used in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions. The standard test conditions are 5 days at 20°C.

Biomass - The amount of living matter in a given area.

Biota - Animal and plant life, or fauna or flora, of a stream or other water body.

Bubbler tube - A level measurement device using a compressed gas source and a dip tube submerged in the channel. The backpressure on the gas flow through the dip tube is proportional to the liquid level.

Chemical oxygen demand (COD) - A measure of the oxygen-consuming capacity of inorganic and organic matter present in water or wastewater. It is expressed as the amount of oxygen, in mg/l, consumed from a chemical oxidant in a specific test. (It does not differentiate between stable and unstable organic matter and thus does not necessarily correlate with biochemical oxygen demand.)

Coliform-group bacteria - A group of bacteria predominantly inhabiting the intestines of man or animal, but occasionally found elsewhere.

Combined sewer - A sewer receiving both intercepted surface runoff and municipal sewage.

Composite sample - A sample formed by mixing portions of individual samples taken at specific times.

Current meter - An instrument for measuring the velocity of flowing water.

Discharge - In its simplest concept discharge means outflow; therefore, the use of this term is not restricted as to course or location, and it can be applied to describe the flow of water from a pipe or from a drainage basin. If the discharge occurs in some course or channel, it is correct to speak of the discharge of a canal or of a river. It is also correct to speak of the discharge of a canal or stream into a lake, a stream, or an ocean.

Discrete sample - A sample taken at a particular instant in time.

Dissolved oxygen (DO) - The oxygen dissolved in water or other liquid, usually expressed in milligrams per liter, parts per million or percent saturation.

Dissolved solids - Solids physically suspended in sewage which cannot be removed by proper laboratory filtering.

Distribution graph (distribution hydrograph) - A "unit hydrograph" of "direct runoff" modified to show the proportions of the volume of runoff that occurs during successive equal units of time.

Drainage basin - A part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water.

Ecosystem - Energy-driven complex of a community or organisms and its controlling environment.

Escherichia coli (E. coli) - One of the species of bacteria in the coliform group. Its presence is considered indicative of fresh fecal contamination.

Eutrophication - The process of maturation of a lake from a nutrient-poor to a nutrient-rich body of water.

Evapotranspiration - Water withdrawn from a land area by evaporation from water surfaces and moist soil and plant transpiration.

Fermentation tube test - A test method to determine the coliform bacteria density of a water sample.

Flood-frequency curve - 1. A graph showing the number of times per year on the average, plotted as abscissa, that floods of magnitude, indicated by the ordinate, are equaled or exceeded. 2. A similar graph but with "recurrence intervals" of floods plotted as abscissa.

Frequency - The average recurrence interval of rains equal to or greater than a certain magnitude.

Flume - A structure inserted in a channel which constricts the flow and provides a known, repeatable relationship between flow and depth.

Gage height - The water-surface elevation referred to some arbitrary gage datum. Gage height is often used interchangeably with the more general term "stage" although gage height is more appropriate when used with a reading on a gage.

Gaging station - A particular site on a stream, canal, lake, or reservoir where systematic observations of "gage height" or "discharge" are obtained.

Gradient - Change of elevation, velocity, pressure, or other head characteristics per unit length; slope.

Ground water - Water in the ground that is in the "zone of saturation", from which wells, springs, and "ground-water runoff" are supplied.

Head - 1. The height of water above any plane or reference. 2. The energy, either kinetic or potential, possessed by each unit weight of a liquid, expressed as the vertical height through which a unit weight would have to fall to release the average energy possessed. Used in various compound terms such as pressure head, velocity head, and lost head.

Heavy metals - Metallic elements having high atomic weights such as cadmium, chromium, copper, iron, lead, manganese, nickel, and zinc. These elements in low concentrations may have toxic effects on the biological systems of a receiving water.

Indicator - An organism, species, or community that shows the presence of certain environmental conditions. For example, coliform bacteria, while not pathogenic themselves, indicate that pathogenic organisms may be present.

Indigenous - Refers to an organism that is native, not introduced, in an area.

Limnology - Scientific study of bodies of fresh water, as lakes or ponds, with reference to their physical, geographical, biological, and other features.

Littoral - Of, or pertaining to, a shore, especially a seashore. More specifically, the zone of the sea floor lying between tide levels.

Macroinvertebrates - Animals without backbones that are visible to the unaided eye, e.g., insects, and are retained on a U.S. Standard No. 30 sieve.

Macronutrient - A chemical element necessary in large amounts (usually greater than 1 part per million in the plant) for the growth of plants, usually applied artifically in fertilizer or liming materials. "Macro" refers to quantity and not the essentiality of the element.

Microorganisms - Forms of life that are either too small to be seen with the unaided eye or are barely discernible.

Most probable number (MPN) - An estimate, based on certain probability formulas, of the most probable number of coliform organisms in a water sample. (See plate count.)

Nutrient - A substance that provides nourishment and promotes growth of a living organism. Nitrogen and phosphorus are two of the most important nutrients to consider relative to eutrophication.

Oligotrophic lake - Lake or other contained water body poor in nutrients. Characterized by low quantity of planktonic algae, high water transparency with high dissolved oxygen in upper layer, adequate dissolved oxygen in depth layers, low organic sulfide in water and deposits.

Pathogenic bacteria - Bacteria which cause disease.

pH - A convenient method of expressing small differences in the acidity or alkalinity of solutions. Neutrality = pH 7.0; lower values indicate increasing acidity; higher values indicate increasing alkalinity.

Phytoplankton - Plant microorganisms, such as certain algae, living unattached in water.

Plate count - Number of colonies of bacteria grown on selected solid media at a given temperature and incubation period; usually expressed in number of bacteria per milliliter of sample. (See most probable number.)

Polychlorinated biphenyls (PCB's) - A group of synthetic organic chemicals which are of concern because of possible adverse effects to animals and man and because of their slow rate of degradation.

Receiving waters - Rivers, lakes, oceans or other water courses that receive treated or untreated wastewaters or drainage.

Sanitary sewer - A sewer that carries liquid and water-carried wastes from residences, commerical buildings, industrial plants, and institutions, together with relatively low quantities of ground, storm, and surface waters that are not admitted intentionally.

Storm sewer - A sewer that carries intercepted surface runoff, street wash and other wash waters, or drainage, but excludes domestic sewage and industrial wastes.

Suspended solids - Solids physically suspended in water which can be removed by proper laboratory filtering.

Total solids - The total amount of solids in solution and suspension.

Toxic material - A material having an adverse or even fatal effect on living organisms when released into the environment.

Volatile suspended solids - That portion of the total suspended solids which will burn at 550°C. These solids are generally considered to be organic in nature.

Water quality standards - Minimum requirements or purity of water for the intended uses with respect to physical, chemical and/or biological characteristics.

Water sample - A representative part or portion used to determine qualities of a larger body of water.

Weir - A plate inserted across a channel which constricts the flow and provides a known, repeatable relationship between flow and depth.

Zooplankton - Animal microorganisms living unattached in water. They include small crustacea, such as daphnia and cyclops, and single-celled animals, such as protozoa, etc.

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FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements that affect the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge and technology of materials properties, using available natural materials, improving structural foundation materials, recycling highway materials, converting industrial wastes into useful highway products, developing extender or substitute materials for those in short supply, and developing more rapid and reliable testing procedures. The goals are lower highway construction costs and extended maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

6. Improved Technology for Highway Construction

This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. Improved Technology for Highway Maintenance

This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. Other New Studies

This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.