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NPDES COMPLIANCE SAMPLING MANUAL

U.S. ENVIRONMENTAL PROTECTION AGENCY

ENFORCEMENT DIVISION

OFFICE OF WATER ENFORCEMENT

COMPLIANCE BRANCH

DISCLAIMER

This manual has been reviewed by the Office of Water Enforcement, U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ACKNOWLEDGEMENT

The Work Group wishes to express their appreciation to the secreterial staff of the Compliance Branch, Enforcement Division, Office of Water Enforcement, for the assistance provided in the preparation of this Manual, especially Mrs. Bennie M. Yeargin, Mr. Kenneth B. Goggin and Ms. Jacqueline A. Price.

F O R E W O R D

The NPDES compliance inspection program represents a significant commitment of resources by the States and EPA to the verification of permit effluent limitations and assurance that permit requirements for monitoring, reporting and compliance schedules are being met and enforced on a nationally consistent basis. While compliance inspections make up only one segment of the overall national water enforcement program, they are highly visible and may be the only direct contact that the permittee has with regulatory personnel. Thus, compliance inspections must be performed in a thorough, professional manner, with nationally consistent coverage of key compliance elements. Reporting of inspection data must also cover the key compliance elements so that the data derived from this program can be aggregated nationally, regionally and by States for purposes such as program assessment, budget development and reporting to Congress.

The previously distributed NPDES Compliance Evaluation Inspection Manual (CEI) described the objectives and procedures for performing non-sampling inspections. The NPDES Compliance Sampling Inspection Manual (CSI) describes technically sound procedures, derived from the first hand experience of EPA and State personnel directly involved in compliance inspections, for the collection of representative samples, flow measurement, sample handling and field quality assurance.

The CEI and CSI Manuals and the revised Compliance Inspection Report Form, in conjunction with the annual program guidance and other memoranda dealing with inspection policy, form the framework for the compliance inspection program. Following the procedures and policies outlined in these documents will improve the quality of NPDES compliance inspections, enhance the value of data derived from these inspections, and better serve the needs of the overall NPDES enforcement program.

The manual is made-up in a loose-leaf format so that revisions or additions can be easily accomodated. Any comments or additions you may wish to make should be directed to the Compliance Inspection Manual Review Committee, Compliance Branch (EN-338), Enforcement Division, Office of Water Enforcement, U.S. Environmental Protection Agency, 401 M Street, S.W., Washington, D.C. 20460.

June 1977

Stanley W. Legro
Assistant Administrator
for Enforcement

NPDES COMPLIANCE SAMPLING MANUAL

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SECTION I - SUMMARY AND CONCLUSIONS

A. Wastewater Sampling Objectives

Wastewater sampling is being conducted on an extensive scale by regulatory agencies to verify compliance with NPDES permit requirements. Specific objectives in collecting this data may vary, but generally include the following:

1. Verify compliance with effluent limitations.
2. Verify self-monitoring data.
3. Verify that parameters specified in the NPDES permit are consistent with wastewater characteristics.
4. Support enforcement action.
5. Support permit reissuance and/or revision.

B. Obtaining Representative Data

In order to accomplish these objectives, it is imperative that data collection activities be of high quality. In performing these activities consideration should be given to the following:

1. Variation of flow rates and pollutant concentrations.
2. Unique properties of materials discharged.
3. Selection of proper sampling equipment.
4. Installation of appropriate flow monitoring devices or

accuracy verification of on-site devices.

5. Collection of representative samples.
6. Proper sample collection, handling and preservation.
7. Performance of prescribed analytical techniques within allowable sample holding times.
8. Proper maintenance and calibration of automatic sampling equipment and analytical devices.

C. Accomplishment of Compliance Sampling Objectives

Obtaining representative data can be accomplished by adhering to the following general guidelines:

1. Sample collection and flow monitoring site selections require on-site supervision by experienced professionals with backgrounds in hydraulics, chemistry, plant processes and wastewater sampling techniques.
2. Sampling equipment selection and installation must be tailored to the hydraulic characteristics and physical and chemical constituents of the wastewater.
3. Sampling programs must include a minimum of a 24 hour or operating day composite supplemented by two or more grab samples. When extenuating circumstances exist such as product line changes, variable production schedules or enforcement action, a more extensive program may be necessary.

4. Sample handling must include an adequate chain of custody procedure.

5. Quality assurance programs in the field and the laboratory must be instituted to insure the production of accurate, precise and defensible data.

D. Error Minimization

By adhering to these recommended guidelines, errors will be minimized. Although most of these errors defy exact quantification, the state of the art affords the following conclusions. Using currently existing primary devices and recorders, flows can be accurately measured within $\pm$ 10%. Furthermore, judicious selection of automatic sampling equipment assures consistent sample collection. However, due to the difficulity in obtaining a representative sample of the entire wastewater stream, especially for suspended solids, careful attention must be given to the location of the sampling probe. Limited data indicate that despite properly locating the sampling probe at 0.4 to 0.6 of the stream depth in the area of maximum turbulence and sampling at a rate equal to or greater than the wastewater velocity, inherent bed loads at the monitoring site can cause suspended solids results to be approximately 30% low (1). Conversely, if the probe is located on the bottom of the channel, within the bed load, results can be considerably higher than actual. To minimize analytical error and to provide national uniformity of analytical techniques, only those approved test procedures listed in Table I, 40 CFR Part 136, (as last amended on December 1, 1976), or alternative test procedures approved by the Regional Administrator for the area where the discharge occurs, may be used for reporting discharge parameter values.

REFERENCES - SECTION I

1. Reed, G.D., "Evaluation Of The Standard Sampling Technique For Suspended Solids," U.S. Environmental Protection Agency, Region VII, S&A Division, Technical Support Branch, EPA-907/9-77-001(1977).

SECTION II - I N T R O D U C T I O N

A. Background

The Federal Water Pollution Control Act Amendments (FWPCA) of 1972, the Act, established the objective of restoring and maintaining the chemical, physical, and biological integrity of the Nation's waters. To achieve this objective, the Act set forth a series of goals, including the goal of eliminating the discharge of pollutants into navigable waters by 1985. The principle mechanism for reducing the discharge of pollutants is through implementation of the National Pollutant Discharge Elimination System (NPDES) established by Section 402 of the Act.

NPDES permits have been issued to approximately 50,000 municipal and industrial point sources. Permits contain four primary elements: (1) final effluent limitations reflecting statutorily required treatment levels; (2) interim effluent limitations governing until the attainment of final effluent limitations; (3) construction schedules for the achievement of final effluent limitations; and (4) reporting requirements relating to compliance with milestones contained in construction schedules and to compliance with effluent limitations established for each parameter limited in the permit for both interim or final effluent limitations.

Compliance with effluent limitations and self-monitoring requirements of NPDES permits is assessed by the regulatory agency through a combined program of self-monitoring data review and facility inspections.

B. Enforcement Management System

In order to better manage the Agency's resources committed to gathering and verifying information regarding permit compliance, a number of important projects are presently being sponsored by the Office of Water Enforcement. These projects all tie in with the development of an overall Enforcement Management System (EMS) which will enable Regions and States to more efficiently handle compliance information submitted by the permittees (1). EMS will improve the Agency's response time to violations, provide a more uniform national enforcement response to violations, and insure better control of information that is placed into the EMS system. It is in this last area, improvement in the quality of information that is gathered by the field staff, that this manual is designed to fill a need.

The previously completed NPDES Compliance Evaluation Inspection Manual (July 1976) described procedures for conducting non-sampling inspections that satisfy enforcement needs (2). The objective of the NPDES Compliance Sampling Manual is to perform a similar function for sampling inspections, i.e., to describe procedures that will provide effluent data that meets enforcement needs.

C. Work Group Membership

The NPDES Compliance Sampling Manual is designed for use by the inspection staffs in EPA Regions and States. The manual was developed by a work group consisting of State and EPA personnel:

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Richard Christensen, Michigan Department of Natural Resources
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William Keffer, U.S. EPA, Region VII
Edward Berg, U.S. EPA, Environmental Monitoring and Support Laboratory-Cincinnati
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Teresa Wehner, U.S. EPA, Washington, D.C.

Comments and suggestions were requested from EPA Regional Offices, States, selected Federal Agencies and Headquarters personnel. The work group wishes to thank the reviewers for their guidance and assistance in the preparation of this manual.

After gaining some experience with the use of the manual, readers are encouraged to offer constructive criticism and proposed revisions to the work group chairman. The necessary revisions will keep this manual a useful working tool.

REFERENCES - SECTION II

1. "Enforcement Management System Guide", U.S. Environmental Protection Agency, Office of Enforcement, Office of Water Enforcement (3/77).

2. "NPDES Compliance Evaluation Inspection Manual", U.S. Environmental Protection Agency, Office of Enforcement, Office of Water Enforcement (7/76).

SECTION III - NPDES PERMIT SAMPLING REQUIREMENTS

A. Introduction

National Pollutant Discharge Elimination System (NPDES) permits contain specific and legally enforceable effluent limitations and self-monitoring requirements for flow measurement and sampling. The sampling frequency, the sample type (grab or composite), the parameters to be monitored, the parameter limitations, the analytical methods, and the reporting frequency are determined by the permitting agency. Self-monitoring requirements must be such as to enable reasonable assessment of the discharger's performance relative to permit effluent limitations and the potential impact on the environment. Such factors as flow and concentration variability, treatment methodology, relative amounts of cooling and process wastewater, and receiving water quality are considered in establishing the self-monitoring requirements.

B. Self-Monitoring Data

1. Permit Specifications

The NPDES permit specifies limitations for certain parameters (e.g. pH, biochemical oxygen demand, suspended solids, etc). The limitations generally are in terms of parameter weight and/or concentration and are specified for a given time frame. Common time frames specified in NPDES permits are daily average, daily maximum, seven consecutive day average, and thirty consecutive day average. Time frames are defined in the NPDES permit.

Self-monitoring data are reported by the permittee at intervals specified in the permit. Generally, the reports are submitted to the permitting agency monthly, quarterly or semi-annually.

2. Use of Self-Monitoring Data

Regulatory agencies principally use self-monitoring data to assess compliance with permit limitations. Self-monitoring data showing permit violations may also be used as primary evidence in an enforcement action. In many cases, however, additional information may be needed to verify or supplement self-monitoring data. Where independent evidence is gathered by the regulatory agency, self-monitoring data may be used as corroborative evidence in the enforcement action or vice veras.

C. Compliance Monitoring

1. General

Compliance monitoring is required to document the accuracy and completeness of self-monitoring and reporting activities of permittees and to provide sufficient documentation and verification to justify and support enforcement actions. All compliance inspection activity should be conducted on the premise that it may lead to enforcement action.

2. Definitions

The term "compliance monitoring" is a generic term meant to cover all activities taken by Federal or State regulatory agencies to ascertain a permittee's compliance status. As thus defined compliance monitoring is composed of two elements:

(a) Compliance Review - the review of all written material relating to the status of compliance of an NPDES permit, including Compliance Schedule Reports, Discharge Monitoring Reports, Compliance Inspection Reports, etc.

(b) Compliance Inspection - all field activities conducted to determine the status of compliance with permit requirements including Compliance Evaluation Inspections (non-sampling), Sampling Inspections, production facility inspections, and remote sensing (e.g. aerial photographs).

3. Objectives of Compliance Evaluation Inspection

A compliance evaluation inspection is undertaken to accomplish one or more of the following objectives:

(a) observe the status of construction required by the permit;

(b) assess the adequacy of the permittee's self-monitoring and reporting program;

(c) check on the completeness and accuracy of the permittee's performance/compliance records;

(d) evaluate the permittee's operation and maintenance activities;

(e) determine that permit requirements are being met; and

(f) assess the adequacy of the permit.

4. <u>Compliance Evaluation Inspection Tasks</u>

To achieve the objectives of a compliance evaluation inspection, a review of one or more of the following items will be necessary:

(a) the permit;

(b) self-monitoring data;

(c) laboratory analytical techniques, methods and quality assurance procedures;

(d) field handling, sample transport, and preservation procedures;

(e) data handling and records maintenance procedures;

(f) compliance with implementation schedules; and

(g) location and calibration of required monitoring devices, e.g., recording pH meter, DO meter, flow recorder etc.

Detailed procedures for conducting a compliance evaluation inspection are contained in the Compliance Evaluation Inspection Manual, EPA, Office of Water Enforcement, July 1976.

5. Objectives of Compliance Sampling Inspection

A compliance sampling inspection is conducted to accomplish one or more of the following objectives:

(a) verify compliance with effluent limitations;

(b) verify self-monitoring data;

(c) verify that parameters specified in the permit are consistent with wastewater characteristics;

(d) support permit reissuance and revision;

(e) support enforcement action;

6. Compliance Sampling Inspection Tasks

To achieve the objectives of a compliance sampling inspection, one or more of the following tasks will be accomplished:

(a) sampling at the locations and for the parameters specified in the NPDES permit;

(b) sampling at locations and for parameters not specified in the NPDES permit as requested by enforcement personnel;

(c) verifying operation and calibration of monitoring equipment;

(d) measuring flow by either verifying accuracy of in-plant equipment or actual independent flow measurement.

The inspection should also verify that:

(a) the permittee's sampling location(s) includes all the effluent from process and nonprocess wastewater system(s);

(b) the sampling location specified in the permit is adequate for the collection of a representative sample of the wastewater;

(c) the permittee's sampling technique is adequate to assure the collection of a representative sample;

(d) the permit sampling and monitoring requirements will yield representative samples; and

(e) the parameters specified in the permit are adequate to cover all pollutants of concern that may be discharged by the permittee.

D. Adequacy of Data

Samples collected by field personnel must be relevant to the effluent limitation requirements of the permit. Consequently, when the permit requires a "24 hour composite sample" aliquots must be taken in a manner and at a frequency such that the resulting composite sample is representative of the actual discharge during the 24 hour period. Confidence in the reliability of discharge data will be enhanced by using a minimum of two independent grab samples in addition to the 24 hour period or operating day composite.

E. Determining Compliance With Effluent Limitations

The following paragraphs describe sampling and measurement procedures that are related to effluent limitations defined by the permit. The majority of compliance sampling inspections deal only with the verification of instantaneous and short term (daily maximum) effluent limitations. Thus, for routine compliance sampling inspections, the procedures described for instantaneous and daily maximum conditions should be followed. However, in some cases data will be needed to verify a permittee's ability to meet effluent limitations over a more extended time frame, i.e. 7-day average or 30-day average conditions. For such cases, the procedures described for 7-day and 30-day conditions should be employed. It should be remembered that resource requirements will preclude the continuous sampling of a source for a calendar month in all but the most demanding cases.

1. <u>Instantaneous Conditions</u> Instantaneous conditions are conditions that occur at any single moment in time. Permit compliance with such conditions requires that monitoring be conducted when the installation is in operation and that sufficient measurements or samples be taken to protect the data from error. Grab samples are normally used to characterize "instantaneous conditions".

2. <u>Daily Maximum Conditions</u> The time frame for the expression of the daily maximum limitations is a calendar day. Where the nature of the effluent will allow (absence of separating, interacting, or unstable components), compliance with daily maximum conditions is determined by analysis of a daily composite sample. Procedures for the collection of composite samples are described in the Sample Collection Section.

In those cases where a daily maximum is required and a sample cannot be composited, such as for oil and grease or time dependent determinations, individual grab samples must be collected within prescribed time intervals (depending on the sampling situation), analyzed individually, and their flow weighted average values calculated. In such situations, minimum and maximum values should also be reported. On-site instrumental measurements or observations should be made at the same frequency as the separate grab samples described above.

3. 7-Day Average Conditions The time frame for the expression of limitations is seven consecutive days. The 7-day average is calculated from daily averages, weighted by time or flow as required by the permit. 7-day average limitations generally apply only to publicaly owned treatment works.

4. 30-Day Average Conditions Case preparation may require samples to be taken for each operating day during the month. This could range from 22 days of sampling for an industry in production 5 days per week to 30 days of sampling for a publicly owned wastewater treatment facility. The 30-day average would then be the arithmetic average of the daily values. For permits containing fecal coliform limits, the 30-day average would be the geometric mean of the daily values.

F. Sample Collection And Handling

All samples must be collected according to the procedures described in the Sample Collection Section and handled according to procedures described in the Quality Assurance Section. A chain-of-custody procedure is described in Section VIII. This, or an equivalent procedure* must be adhered to in order to document that the integrity of the sample was maintained from the time of collection through transport to the laboratory and subsequent analyses.

*An "equivalent procedure" is a sample handling procedure that is approved by the enforcement attorneys of the regulatory agency.

SECTION IV - SAMPLE COLLECTION

A. INTRODUCTION

Sample collection is an important part of any survey or other program to assess industrial or municipal wastewater discharges. Without proper sample collection techniques the results of a wastewater survey are neither useful nor valid, even with the most precise or accurate analytical measurements.

The planning and on-site implementation of an appropriate sample collection program requires supervision by technically qualified personnel with knowledge of the industrial or municipal wastewater treatment processes. The characteristics and pollutant levels in the wastewater are dependent on the relative flows and composition of the individual sources contributing to the effluent. The flow and composition of the individual discharge sources can vary widely over a long time period, over a short time period, and in some cases, even instantaneously where batch type operations are carried out at the plant. Therefore, the first step in any sample collection program is to evaluate carefully the nature of the processing operations, the individual waste sources, and the paths of the wastewaters in the overall sewer system.

Carrying out an appropriate sample collection program includes the development of a study plan which contains the following items:

1. Selection of parameters to be measured.
2. Selection of representative sampling sites.
3. Collection of sufficient volumes of the wastewater to carry out the required analyses.
4. Selection and proper preparation of sample containers.
5. Preservation of samples to maintain the samples' integrity.
6. Identification of each sample by proper labeling of the containers.
7. Procedures to insure that recommended sample holding times are not exceeded.
8. Procedures for identifying and handling potentially hazardous samples.
9. Chain of custody procedure.

B. Sampling Considerations

1. General

The wide variety of conditions existing at different sampling locations always requires that some judgement be made regarding the methodology and procedure for collection of representative samples of wastewater. Each sampling point will warrant attention commensurate with its complexity. There are, however, basic rules and precautions generally applicable to sample collection. Some important considerations for obtaining a representative sample are as follows:

(a) The sample should be collected where the wastewater is well mixed. The sample should be collected near the center of the flow channel, at 0.4 - 0.6 depth, where the turbulence is at a maximum and the possibility of solids settling is minimized. Skimming of the water surface or dragging the channel bottom should be avoided.

(b) In sampling from wide conduits, cross sectional sampling should be considered. Dye may be used as an aid in determining the most representative sampling point(s).

(c) The sampling of wastewater for immiscible liquids, such as oil and grease, requires special attention. Oil and grease may be present in wastewater as a surface film, an emulsion, in solution, or as a combination of these forms. As it is very difficult to collect a representative oil & grease sample, the inspector must carefully evaluate the location of the sampling point. The most desirable sampling location is the point where greatest mixing is occuring.

Quiescent areas should be avoided, if possible. Because losses of oil and grease will occur on sampling equipment, the collection of a composite sample is impractical. Individual portions collected at prescribed time intervals must be analyzed separately to obtain the average concentrations over an extended period.

(d) If manual compositing is employed, the individual sample bottles must be thoroughly mixed before pouring the individual aliquots into the composite container.

2. <u>Sample Location</u>

(a) General

Samples should be collected at the location specified in the NPDES permit. In some instances the sampling location specified in the permit or the location chosen by the permittee may not be adequate for the collection of a representative sample. In such instances, the inspector is not precluded by permit specifications from collection of a sample at a more representative location. Where a conflict exists between the permittee and the regulatory agency regarding the most representative sampling location, both sites should be sampled and the reason for the conflict noted in the inspection report. Recommendation for any change in sampling location should be given to the appropriate permitting authority.

(b) Influent

Influent wastewaters are preferably sampled at points of highly turbulent flow in order to insure good mixing; however, in many instances the most desirable location is not accessible. Preferable raw waste sampling points are: (1) the upflow siphon following a comminutor (in absence of grit chamber); (2) the upflow distribution box following pumping from main plant wet well; (3) aerated grit chamber; (4) flume throat; and (5) pump wet well. In all cases, samples should be collected upstream from recirculated plant supernatant and sludges.

(c) Effluent

Effluent samples should be collected at the site specified in the permit, or if no site is specified in the permit, at the most representative site downstream from all entering waste streams prior to entry into the receiving waters. If a conflict exists between the permittee and inspector regarding the location of the most representative site, follow the procedure outlined in Section 2(a) above.

(d) Pond and Lagoon Sampling

Generally, composite samples should be employed for the collection of wastewater samples from ponds and lagoons. Even if the ponds and lagoons have a long detention time, composite sampling is necessary because of the tendency of ponds and lagoons to short circuit. However, if dye studies or past experience indicate a homogenous discharge, a grab sample may be taken as representative of the waste stream.

3. Sample Volume

The volume of sample obtained should be sufficient to perform all the required analyses plus an additional amount to provide for any quality control needs, split samples or repeat examinations. Although the volume of sample required depends on the analyses to be performed, the amount required for a fairly complete analysis is normally 2 gallons (7.6 liters) for each laboratory receiving a sample. The laboratory receiving the sample should be consulted for any specific volume requirements. Individual portions of a composite sample should be at least 100 milliliters in order to minimize sampler solids bias. Refer to EPA's "Methods for Chemical Analysis of Water and Wastes 1974" for the sample volumes required for specific types of pollutant measurements.

4. Selection and Preparation of Sample Containers

It is essential that the sample containers be made of chemically resistant material and do not affect the concentrations of the pollutants to be measured. In addition, sample containers must have a closure which will not contaminate the sample. See EPA's "Methods for Chemical Analysis of Water and Wastes 1974" for selecting container materials for specific types of pollutant measurements.

C. Sampling Techniques

1. Grab Samples

A grab sample is defined as an individual sample collected over a period of time not exceeding 15 minutes. Grab samples represent only the condition that exists at the time the wastewater is collected. The collection of a grab sample is appropriate when it is desired to:

(a) Characterize the wastewater stream at a particular instance in time;
(b) Provide information about minimum and maximum concentrations;
(c) Allow collection of variable sample volume;
(d) Comply with the NPDES permit monitoring specifications; or
(e) Corroborate with composite sample.

In addition, there are certain parameters, such as pH, temperature, residual chlorine, D.O., oil and grease, coliform bacteria, that must be evaluated in situ or by using a grab sample because of biological, chemical or physical interactions which take place after sample collection and affect the results. Special precautions to be used in the collection and handling of selected parameters are discussed in the Quality Assurance Section.

2. Composite Samples

A composite sample should contain a minimum of eight discrete samples taken at equal time intervals over the compositing period or proportional to the flow rate over the compositing period. More than the minimum number of discrete samples will be required where the wastewater loading is highly variable. Six acceptable methods for collecting composite samples are described in Table IV-1.

(a) Selection of Sample Type

For facilities where production and flow rates vary, composite sampling is necessary to provide a representative picture of the quality of the waste stream. Composite samples show the average condition of the wastewater discharged during a shift, day or longer production period. If the flow rate does not vary by more than ± 15 percent of the average flow rate, a time-intervaled composite (method 3, Table IV-1) will provide a

TABLE IV - 1
COMPOSITING METHODS

Method No.	Sampling Mode	Compositing Principle	Comments	Disadvantages
1.	Continuous	Constant sample pumping rate	Practicable but not widely used	Yields large sample volume, may lack representativeness for highly variable flows
2.	Continuous	Sample pumping rate proportional to stream flow	Not widely used	Yields large sample volume but requires accurate flow measurement equipment
3.	Periodic	Constant sample volume, constant time interval between samples	Widely used in automatic samplers and widely used as manual method	Not most representative method for highly variable flow or concentration conditions
4.	Periodic	Constant sample volume, time interval between samples proportional to stream flow	Widely used in automatic sampling but rarely used in manual sampling	Manual compositing from flow chart
5.	Periodic	Constant time interval between samples, sample volume proportional to total stream flow since last sample	Not widely used in automatic samplers but may be done manually	Manual compositing from flow chart
6.	Periodic	Constant time interval between samples, sample volume proportional to stream flow at time of sampling	Used in automatic samplers and widely used as manual method	Manual compositing from flow chart

AFTER: Shelley & Kirkpatrick (2)

representative measurement of the wastewater characteristics and load discharged over the sampling period.

(b) Compositing Method

The preparation of a composite sample can be performed in various ways. Table IV-2 and Figure IV-1 summarize the technique for preparing a manual composite from time constant, volume variable samples (method 6, Table IV-1). Note that the average daily flow rate is needed to compute the quantity of pollutants discharged. The instantaneous flow rate should not be used to compute daily loadings unless it is known that the instantaneous and average daily flow rates are equivalent.

When using a volume constant, time proportional compositing method (method 4, Table IV-1) previous flow records should be used to determine an appropriate flow volume increment so that a representative sample can be obtained without overrunning the capacity of the sample container.

In any manual compositing method, sample manipulation should be minized to reduce the possibility of contamination.

TABLE IV - 2
MANUAL COMPOSITING METHOD
(No. 6)

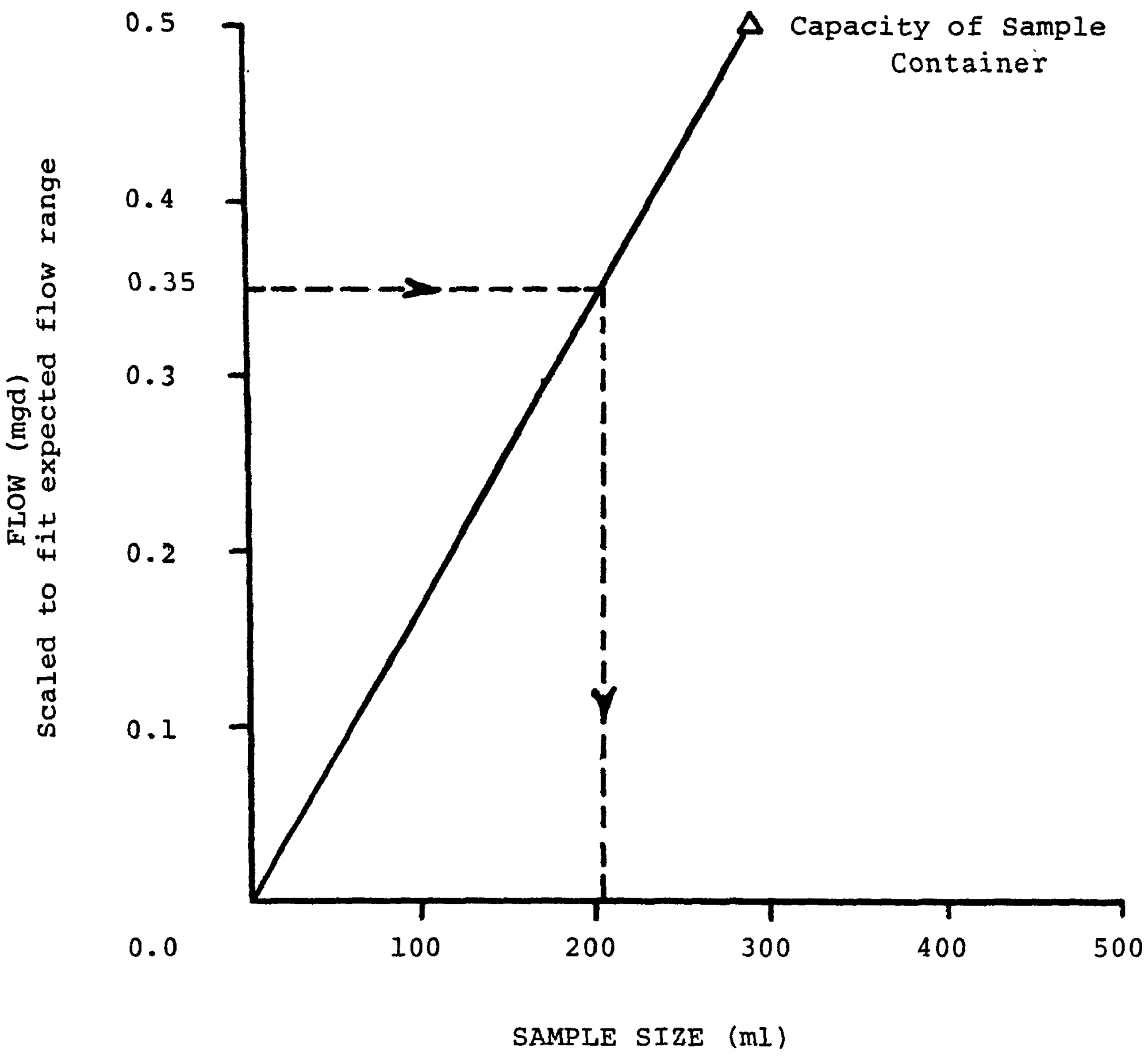
Bottle No.	Time Aliquot Collected	Flow (MGD)	Sample size (ml)
1	0800	0.07	40
2	0900	0.09	55
3	1000	0.10	60
4	1100	0.13	80
5	1200	0.16	95
6	1300	0.21	125
7	1400	0.23	135
8	1500	0.26	150
9	1600	0.29	170
10	1700	0.31	180
11	1800	0.31	180
12	1900	0.30	175
13	2000	0.28	165
14	2100	0.22	130
15	2200	0.18	105
16	2300	0.17	100
17	2400	0.28	165
18	0100	0.35	205
19	0200	0.39	230
20	0300	0.45	260
21	0400	0.42	245
22	0500	0.42	245
23	0600	0.42	245
24	0700	0.39	230
		6.43	3770

Average daily flow $= \frac{\text{sum of flows}}{\text{24 hrs.}} = \frac{(6.43)}{24} = 0.27$ mgd

*Method is for 24-hour composite using 24 discrete samples

FIGURE IV-1

METHOD FOR DETERMINING COMPOSITE ALIQUOT SIZE



NOTE: Maximum flow rate scaled to fit sample container size.

D. Sample Preservation

1. General

In most cases, wastewaters contain one or more unstable pollutants that require immediate analyses or preservation. The rate of change of pollutant concentration is influenced by temperature, pH, bacterial action, concentration, and intermolecular reactions. Since treatment to fix one constituent may affect another, preservation is sometimes complicated, thus necessitating the collection of multiple samples or the splitting of a single sample into multiple parts.

Prompt analysis is the most positive assurance against error from sample deterioration, but this is not always possible for composite samples in which portions may be stored for as long as 24 hours. It is important that stabilization of the wastewater be provided during compositing, where possible, in addition to preservation of the composited sample before transit to the laboratory. Procedures used to preserve samples include refrigeration, pH adjustment, and chemical treatment. Refrigeration is the most common method of sample preservation. Temperature control near 4°C retards bacterial action and suppresses volatilization of most dissolved gases.

There are a variety of individual preservation techniques depending on the constituent to be analyzed. A detailed discussion on the subject is presented in the section on Quality Assurance.

2. Compliance Considerations

The list of approved test procedures in 40CFR Part 136(F.R. Vol. 41, No. 232, Dec. 1, 1976), Guidelines Establishing Test Procedures for Analysis of Pollutants-Amendments, is the only legally binding reference the Agency has on establishing test procedures for analysis of pollutants for the NPDES program. Included in the referenced test procedures are the analytical method, preservation method and sample holding time.

E. Analytical Methods

1. General

The discharge parameter values for which reports are required must be determined by one of the standard analytical methods cited in Table I, 40CFR Part 136.3(F.R. Vol. 41, No. 232, Dec. 1, 1976) or by an alternate test procedure approved by the Regional Administrator upon the recommendation of the Director of the Environmental Monitoring and Support Laboratory - Cincinnati.

2. Alternate Test Procedure

In instances where an effluent contains a pollutant for which a test procedure is not specified in Table I, 40CFR Part 136.3, or the permittee desires to use an analytical method other than the prescribed method, an application for approval of an alternate test procedure must be filed with the Regional Administrator in the Region where the discharge occurs. Application should be filed according to the provisions contained in 40CFR Part 136.4(c), "Application for alternate test procedures".

Where approval for an alternative test procedure for nationwide use is desired, application is not restricted to NPDES permittees and the application should be directed to the Director, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 45268. Instructions regarding the information required in support of an application for approval of an alternative test procedure for nationwide use is contained in 40 CFR Part 136.4(d).

F. Sample Identification

Each sample must be accurately and completely identified. It is important that any label used to identify the sample be moisture-resistant and able to withstand field conditions. A numbered label associated with a field data sheet which contains detailed information on the sample may be preferrable to using only the label for information.

The information provided for each sample should include the following:

1. Designation and location description of sample site.
2. Name of collector(s).
3. Date and time of collection.
4. Indication of grab or composite sample with appropriate time and volume information.
5. Indication of parameters to be analyzed.
6. Notation of conditions such as pH, temperature, chlorine residual and appearance that may change before the laboratory analysis, including the identification number of instruments used to measure parameters in the field.
7. Indication of any unusual condition at the sampling location and/or in the appearance of the wastewater.
8. Preservative used.
9. Any noteworthy additional information.

For additional information regarding sample identification techniques, consult the Chain of Custody Procedure described in Section VIII.

G. Safety Considerations

NPDES Compliance Sampling Inspections are to be conducted in a safe manner consistent with EPA safety regulations and any special safety regulations associated with the particular facility being inspected.

Inspection supervisors are responsible for insuring that day-to-day work being carried out under their supervision is accomplished in accordance with established safety rules and policies. Supervisors are responsible for insuring that employees perform their jobs in a safe manner and for initiating immediate corrective action as soon as an unsafe situation or procedure is observed.

The inspector should be familiar with EPA's Occupational Safety and Health rules and policies contained in the publication "Occupational Safety And Health For The Federal Employee"(3). Other references dealing with various aspects of inspection safety are listed at the end of this section (4&5).

REFERENCE - SECTION IV

1. "Methods For Chemical Analysis Of Water And Wastes, 1974," U.S. Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. (1974).

2. Shelley, P.E., and Kirkpatrick, G.A., "An Assessment of Automatic Sewer Flow Samplers," U.S. Environmental Protection Agency, EPA-600/2-75-065, Washington, D.C. (12/75).

3. "Occupational Safety And Health For The Federal Employee," U.S. Environmental Protection Agency, Office of Planning and Management, Occupational Health And Safety Office, Washington, D.C. (12/76).

4. "NEIC Safety Manual," U.S. Environmental Protection Agency, Office of Enforcement, National Enforcement Investigation Center, EPA-330/9-74-002-B, Denver, Colorado (2/77).

5. "Safety In Wastewater Works," Water Pollution Control Federation Manual of Practice No. 1, Safety Committee WPCF, Washington, D.C. (1969).

SECTION V

AUTOMATIC SAMPLERS

A. Introduction

The issuance of NPDES permits containing self-monitoring requirements calling for the collection of composite samples, the significant labor cost saving, and the increased data reliability are the main reasons for the recent increase in use of automated sample collection devices.

There are currently about 100 manufacturers of portable automatic sample collection devices. These devices have widely varying levels of sophistication, performance, mechanical reliability, and cost. No individual composite sampler now on the market can be considered ideal for every application. Selection of a unit or variety of units for a field data gathering program should be preceded by a careful evaluation of such factors as:

(a) The range of intended use.

(b) The skill level required for installation and operation of the automatic sampler.

(c) The amount of unavoidable error that can be tolerated in the sample collection system.

The references listed at the end of this section discuss the theoretical design considerations and actual field performance data from a variety of sources and should be reviewed prior to the purchase of an automatic sampler.

B. Automatic Sampler Subsystem Components

Five inter-related automatic sampler subsystem components are discussed briefly below based on material presented in references 6 & 7.

1. Sample Intake Subsystem

The operational function of a sample intake is to reliably gather a representative sample from the flow stream in question. Its reliability is measured in terms of freedom from plugging or clogging and vulnerability to physical damage from large objects in the flow.

The sample intake of many commercially available automatic samplers is often only the end of a plastic suction tube. Users are left to their own ingenuity and devices to convert this tube to an intake which will collect a representative sample of a highly stratified, nonhomogeneous liquid waste. Most recent available information indicates that a single point intake is not likely to be very satisfactory (see references 2 & 5). Current assessment of the state-of-the-art suggest that a fixed nozzle type intake located at 0.4 to 0.6 of the stream depth in the area of maximum turbulence with an intake velocity equal to or greater than the average wastewater velocity at the sample point provides the most representative sample. This technique ignores contribution from bedload or floatable solids. Improvements can be made through the use of multiple samplers with intakes at variable depths.

2. Sample Gathering Subsystem

Three basic sample gathering methods, mechanical, forced flow, and suction lift, are available in commercial samplers.

(a) Mechanical - Many of the mechanical devices, such as cups on cables, calibrated scoops, and paddle wheels with cups, were developed for a single site utilizing a primary flow device. Mechanical devices have arisen from one of two basic considerations:

i. Site conditions requiring very high lifts; or

ii. Desire to collect samples integrated across the entire flow depth.

Most mechanical units offer significant obstruction to the flow stream at least during the sampling episodes. The tendency for exposed mechanisms to foul, together with the added vulnerability of many moving parts, means that successful operation will require periodic inspection, cleaning, and maintenance.

(b) Forced Flow - All forced flow methods (pumps and pneumatic ejection) offer some obstruction to the flow, but generally less than mechanical gathering methods. Pumps offer the ability to sample at great depths and maintain high flow velocities, but repairs are more expensive because of poor accessibility. Pneumatic ejection units are generally low volume samplers, and the small sample volume generally prevents collection of the most representative sample. The use of air or inert gas to force the sample into the collection container makes pneumatic ejection units desirable for applications where an explosion hazard exists.

(c) Suction Lift - Suction lift units without detachable gathering systems are practically limited to operation at heads of 25 feet or less because of atmospheric pressure and internal friction losses. Devices in this category include pre-evacuated bottles, suction pumps with metering chambers, and peristaltic pumps. With all suction devices, when the pressure on a liquid which contains dissolved gases is reduced, the dissolved gases will tend to pass out of solution. In so doing, the gases will leave the surface and entrain suspended solids enroute. This phenomenon may result in the surface layer of the liquid being enhanced in suspended solids. To avoid this problem, the first flow of any suction lift sampler should be returned to waste. Also, metering chambers should be sized to collect a minimum of 100 ml per sampling event to minimize the concentration effect. The suction lift gathering method offers more advantages and flexibility for many applications than either mechanical or forced flow sampling systems.

3. Sample Transport Subsystem

The majority of the commercially available composite samplers have fairly small diameter tubing in the sample train. This tubing is vulnerable to plugging, due to the buildup of fats, etc. Adequate flow rates must be maintained throughout the sampling train in order to effectively transport the suspended solids. Information in the cited literature and actual field experiences indicate that transport lines less than 0.64cm (0.25in) ID should not be used. Sample train velocities should exceed 2 fps and be constant and controllable for general application in municipal and industrial sampling. Sharp bends, twists, or kinks in the sampling line should be avoided to minimize problems with debris clogging the system.

To optimize sampler performance and reliability, the sampler should be capable of rapidly purging the intake system prior to and immediately after each sample collection. This feature becomes more important as the sampler design sophistication approaches isokinetic sampling. (Rate of flow into the sampler is equal to the rate of flow in wastewater stream).

4. Sample Storage Subsystem

Both discrete samples and single bottle collection are desirable features for certain applications. Discrete samples are subject to considerably more error introduced through sample handling, but do provide opportunity for manual flow compositing and time history characterization of a waste stream during short period studies. Total sample volumes collected should be 2 gallons (7.6 liters) at a minimum. Sample containers should be easily cleaned or disposable and shaped to facilitate transfer of the solids laden sample. The requirements for sample preservation are discussed in the Quality Assurance Section and will not be repeated here except to note that refrigeration to 4°C is the best single preservation method and will be required in all automatic composite samplers.

5. Controls and Power Subsystem

Solid state control units, encapsulated to minimize the effect of highly-humid and corrosive atmospheres frequently encountered in the field, have increased the reliability of sampler control systems.

6. Sampler Reliability

Composite samplers are subject to a variety of rough usage from transportation and handling, inadvertent submergence during field surveys and inadequate care and forethought on the part of the users. Optimal performance, 95 percent success in obtaining the programed sample, can be obtained through training of the users, a routine service program and an effective dialogue with the vendor to modify any major deficiencies. Performance summaries from EPA Region VII field group is presented in reference 1.

Statistically, the data in reference 1 are too limited to recommend or reject any particular sampler; however, sampling of raw wastewaters produced the major number of compositor malfunctions and more reliable operation can be expected when sampling treated wastewaters.

C. Installation And Operation Of Automatic Sampling Equipment

1. Site Selection

At locations which have not been previously sampled, the field staff should have a qualified team leader present to select the sampling point, to inspect the flow measurement device and to supervise installation of the sampling equipment. This practice reduces the risk of sampler malfunction and missed samples, improves the representativeness of the data, and results in a more detailed and informative report.

The primary reason for maintaining a variety of samplers for use by a field staff is the number of sampling requirements, waste stream characteristics, and site conditions encountered in the field. Utilization of certain sampling equipment is often precluded by the physical characteristics of the sampling point such as, accessibility, site security, and power availability.

Raw municipal wastewaters are preferably sampled at points of highly turbulent flow in order to insure good mixing; however, in many instances the desired location is not accessible. Suggested raw wastewater sampling points are listed in the Section on Sample Collection.

2. <u>Equipment Security</u>

Equipment security is an item of major concern at sites which are outside of fenced treatment facilities. Manhole installations, in which battery operated equipment can be inserted and the cover replaced, will generally provide sufficient security. In exposed locations which require composite samples, one must either risk loss and tampering with equipment or utilize manual sampling procedures. If manpower limitations require use of unattended equipment, the sampler should be provided with a lock or seal which would indicate tampering if broken or removed.

3. Power Source

Samplers capable of both AC and DC operation are desirable. This feature increases the overall flexibility of the unit, and also enhances winter operation reliability. Battery operated units become less reliable at extremely low temperatures. Generally, line operated samplers are more reliable than battery-operated models for the sampling of raw wastewaters, due to the high vacuum and purging feature of the line operated units. In every case, line current should be used by the sampling team if it is available at the sampling site.

4. Waste Characteristics

The physical and chemical characteristics of the waste stream also play a part in determining the type of sampler to use. Wide fluctuations in pH, concentration, color, and volume encountered with some industrial wastewaters will generally require a discrete sample collector in order that aliquots can be analyzed individually.

5. Sample Preservation During Compositing Period

All samples should be kept near 4°C during the composite period. A number of commercial samplers contain integral ice compartments. With other units, samples can be chilled by placing the sample collection container in an ice chest along with a bag of ice. The ice chest can be placed on end with the drain hole on top, and the discharge tube of the sampler threaded through this hole and into the sample container.

6. Winter Operations

Winter operation of sampling equipment can be a trying experience. During particularly cold weather, sampler malfunctions due to freezing of intake lines may run as high as 60 percent. Recently, heated teflon lines have become available to eliminate this problem, but they are expensive. This problem may also be handled by placing the automatic sampler inside an insulated housing containing a thermostatically controlled 100 watt electric light bulb. The heat given off by the bulb is normally sufficient to prevent problems caused by freezing. NOTE: Catalytic type heaters should not be used because they give off vapors that can affect sample composition.

The chance of sampler freezing may also be lessened by locating the sampler below ground in a manhole or wet well. If installed below ground, the sampler should be secured in place. In manholes the sampler may be tied to the steps (fiber glass tape) or suspended from a rope tied securely to a stake in the ground. When installing samplers in manholes or wet wells, precautions should be taken to insure that there is adequate ventilation and light. Sites with a history of submergence and/or surcharging after precipitation events should be avoided if possible. Care should also be taken in the placement of the sampler to avoid suction lifts in excess of head limits. Battery operated units generally have more restrictive head limitations than line operated samplers.

D. Desirable Automatic Sampler Characteristics

Listed below are desirable criteria to be used as a guide in choosing a sampler which best meets the need of the individual sample collection program:

1. Capability for AC/DC operation with adequate dry battery energy storage for 120-hr operation at 1-hr sampling intervals.
2. Suitability for suspension in a standard manhole and still be accessible for inspection and sample removal.
3. Total weight including batteries under 18 kg (40 lb).
4. Sample collection interval adjustable from 10 min to 4 hr.
5. Capability for flow-proportional and time-composite samples.

6. Capability for collecting a single 9.5 l (2.5 gal) sample and/or collecting 400 ml (0.11 gal) discrete samples in a minimum of 24 containers.

7. Capability for multiplexing repeated aliquots into discrete bottles.

8. One intake hose with a minimum ID of 0.64 cm (0.25 in.).

9. Intake hose liquid velocity adjustable from 0.61 to 3 m/sec (2.0 to 10 fps) with dial setting.

10. Minimum lift of 6.1 m (20 ft.).

11. Explosion proof.

12. Watertight exterior case to protect components in the event of rain or submersion.

13. Exterior case capable of being locked, including lugs for attaching steel cable to prevent tampering and to provide security.

14. No metal parts in contact with waste source or samples.

15. An integral sample container compartment capable of maintaining samples at 4 to 6°C for a period of 24 hr. at ambient temperature range between -30 to 50°C.

16. With the exception of the intake hose, capability of operating in a temperature range between -30 to 50°C.

17. Purge cycle before and after each collection interval and sensing mechanism to purge in event of plugging

during sample collection and then to collect complete sample.

18. Field repairability.

19. Interchangeability between glass and plastic bottles, particularly in discrete samplers is desirable.

20. Sampler exterior surface painted a light color to reflect sunlight.

REFERENCES - SECTION V

1. Harris, D.J. and Keffer, W.J., "Wastewater Sampling Methodologies and Flow Measurement Techniques," USEPA Region VII, EPA 907/9-74-005, Kansas City, Missouri, (6/1974).

2. Interagency Committee on Water Resources, "Determination of Fluent Sediment Discharge", Report #14 (1963).

3. Lauch, R.P., "Performance of ISCO Model 1391 Water and Wastewater Sampler," U.S. Environmental Protection Agency, EPA-670/4-75-003, Cincinnati, Ohio, (4/75).

4. Lauch, R.P., "Application and Procurement of Automatic Wastewater Sampler," U.S. Environmental Protection Agency, EPA-670/4-75-003, Cincinnati, Ohio, (4/75).

5. Lauch, R.P., "A Survey of Commercially Available Automatic Wastewater Samplers", U.S. Environmental Protection Agency, EPA-600/4-76-051, Cincinnati, Ohio, (9/76).

6. Shelley, P.E. "Design and Testing of a Prototype Automatic Sewer Sampling System" prepared for the Office of Research and Monitoring, U.S. Environmental Protection Agency EPA-600/2-76-006, Washington, D.C. (3/75).

7. Shelley, P.E., and Kirkpatrick, G.A., "An Assessment of Automatic Sewer Flow Samples" prepared for the Office of Research and Monitoring, U.S. Environmental Protection Agency, EPA-600/2-75-065 Washington, D.C. (12/75).

8. Wood, L.B. and Stanbridge, H.H., "Automatic Samplers," Water Pollution Control, Vol. 67, No. 5, pp495-520 (1968).

SECTION VI

WASTEWATER FLOW MEASUREMENT

A. Introduction

The measurement of flow in conjunction with wastewater sampling is essential to almost all water pollution control activities. All activities such as NPDES permit compliance monitoring, municipal operation and maintenance, planning and research rely on accurate flow measurement data. The importance of obtaining accurate flow data cannot be overemphasized, particularly with respect to NPDES compliance monitoring inspections, since these data should be usable for enforcement purposes. NPDES permits limit the quantity (mass loading) of a particular pollutant that may be discharged. The error involved in determining these mass loadings is the sum of errors from flow measurement, sample collection, and laboratory analyses. It should be obvious that measurement of wastewater flow should be given as much attention and care in the design of a sampling program as the collection of samples and their subsequent laboratory analyses.

The basic objectives of this chapter are:

(1) To discuss basic wastewater flow measurement systems;

(2) To outline what is expected of field personnel with respect to wastewater flow measurement during NPDES compliance monitoring activities; and

(3) To present acceptable wastewater flow measurement techniques commonly used.

A complete discussion of all available flow measurement techniques and the theory behind them is beyond the scope of this manual. Most of the common techniques in current use are covered, however, in rather general terms. A comprehensive list of references is included at the end of this chapter for those who desire a more detailed discussion.

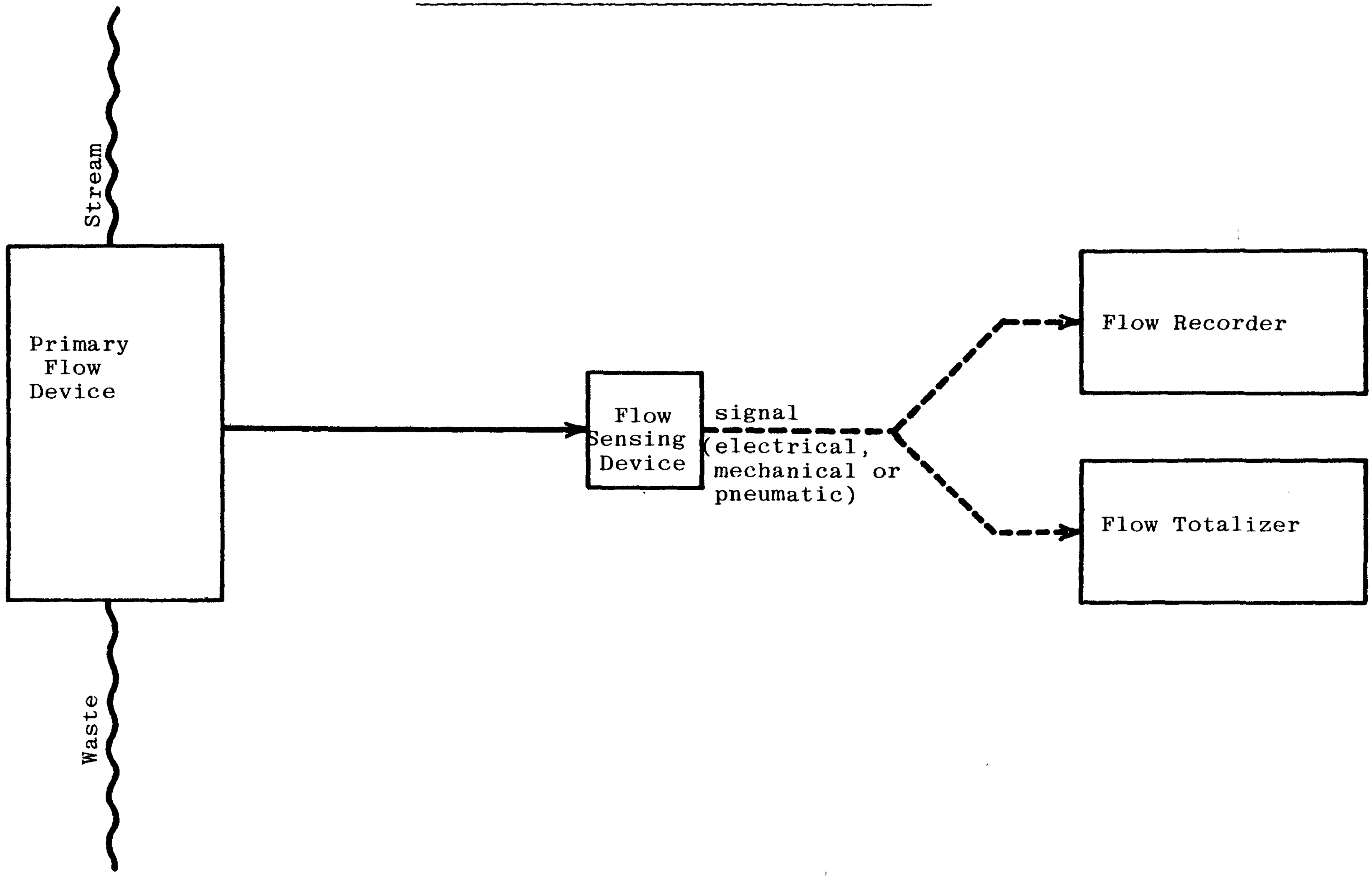
B. Wasterwater Flow Measurements Systems

Flow data may be collected on an instantaneous or a continuous basis. A flow measurement system is required for the collection of continuous data. A typical continuous system consists of a primary flow device, a flow sensor, transmitting equipment, a recorder, and possibly, a totalizer. Instantaneous flow data can be obtained without using such a system.

The heart of a typical continuous flow measurement system, as shown in Figure VI-1, is the primary flow device. This device is constructed such that it has predictable hydraulic responses which are related to the flowrate of water or wastewater through it. Examples of such devices include weirs and flumes which relate water depth (head) to flow, Venturi and orifice type meters which relate differential pressure to flow, and magnetic flow meters which relate induced electric voltage to flow. A standard primary flow device has undergone detailed testing and experimentation and its accuracy has been verified.

FIGURE VI-1

COMPONENTS OF FLOW MEASURING SYSTEMS



A flow sensor is required to measure the particular hydraulic responses of the primary flow device and transmit them to the recording system. Typically, sensors include floats, pressure transducers, capacitance probes, differential pressure cells, electromagnetic cells, etc.

The sensor signal is generally conditioned by using mechanical, electromechanical, or electronic systems. These systems convert the signal into units of flow which are recorded on a chart or put into a data system. Those systems which utilize a recorder are generally equipped with a flow totalizer which displays the total flow on a real time basis.

NPDES permits that necessitate continuous flow measurement require a complete system. Permits that require instantaneous flow measurement do not necessarily dictate the use of any portion of such a system. Techniques are available (described later in this chapter) for measuring instantaneous flow with portable equipment.

An important consideration during sampling inspections for NPDES compliance purposes is that the investigator may want to obtain continuous flow data at a facility where only instantaneous flow data is required by permit monitoring conditions. If an open channel primary flow device is utilized for making instantaneous measurements, only the installation of a portable field sensor and recorder is necessary. If, on the other hand, the facility being investigated does not utilize a primary flow device, and a continuous flow record is desired, the interval. Flow totalizers are easily checked by integrating the area under the curve. If the investigator has the proper equipment and knowledge, electronic recorders and totalizers may be checked by inducing known electric current to simulate flow. The accuracy of closed conduit flow measurement systems can be verified by making independent flow measurements at several different flowrates or by electrically, mechanically or hydraulically inducing known flowrates. Specific techniques for making independent flow measurements are given later in this section.

If the discharger's flow measurement system is accurate within ± 10 percent, the investigator is encouraged to use the installed system. If the flow sensor or recorder is found to be inaccurate, determine if it can be corrected in time for use during the inspection. If the equipment cannot be repaired in a timely manner, the investigator should install a portable flow sensor and recorder for the duration of the investigation. The installation and use of such equipment is preferred over attempts to correct erronéous flow measurement systems. The inspector should note the action taken in the inspection report and inform the permittee that the equipment should be repaired as soon as possible. If non-standard primary flow devices are being used, it is the responsibility of the discharger to supply data supporting the accuracy and precision of the method being employed.

The inspector should evaluate and review calibration and maintenance programs for the discharger's flow measurement system. The permit normally requires that the calibration of such systems be checked by the permittee on a regular basis. The lack of such a program should be noted in the inspection report.

The compliance inspection report should contain an evaluation of the discharge flow measurement system. Inadequacies may be discussed with the permittee during the inspection and deficiencies noted in the report so that follow-up activity can be conducted. Any recommendations to the permittee should be made in such a manner that any subsequent enforcement will not be jepordized.

D. Wasterwater Flow Measurement Methods

This section outlines and familiarizes the field investigator with the most commonly used methods of wastewater flow measurement and the primary devices that will be encountered during NPDES compliance sampling inspections. Volumetric and dilution techniques are presented at the beginning of this chapter, since they are applicable to both open-channel and closed-conduit flow situations. The remaining methods are grouped under categories dealing with open channels and closed-conduits. The general method of checking individual primary flow devices is given, where applicable. Several estimation techniques are presented. However, it should be recognized that flow estimates do not satisfy NPDES permit monitoring investigator's job becomes more difficult. A portable primary flow device will have to be installed. Generally, the investigator is limited to the installation of open channel equipment, since the installation of closed-conduit flowmeters is more complex and time-consuming. This chapter does not cover in detail the installation of primary flow devices, but many of the references cited treat this area quite adequately. The USDI Water Measurement Manual (1) is an excellent reference for details on checking the installation of primary flow devices.

The accuracy of wastewater measurement systems varies widely, depending principally upon the primary flow device used. The total error inherent in a flow measuring system is, of course, the sum of each component part of the system. However, any system that can not measure the wastewater flow within ± 10% is considered unacceptable for NPDES compliance purposes.

C. Field Verification Of Flow Measurement Systems

The responsibility of the investigator during NPDES compliance sampling inspections includes the collection of accurate flow data during the inspection, as well as the validation of such data collected by the permittee for self-monitoring purposes.

The investigator must insure that the flow measurement system or technique being used measures the entire wastewater discharge as described by the NPDES permit. A careful inspection should be made to determine if recycled wastewaters or wastewater diversions are present upstream of the system. The investigator should note any anomalies on the inspection report form or in a bound field notebook.

The investigator's second task is to verify that the system being used is accurate. In cases where the discharger is making instantaneous flow measurements to satisfy permit requirements, the specific method used should be evaluated. If a primary flow device is used, the device should be checked for conformity with recognized construction and installation standards. Any deviation from standard conditions should be well documented. Where there are significant deviations, accuracy of the primary flow device should be checked by making an independent flow measurement.

All components of continuous flow measuring systems should be verified. The primary flow device should be checked for conformity with recognized construction and installation standards (where possible). The flow sensing and recording devices are usually checked simultaneously. The procedure most often used is to make an independent flow measurement utilizing the primary flow device, obtaining the flow rate from an appropriate hydraulic handbook and comparing this flow rate with the recorded value. Since most primary flow devices do not have linear responses, several checks should be made over as wide a flow range as is possible. The accuracy of the recorder timing mechanism may be checked by marking the position of the recorder indicator and checking this position after an known elapsed time requirements unless the permit specifically states that this is permissible.

1. Volumetric Techniques

Volumetric flow techniques are among the simplest and most accurate methods for measuring flow. These techniques basically involve the measurement of volume and/or the measurement of time required to fill a container of known size.

(a) Vessel Volumes

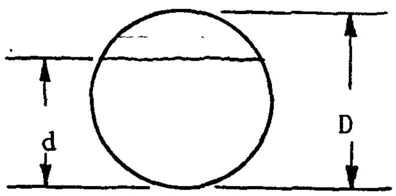
The measurement of vessel volumes to obtain flow data is particularly applicable to batch wastewater discharges. An accurate measurement of the vessel volume(s) and the frequency that they are dumped is all that is required. An accurate engineering tape measure to verify vessel dimensions and a stop watch are the only required field equipment. The equations for calculating the volumes of various containers is given in Figure VI-2.

(b) Pump Sumps

Pump sumps may be used to make volumetric wastewater flow measurements. This measurement is made by observing the sump levels at which the pump(s) cut on and off and calculating the volume contained between these levels. This volume, along with the number of pump cycles, will give a good estimate of the daily wastewater flow. One source of error in this measurement is the quantity of wastewater that flows into the sump during the pumping cycle. This error may be particularly significant if the

FIGURE VI-2
EQUATIONS FOR CONTAINER VOLUMES

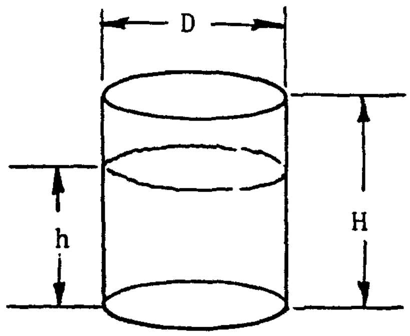
SPHERE



Total Volume
$V = 1/6\ \pi D^3 = 0.523598 D^3$

Partial Volume
$V = 1/3\ \pi d^2\ (3/2\ D - d)$

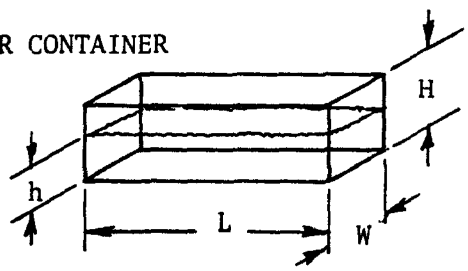
RIGHT CYLINDER



Total Volume
$V = 1/4\ \pi D^2 H$

Partial Volume
$V = 1/4\ \pi D^2 h$

ANY RECTANGULAR CONTAINER



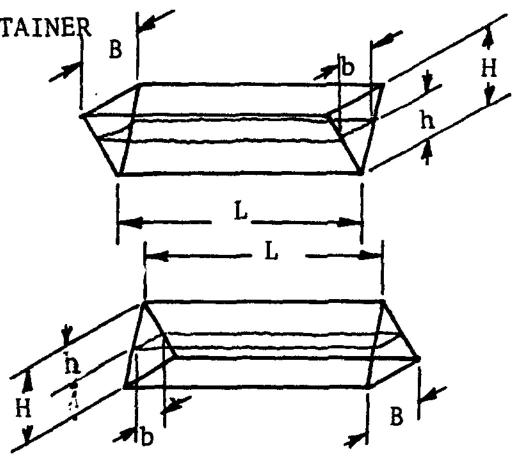
Total Volume
$V = HLW$

Partial Volume
$V = hLW$

TRIANGULAR CONTAINER

Case 1

Case 2

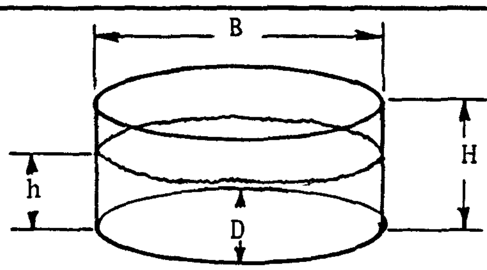


Partial Volume (case 1)
$V = 1/2\ hbL$

Total Volume
$V = 1/2\ HBL$

Partial Volume (case 2)
$V = 1/2\ L\ (HB - hb)$

ELLIPTICAL CONTAINER



Total Volume
$V = \pi BDH$

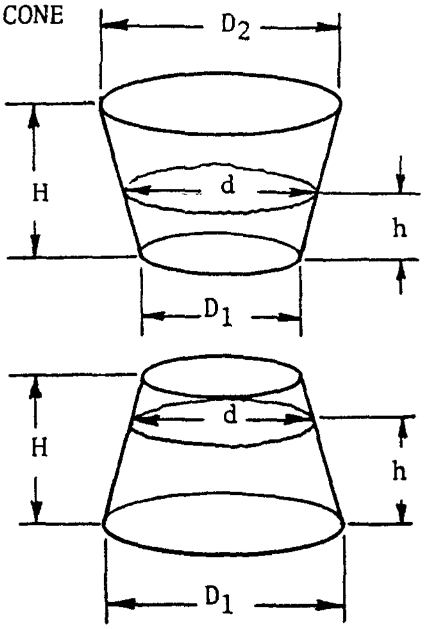
Partial Volume
$V = \pi BDh$

FIGURE VI-2 (CONTINUED).

FRUSTUM OF A CONE

Case 1

Case 2



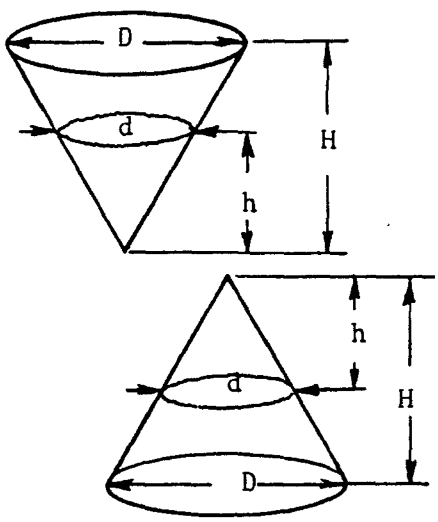
Total Volume
$V = \pi/12\ H\ (D_1^2 + D_1 D_2 + D_2^2)$

Partial Volume
$V = \pi/12\ h\ (D_1^2 + D_1 d + d^2)$

CONE

Case 1

Case 2



Partial Volume (case 1)
$V = 1/12\ \pi\ d^2 h$

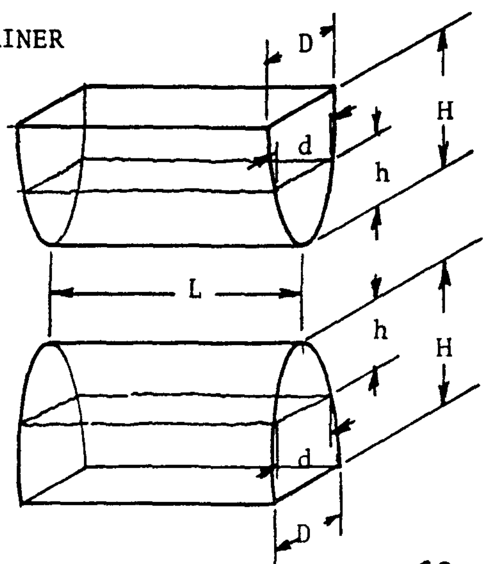
Total Volume
$V = 1/12\ \pi\ D^2 H$

Partial Volume (case 2)
$V = 1/12\ \pi (D^2 H - d^2 h)$

PARABOLIC CONTAINER

Case 1

Case 2



Partial Volume
$V = 2/3\ hdL$

Total Volume
$V = 2/3\ HDL$

Partial Volume
$V = 2/3\ (HD - hd)\ L$

sump is large, the rate of inflow is high, and/or the pumping cycle is long. This error may be accounted for if the inflow is fairly constant, by measuring the time required to fill the sump and adding this additional flow for each pump cycle. The number of times that the pump cycles during a measurement period may be obtained by using a counter on the pump or using a stage recorder to indicate the number of pump cycles.

(c) Bucket and Stopwatch

The bucket and stopwatch technique is particularly suited to the measurement of small wastewater flows. It is accurate and easy to perform. The only equipment required to make this measurement are a calibrated container (bucket, drum, tank, etc.) and a stop watch. The container should be calibrated carefully, using primary standards, or other containers which have been calibrated using such equipment. Ordinarily, this measurement is made at the end of a pipe; however, using some ingenuity, a bucket and stopwatch flow measurement may be made in ditches and other open channel locations. Short sections of pipe may be used to channel or split flows into measurable portions. A shovel is often needed to dig a hole under a pipe or in an open channel to get the container under the wastewater stream that is to be measured. As with all flow measurement techniques, it is important to insure that all of the wastewater stream is measured. This method is limited by the amount of flow that can practically be measured in a reasonably sized container. A five gallon bucket filled to capacity, for example, would weigh 42 pounds. Also, the filling time of the container should be sufficiently long so that the calibrated container can be moved in and out of the wastestream without spilling the contents or overflowing the bucket. A minimum filling time of 10 seconds is recommended. If the container is hand-held, the practical limit of container size is what can be comfortably handled, about five gallons. Therefore, with a 5-gallon container, the maximum flow that could practically be measured would be 30 gpm. At least three consecutive measurements should be made, and the results averaged.

(d) Orifice Bucket

The orifice bucket permits the investigator to measure higher wastewater flows than is possible by using a bucket and stopwatch. An orifice bucket is a metal container (bucket) that has been modified by cutting holes (orifices) in the bottom. The bucket is calibrated by plugging the orifices with rubber stoppers and using bucket and stopwatch measurements to calibrate the bucket. The calibration curve relates the depth of the water in the bucket, for various combinations of orifices, to the flowrate. This method is usable over a flow range of 7 to 100 gpm. Construction of the orifice bucket and directions for its use is given by Smoot (3).

2. Dilution Methods

Dilution methods for water and wastewater flow are based on the color, conductivity, fluorescence, or other quantifiable property of an injected tracer. The dilution methods require specialized equipment, extreme attention to detail by the investigator, and are time consuming. However, these techniques offer the investigator:

- A method for making instantaneous flow measurements where other methods are inappropriate or impossible to use;
- A reference procedure of high accuracy to check in situ those primary flow devices and flow measurement systems that are nonstandard or are improperly installed; and
- A procedure to verify the accuracy of closed conduit flow measuring systems.

The tracer may be introduced as a slug (instantaneously) or on a continuous flow basis. The constant rate dilution method is performed by injecting a tracer at a constant rate into a wastewater stream at an upstream location and measuring the resulting tracer concentration at a downstream location. The method is based on the following continuity equation:

$$Q = q(C_1-C_2)/(C_2-C_0) \quad (1)$$

Where: Q = Flowrate of the stream to be measured

q = Constant flowrate of injected tracer

C_1 = Concentration of injected tracer

C_2 = Concentration of tracer in the stream at downstream sampling location

C_0 = Background tracer concentration upstream from the tracer injection site.

If the flowrate and background concentration of the injected tracer are negligible when compared to the total stream characteristics, this equation reduces to:

$$Q = qC_1/C_2 \qquad (2)$$

Where Q, q, C_1 and C_2 are as previously defined for equation (1).

The use of this method requires that the following conditions be attained:

- The injection rate of the tracer (q) must be precisely controlled and must remain constant over the measurement period;
- The tracer used must not degrade, sorb, or be changed in basic characteristics by environmental factors or the wastestream to which it is added;
- The location of injection and sampling sites must be judiciously selected and located such that the dye is well mixed across the cross-section, so that a concentration plateau is reached during the measurement period; and

- The tracer used must be capable of being analyzed precisely.

In practice, many tracers have been used for dilution flow measurements including sodium chloride, lithium chloride, and fluorescent dyes. Fluorescent dyes and fluorometric analyses have been widely employed in dilution measurements and are particularly convenient. The tracer is normally injected into the wastestream by using a piston type chemical metering pump. The use of this type of pump is almost mandatory to maintain a constant injection rate. Automatic samplers are widely used to collect samples during the period of measurement. If fluorescent dyes are used, a submersible pump may be used in conjunction with a flow-through fluorometer and recorder to provide a continuous record of the dye concentration at the sampling point.

The flowrate may also be determined by making a slug (instantaneous) injection of tracer and measuring the resultant concentration at the downstream location during the entire time of passage of the tracer. The principle of the slug injection method is expressed in the following equation:

$$Q = C_1 \times V / \int_0^\infty (C_2 - C_0)\,dt \qquad (3)$$

Where: V = Volume of tracer injected

t = time

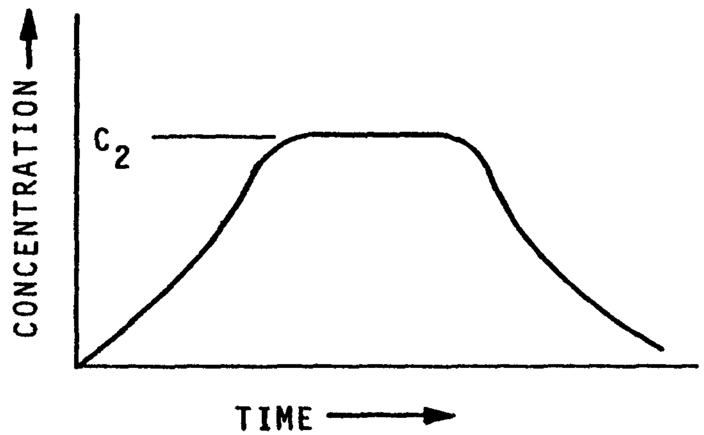
Q, q, C_0, C_1, C_2 are as previously defined for equation (1).

The principal advantage of this method is that sophisticated equipment is not required to inject the tracer. The disadvantages of the method are that it may not be used for unsteady flow situations and the entire tracer pulse must be sampled. The latter problem is easily solved by using fluorescent dyes and a flow-through fluorometer and recorder. The denominator of equation (3) may then be obtained by simply integrating the fluorometer recorder chart (after allowing for the background concentration, C_0) for the measurement period.

A graphical comparison of the constant rate and slug injection methods is given in Figure VI-3. The use of dilution techniques is covered in detail in the references (1, 3, 4). The monograph available from the Turner Design Company (4) is a particularly valuable reference for the use of fluorescent dyes and fluorometers in dilution flow measurement work. Experience indicates that accuracies of ±3 percent are achievable utilizing the dilution method under field conditions.

3. Open Channel Flow Measurements

The measurement of wastewater flow in open channels is the most frequently encountered situation in field investigations. An open channel is defined as any open conduit such as a ditch or flume or any closed conduit such as a pipe, which is not flowing full. The most commonly encountered methods and primary flow devices used in measuring open channel wastewater flow are described in this section. Several flow estimation techniques are also presented.



a. CONCENTRATION-TIME CURVE FOR CONSTANT-RATE INJECTION METHOD.

$$Q = \left(\frac{C_1 - C_2}{C_2 - C_o}\right) q$$

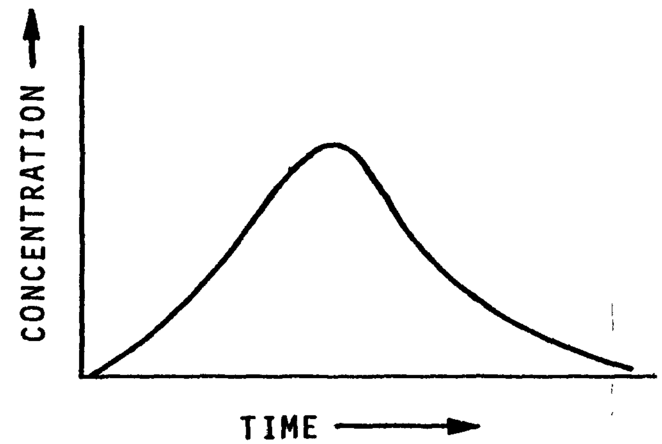
Q IS FLOW RATE OF STREAM

q IS FLOW RATE OF CHEMICAL

C_o IS BACKGROUND CONCENTRATION OF STREAM

C_1 IS CONCENTRATION OF CHEMICAL INJECTED

C_2 IS CONCENTRATION OF STREAM PLATEAU



b. CONCENTRATION-TIME CURVE FOR SLUG-INJECTION METHOD.

$$Q = \frac{v\ C_1}{\int_0^\infty (C - C_o)\,dt}$$

Q IS FLOW RATE OF STREAM

v IS VOLUME OF CHEMICAL INJECTED

C_o IS BACKGROUND CONCENTRATION OF STREAM

C_1 IS CONCENTRATION OF CHEMICAL INJECTED

C IS INSTANTANEOUS STREAM CONCENTRATION

FIGURE VI-3
CONSTANT RATE AND SLUG INJECTION METHODS (10)

The measurement accuracies quoted in this section apply only to the specific method or to the primary flow device being discussed. The total error involved in a continuous flow measurement system, which is the sum of the errors of each component, is beyond the scope of this discussion. The reader is referred to the list of references at the end of this chapter for such a discussion.

(a) Velocity-Area Method

(i) Introduction

The velocity-area method is the established method of making instantaneous flow measurements in open channels. This method is particularly useful where the flow is too large to permit the installation of a primary flow device. It is also useful for checking the accuracy of an installed primary flow device or other flow measurement method. The basic principle of this method is that the flow (Q) in a channel is equal to the average velocity (V) times the cross-sectional area of the channel (A) at the point where the average velocity was measured, i.e., $Q = V \times A$. The velocity of water or wastewater is determined with a current meter; the area of the channel is calculated by using an approximation technique in conjunction with a series of velocity measurements.

While the velocity-area method is an instantaneous flow measurement method, it can be used to develop a continuous flow measurement system. This is accomplished by making a number of individual measurements at different flow rates and developing a curve or curves that relate water depth (head) to discharge (generally referred to as a rating curve). This curve can then be utilized along with a stage recorder to provide a continuous flow record.

This method requires some experience and good judgement in practice. A complete description of the equipment needed and the basic measurement methods are given in the references (1, 3, 5). Before attampting to use current meters or the velocity-area method, the neophyte investigator should accompany an experienced field professional during the conduct of several such measurements.

The accuracy of this method is directly dependent on the experience of the investigator, the strict adherence to procedures outlined in the references, and the care and maintenance of the equipment used. An experienced field investigator can make flow measurements using current meters that are accurate within a ± 10 percent.

(ii) Current Meters

There are two types of current meters, rotating element and electromagnetic. Conventional rotating element current meters are of two general types--the propeller type with the horizontal axis as in the Neyrpic, Ott, Hoff, and Haskell meters (Figure VI-4), and the cup-type instrument with the vertical axis as in the Price A-A and Pygmy meters (Figure VI-5).

In comparison with horizontal-axis (propeller) meters, the vertical axis (cup type) meters have the following advantages:

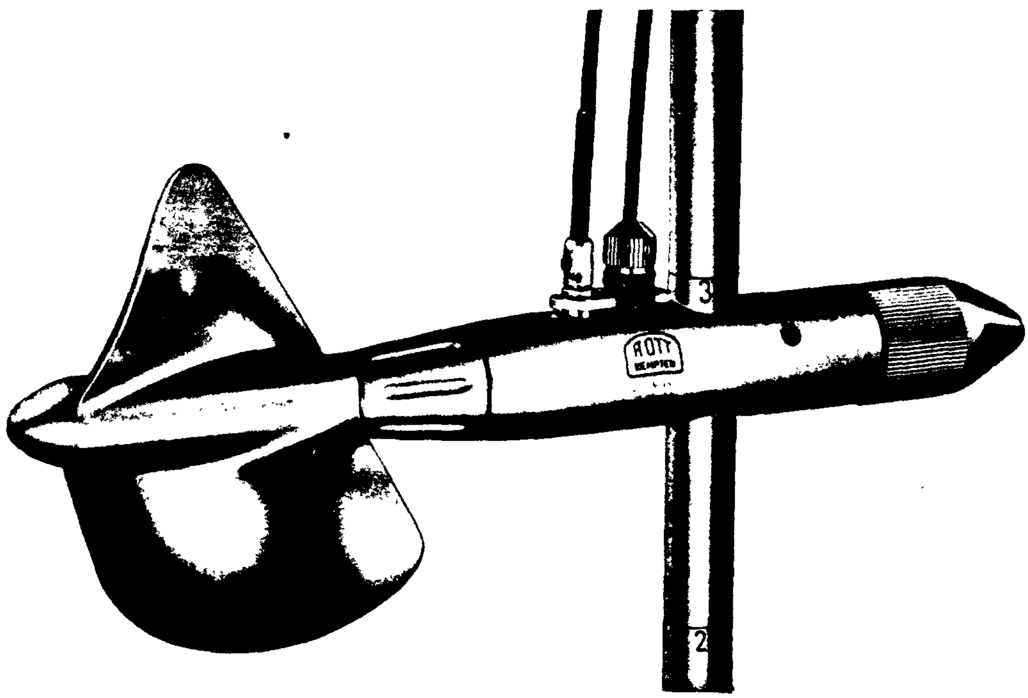
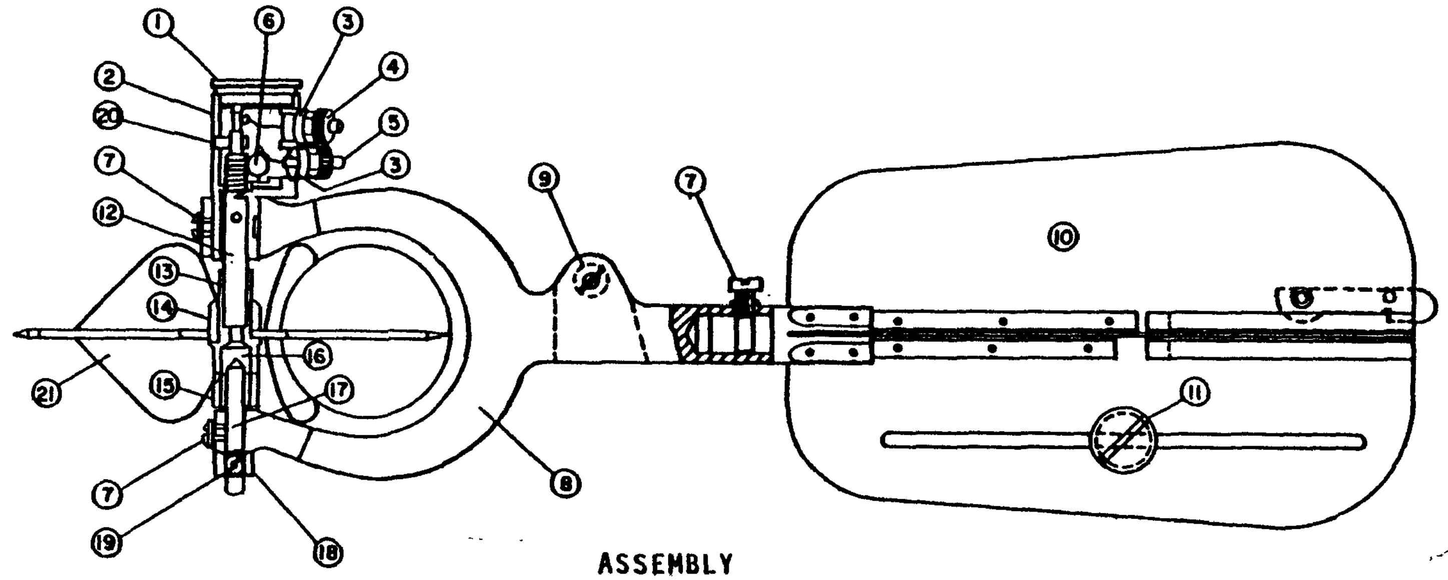


FIGURE VI—4

OTT TYPE HORIZONTAL AXIS CURRENT METER



ASSEMBLY

LIST OF PARTS

1. CAP FOR CONTACT CHAMBER
2. CONTACT CHAMBER
3. INSULATING BUSHING FOR CONTACT BINDING POST
4. SINGLE-CONTACT BINDING POST
5. PENTA-CONTACT BINDING POST
6. PENTA GEAR
7. SET SCREWS
8. YOKE
9. HOLE FOR HANGER SCREW
10. TAILPIECE
11. BALANCE WEIGHT
12. SHAFT
13. BUCKET-WHEEL HUB
14. BUCKET-WHEEL HUB NUT
15. RAISING NUT
16. PIVOT BEARING
17. PIVOT
18. PIVOT ADJUSTING NUT
19. KEEPER SCREW FOR PIVOT ADJUSTING NUT
20. BEARING LUG
21. BUCKET WHEEL

FIGURE VI-5
ASSEMBLY DRAWING OF PRYCE TYPE AA CURRENT METER (10)

(1) Their threshold velocities are usually lower;

(2) The lower pivot bearing operates in an air pocket, so the likelihood of silt intrusion is reduced;

(3) The meter, in particular the Price type, has earned a reputation for sturdiness and reliability under field use.

On the other hand, the propeller and ducted meters have the advantages of being less sensitive than Price meters to velocity components not parallel to the meter axis, being smaller in size, and being more suited for mounting in multiple units.

Current meters are provided with either a direct readout or a method for counting meter revolutions and a rating curve or table that relates meter vane rotation to velocity. Regardless of type, all current meters must receive the best of care during transportation and use to insure accurate velocity measurements. If the cups or blades on a conventional current meter become bent or damaged, the results obtained from the rating curve for the meter will be unreliable. Meter damage may occur because of improper packing and careless handling in transportation. Meters should be transported in substantial wooden or other rigid cases with properly fitted interior supports to prevent movement and damage to the delicate parts. Although all current meters are provided with a rating curve or table, they should be recalibrated periodically. If there is any sign of damage to any of the moving parts of the meter, it should be reconditioned and recalibrated.

(iii) Field Practice

The two principal methods for determining mean velocities in a vertical section with a current meter are the two-point method and the six-tenths-depth method. The two-point method consists of measuring the velocity at 0.2 and then at 0.8 of the depth from the water surface, and using the average of the two measurements. The accuracy obtainable with this method is high and its use is recommended. The method should not be used where the depth is less than two feet and should always be used at depths greater than two and one-half feet.

The six-tenths-depth method consists of measuring the velocity at 0.6 of the depth from the water surface, and is generally used for shallow depths where the two-point method is not applicable.

Current meters should be carefully checked before each measurement. It is good field practice to periodically check each current meter against one known to be in calibration. When making a measurement, the cross-section of the stream or channel should be divided into vertical sections, such that there will be no more than 10 percent, and preferably not more than 5 percent, of the discharge between any two adjacent vertical segments. This, of course, is possible only in open conduits. When making measurements through a manhole, it is rarely possible to obtain more than one section (at the center of the channel, normally).

This particular situation can be a significant source of error. Appropriate velocity measurements are made and the depth is measured at each vertical in the cross-section by using a current meter and wading rod or special sounding line and current meter assembly. Depths and velocities are recorded for each section.

(iv) Area and Flow Calculations

The midsection method and Simpson's parabolic rule are two methods for computing flow from current meter measurements. Both are based on the summation of discharges from each section measured.

If the two-point method of determining mean velocities is used, the formula for computing the discharge of an elementary area by the midsection method is:

$$q = \frac{V_1 + V_2}{2} \left[\frac{(L_2 - L_1) + (L_3 - L_2)}{2} \right] d_2 \qquad (4)$$

Where

L_1, L_2, and L_3 = distance in feet from the initial point, for any three consecutive verticals,

d_2 = water depth in feet at vertical L_2,

V_1 and V_2 = velocities in feet per second at 0.2 and 0.8 of the water depth, respectively, at vertical L_2, and

q = discharge in cubic feet per second through section of average depth d_2.

The formula for computing the discharge for each pair of elementary areas by Simpson's parabolic rule is:

$$q' = \left[\frac{V_a+4V_b+V_c}{3}\right]\left[\frac{a+4b+c}{3}\right]L \qquad (5)$$

Where

a, b, and c = The water depths in feet at three consecutive verticals,

V_a, V_b, and V_c = The respective mean velocities in feet per second at these verticals,

L = The distance in feet between the consecutive verticals (note-this distance is not measured from the initial point as in equation (4)),

q' = The discharge in cubic feet per second for the pair of elementary areas.

Typical current meter notes and computations for the midsection method are shown in Figure VI-6.

(b) Weirs

A weir is an obstruction built across an open channel or in a pipe flowing partially full over which water flows. The water usually flows through an opening or notch, but may flow over the entire weir crest. The theory of flow measurement utilizing weirs involves the release of potential (static) energy to kinetic energy. Equations can be derived for weirs of specific geometry which relate static head to water flow (discharge). Weirs are generally classified into two general categories: broad crested and sharp crested.

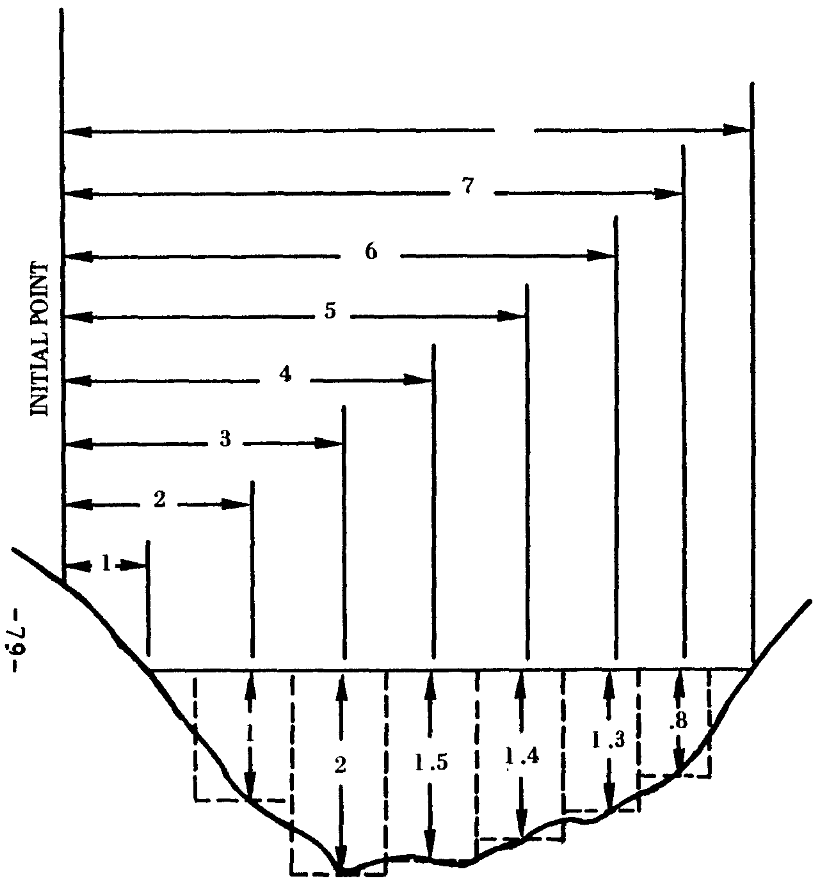


FIGURE VI-6

FIELD NOTES FOR THE MID-SECTION METHOD

River at—

Angle coefficient	Dist. from initial point	Width	Depth	Observation depth	Revolutions	Time in seconds	VELOCITY At point	VELOCITY Mean in vertical	Adjusted for hor. angle or	Area	Discharge
		0.5	0		-	-	-	-		-	-
	2	1.0	1	6	30	47	1.4	1.4		1.0	1.40
	3	1.0	2	2	40	62	1.41	1.34		2.0	2.68
				8	30	52	1.26				
	4	1.0	1.5	2	50	55	1.98	1.75		1.5	2.63
				8	30	43	1.52				
	5	1.0	1.4	6	30	40	1.63	1.63		1.4	2.28
	6	1.0	1.3	6	20	60	.742	.742		1.3	0.96
	7	1.0	0.8	6	15	47	.712	.712		0.8	0.57
	8	0.5	0		-	-	-	-		-	-
		7.0									10.32 cfs

(i) Broad Crested Weirs

Broad crested weirs are normally incorporated into hydraulic projects as overflow structures. However, they can be used to measure flow. Typical broad crested weir profiles are shown in Figure VI-7. The equation for a broad crested weir takes the following form:

$$Q = C\,L\,H^{3/2} \qquad (6)$$

Where

Q = discharge

L = length of weir crest

H = head on weir crest, and

C = coefficient dependent on the shape of the crest and the head.

Values of the coefficient for various shapes of broad crested weirs are given in hydraulic handbooks (6,7). When these structures are used to measure wastewater flow, they should be calibrated using independent flow measurements (refer to techniques later in chapter). A discharge table based on these measurements should be prepared for each installation.

(ii) Sharp Crested Weirs

A sharp crested weir is one whose top edge (crest) is thin or beveled and presents a sharp upstream corner to the water flow. The water flowing over the weir (the weir nappe) does not contact any portion of the downstream edge of the weir, but springs past it. Sharp crested weirs may be constructed in a wide variety of shapes (Figure VI-8). A great deal of work has

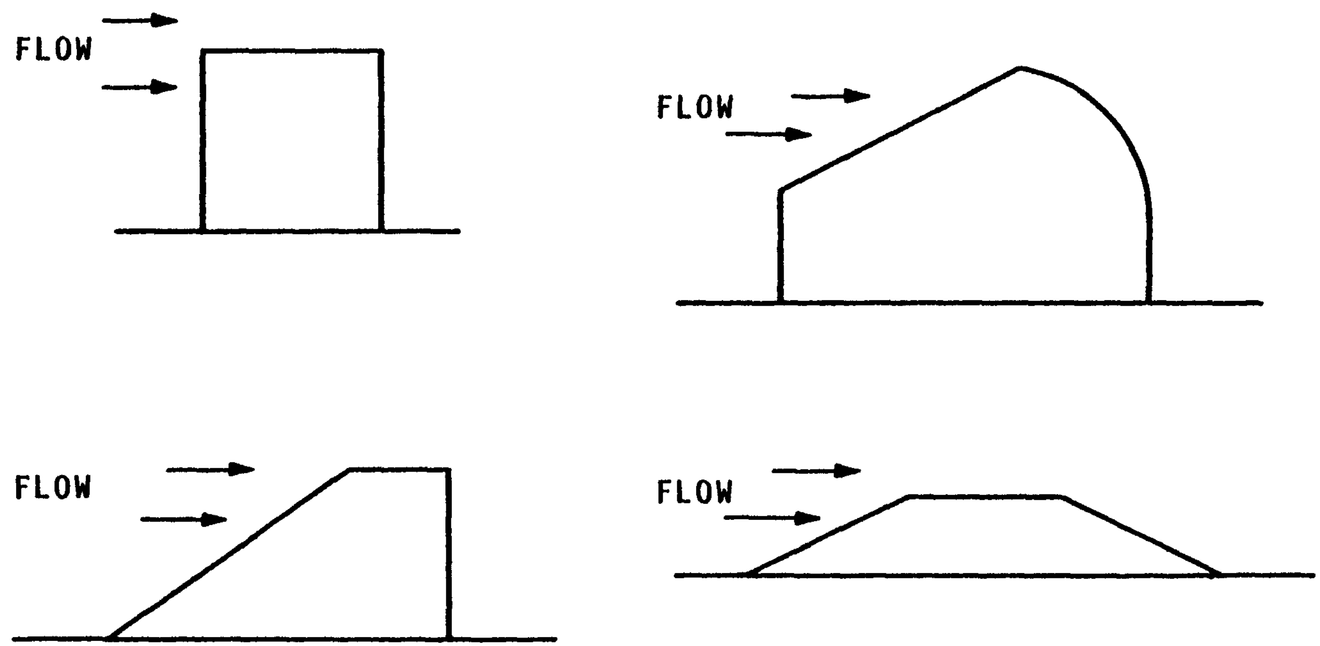


FIGURE VI-7
BROAD-CRESTED WEIR PROFILES (10)

been performed with sharp crested weirs and certain of these weirs are recognized as primary flow devices. If such weirs are constructed and installed in accordance with standard criteria, they can be used in the field without calibration.

The advantages of sharp crested weirs are accuracy and relatively low cost of fabrication and installation. The principal disadvantages are maintenance problems if the wastewater contains corrosive materials, trash or floating solids. These weirs can also cause undesirable settling of solids behind the weirs in the quiescent waters of the weir pool. The nominal accuracy of a standard, properly installed, sharp crested weirs in good condition, is approximately ± five percent (3,8,9,10).

(1) Standard Sharp Crested Weir Shapes

The most commonly encountered sharp crested weirs are the V-notch, rectangular, and Cippoletti. Typically, V-notch weirs are limited to measuring lower flows, while rectangular weirs are used to measure higher flows. When a rectangular weir is constructed with sharp crested sides, it is said to be contracted; when such a weir extends from one side of the channel to the other, and the smooth sides of the channel form the weir sides, the weir is said to be suppressed. Cippoletti weirs combine the features of both the contracted rectangular and V-notch weirs and are used to measure highly variable flows. These weirs and their equations are shown in Figure VI-9.

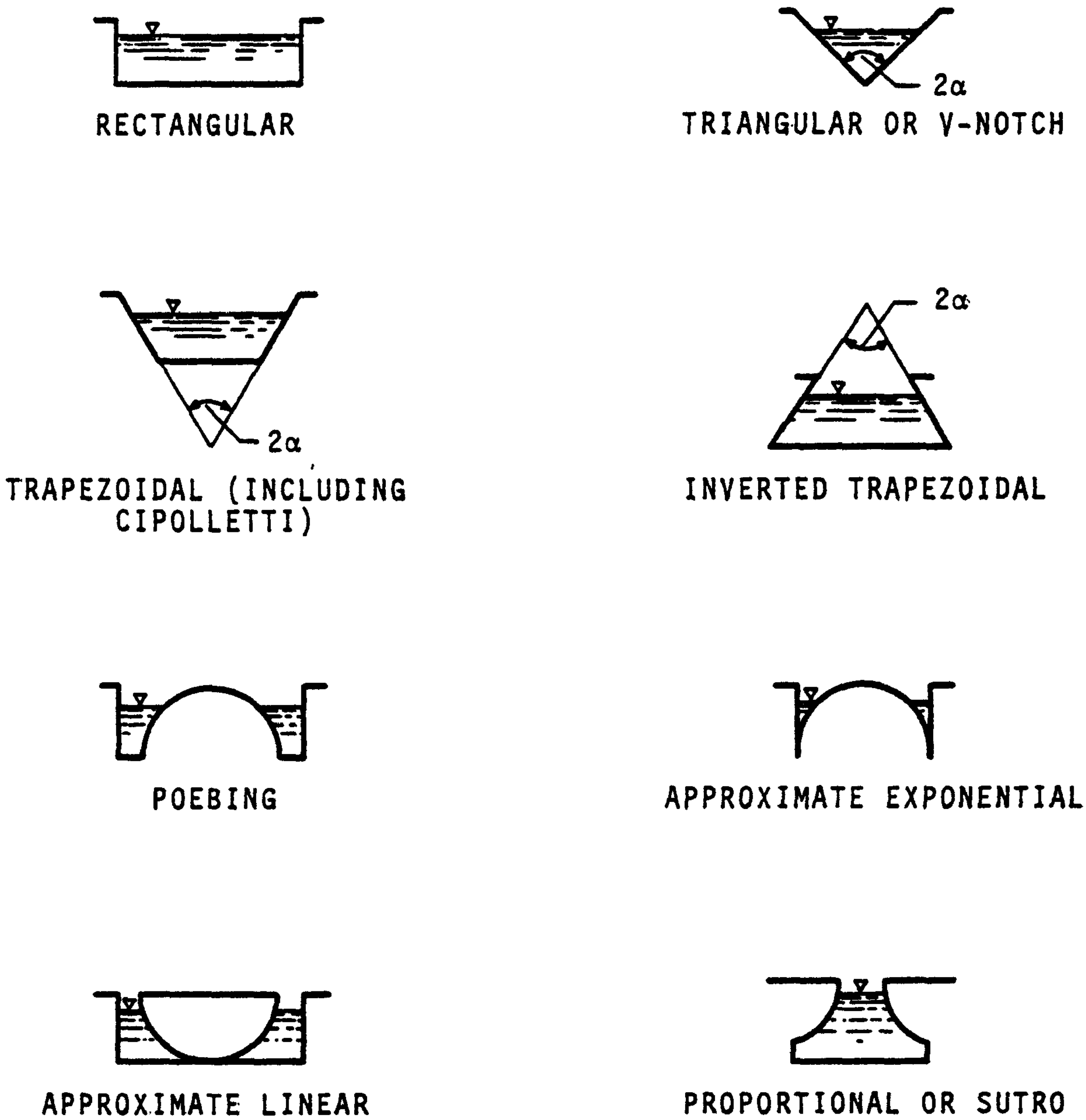


FIGURE VI-8

SHARP CRESTED WEIR PROFILES (10)

$Q = 3.33\,(L-0.2H)H^{3/2}$ (CONT.)

$Q = 3.33\,LH^{3/2}$ (SUP.)

$Q = 3.367\,LH^{3/2}$

90 - $Q = 2.50\,H^{2.50}$

$Q = 2.49\,H^{2.48}$

60 - $Q = 1.443\,H^{2.50}$

45 - $Q = 1.035\,H^{2.50}$

22.5 - $Q = 0.497\,H^{2.50}$

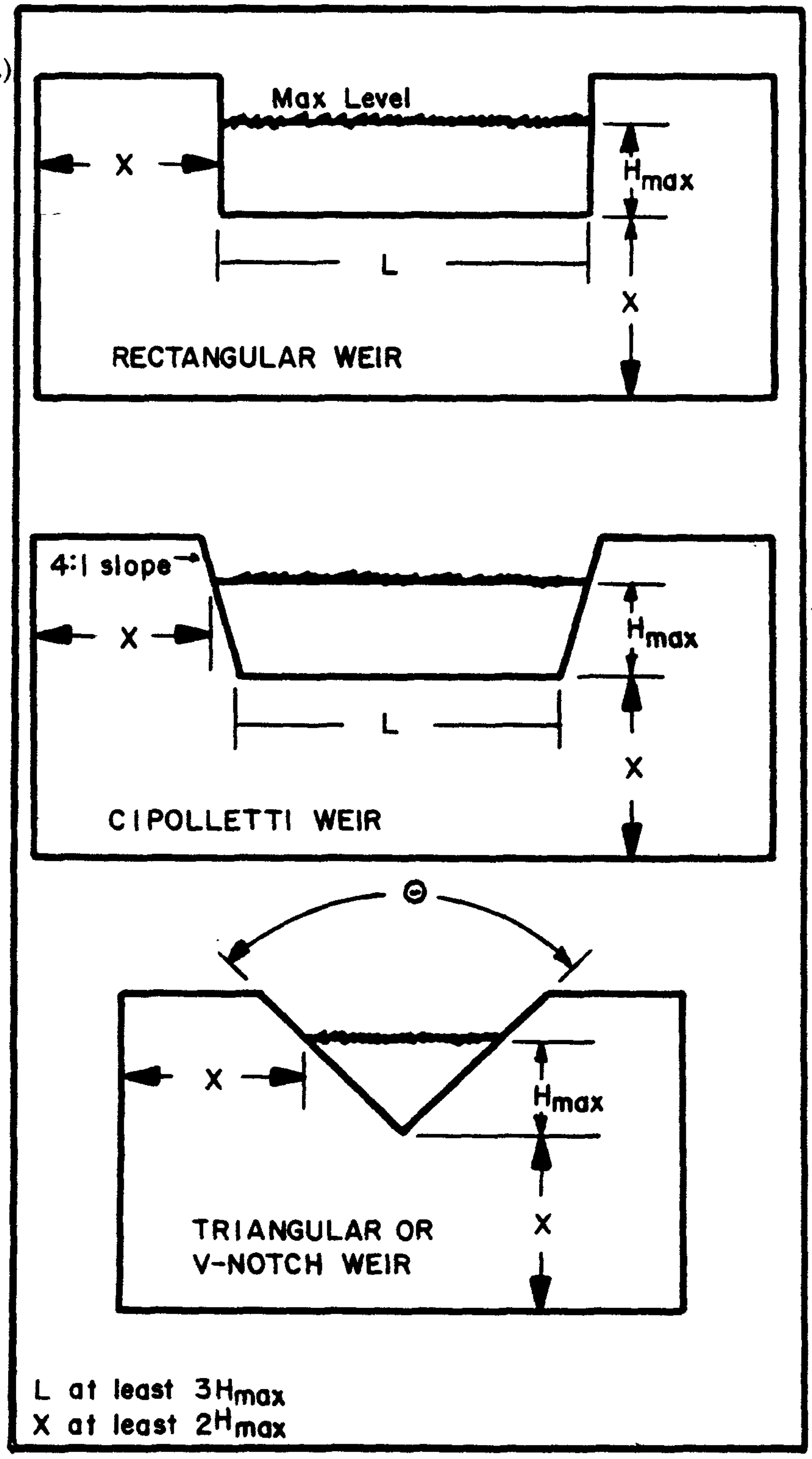


FIGURE VI - 9

THREE COMMON TYPES OF SHARP CRESTED WEIRS AND THEIR EQUATIONS (15)

Occasionally a proportional or "Sutro" weir is encountered in field installations. These weirs are generally used as velocity control devices for municipal sewage treatment plant grit chambers. Flow through these weirs is directly proportional to the head, and the use of sophisticated flow recording equipment is not required. This type of weir is not generally considered to be a primary flow device. The design and construction of these weirs is given in most standard hydraulic handbooks. The remaining sharp crested shapes shown in Figure VI-8 are rarely encountered.

(2) Standard Conditions

The profile of a sharp crested weir is shown on Figure VI-10, along with the standard sharp crested weir nomenclature. Table VI-1 summarizes the standard conditions used for the construction and installation of these weirs.

(3) Field Inspection

All weirs installed by the investigatory agency or those installed by the facility being investigated should be checked for conformance with the standard conditions given in Table VI-1. It should be noted that the dimensions for placement of the weir in the flow channel and the point at which the head is measured are in terms of the maximum head that can be measured for a particular weir. In actual practice, the maximum head expected

TABLE VI-I
STANDARD CONDITIONS FOR SHARP-CRESTED WEIRS
(See Figure VI-10)

1. The weir should be installed so that it is perpendicular to the axis of flow. The weir plate should be level. The sides of rectangular contracted weirs should be truly vertical. V-notch weir angles must be cut precisely.

2. The thickness of the weir crest should be less than 0.1 inch. The downstream edges of the crest or notch should be relieved by chamfering at a 45° angle (or greater) if the weir plate is thicker.

3. The distance from the weir crest to the bottom of the approach channel should not be less than twice the maximum weir head and never less than one foot. The distance from the sides of the weir to the sides of the approach channel should be no less than twice the maximum head and never less than one foot (except for the suppressed rectangular weir).

4. The nappe (overflow sheet) should touch only the upstream edges of the weir crest or notch.

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

6. The measurement of head on the weir should be made at a point at least four (4) times the maximum head upstream from the weir crest.

7. The cross-sectional area of the approach channel should be at least eight times that of the nappe at the weir crest for a distance of 15-20 times the maximum head upstream from the weir. The approach channel should be straight and uniform upstream from the weir for the same distance.

8. If the criteria in Items 3 and 7 are not met, the velocity of approach corrections will have to be made.

9. Heads less than 0.2 feet (2.4 inches) should not be used under ordinary field conditions, because the nappe may not spring free of the crest.

10. All of the flow must pass through the weir and no leakage at the weir plate edges or bottom should be present.

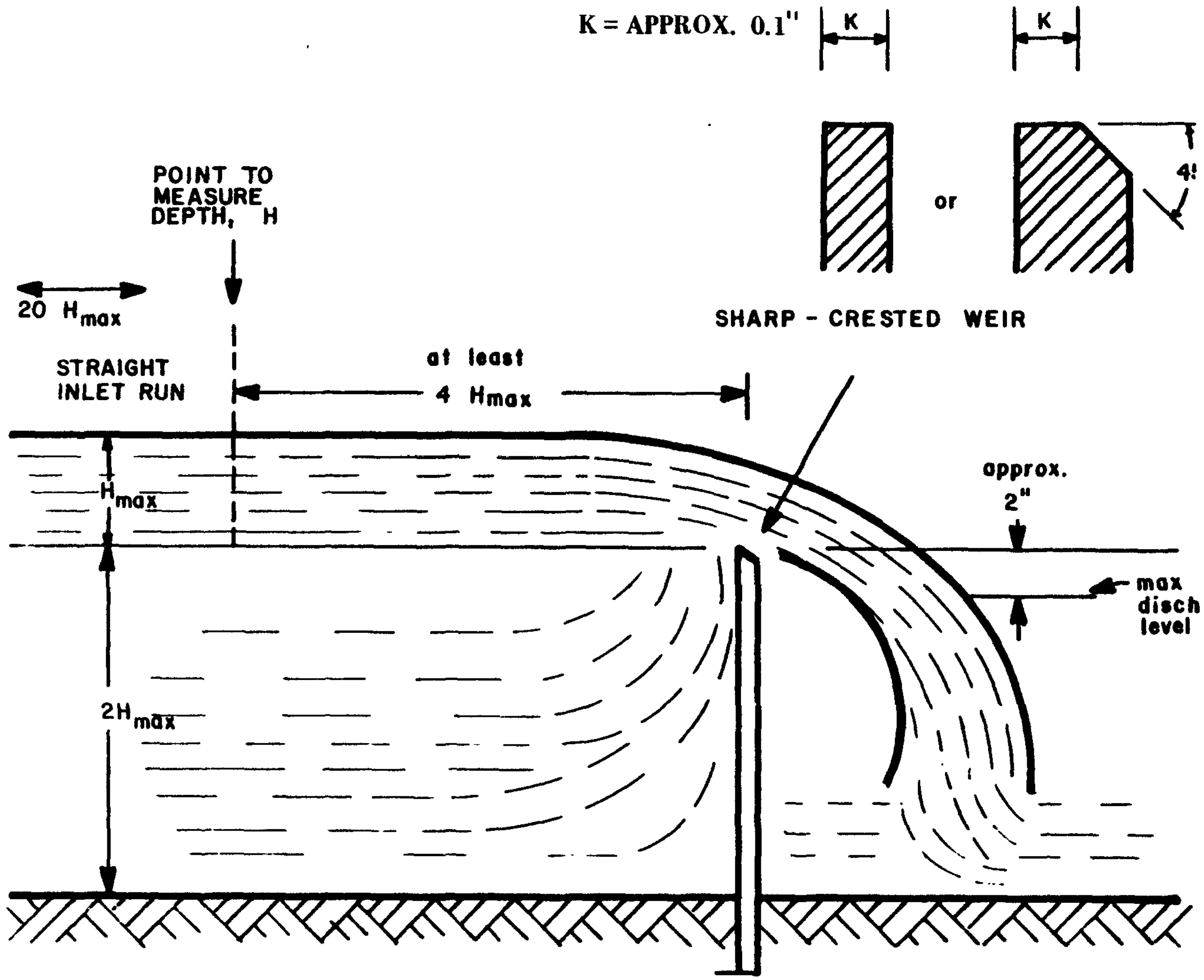


FIGURE VI-10
SHARP CRESTED WEIR NOMENCLATURE (15)

during the measurement period should be used. Any deviation from standard conditions should be noted on the field sheet.

Any trash, slime, or debris should be removed from the weir crest before proceeding with a flow measurement. The head on a sharp crested weir can be measured by knowing the depth of the weir notch from the top of the weir and measuring the head approximately four times the maximum head upstream using the top of the weir as a reference. The head is the difference in these two measurements. A carpenter's level, straight edge and framing square are invaluable for making this measurement. An engineering level and level rod can also be used. The carpenter's level can also be used to plumb the weir. A measuring tape is necessary to check the dimensions of weirs.

A problem frequently encountered when using suppressed rectangular weirs is the lack of ventilation of the weir nappe. When the weir nappe is not ventilated it will stutter or jump erratically. In permanent installations, provisions should be made for a vent to maintain atmospheric pressure behind the nappe. In field installations, flexible plastic tubing can be used for this purpose.

The pool upstream of the weir should be quiescent with approach velocities much less than one foot per second. Generally, excessive approach velocities are not a problem with V-notch weirs. However, if all the standard conditions outlined in Table VI-1 are not met or some other condition is encountered, it is possible to encounter excessive approach velocities when using rectangular weirs. When approach velocities exceed one foot per second, a correction should be applied to the observed measurements. One method of making such a correction is given in Table VI-2.

(4) Use of Weir Tables

The most convenient method for translating weir head measurements to flow is a set of weir tables. The use of weir formulas and curves in the field is not recommended, since this is a cumbersome procedure and leads to numerous computational errors. Excellent weir tables are included in the USDI Water Measurement Manual (1) and the Stevens Water Resources Data Book (11). The explanatory material accompanying these tables should be read thoroughly before they are used. In some cases, flow data are tabulated which are outside the useful range for a particular weir.

(c) Flumes

Flumes are widely used to measure wastewater flow in open channels. They are particularly useful for measuring large flowrates.

(i) Parshall Flumes

The Parshall flume is the most widely used open channel, primary flow device for wastewater flow measurement. Parshall flumes are available in a wide range of sizes and flow capacities, and are available to fit almost any open-channel, flow measuring application. These flumes operate with relatively low head loss, are insensitive to the velocity of approach, and

TABLE VI-2

SHARP CRESTED RECTANGULAR WEIRS
VELOCITY OF APPROACH CORRECTION

1. Compute the Velocity of Approach from: V = Q/A

   Where: V = Velocity of Approach in feet per second
   Q = Discharge in cfs (from weir formula)
   A = Cross-sectional area of approach channel

2. Enter the following table with the velocity of approach (V) and head (H) and obtain the coefficient (C) from the table:

v	h	$h^{3/2}$	H											
			0.2	0.4	0.6	0.8	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0
0.4	0.0025	0.0002	1.014	1.007	1.004	1.004	1.004	1.002	1.002	1.002	1.001	1.001	1.001	1.001
.5	.0039	.0003	1.027	1.013	1.009	1.006	1.006	1.004	1.003	1.002	1.002	1.002	1.001	1.001
.6	.0056	.0005	1.037	1.019	1.013	1.009	1.008	1.005	1.004	1.003	1.003	1.002	1.002	1.002
.7	.0076	.0007	1.050	1.026	1.017	1.013	1.011	1.007	1.006	1.004	1.004	1.003	1.003	1.002
.8	.0099	.0010	1.064	1.033	1.022	1.016	1.014	1.009	1.007	1.006	1.005	1.004	1.003	1.003
.9	.0126	.0014	1.082	1.042	1.029	1.021	1.018	1.012	1.009	1.007	1.006	1.005	1.005	1.004
1.0	.0155	.0019	1.098	1.051	1.034	1.027	1.022	1.015	1.011	1.009	1.007	1.006	1.005	1.005
1.1	.0188	.0025	1.122	1.062	1.041	1.031	1.026	1.017	1.013	1.011	1.009	1.008	1.007	1.006
1.2	.0224	.0033	1.141	1.072	1.049	1.037	1.031	1.021	1.016	1.013	1.011	1.009	1.008	1.007
1.3	.0263	.0041	1.163	1.084	1.057	1.043	1.036	1.024	1.018	1.015	1.012	1.011	1.009	1.008
1.4	.0305	.0051	1.186	1.096	1.036	1.050	1.041	1.028	1.021	1.017	1.014	1.012	1.011	1.010
1.5	.0350	.0064	1.208	1.109	1.075	1.057	1.047	1.032	1.024	1.019	1.016	1.014	1.012	1.011
1.6	.0398	.0079	1.225	1.122	1.084	1.065	1.052	1.035	1.027	1.022	1.018	1.016	1.014	1.012
1.7	.0449	.0095	1.254	1.135	1.093	1.071	1.059	1.040	1.031	1.025	1.021	1.018	1.016	1.014
1.8	.0504	.0111	1.277	1.149	1.104	1.080	1.065	1.045	1.034	1.027	1.023	1.020	1.017	1.016
1.9	.0561	.0132	1.308	1.165	1.115	1.089	1.072	1.049	1.038	1.030	1.026	1.022	1.019	1.017
2.0	.0622	.0154	1.335	1.181	1.126	1.097	1.079	1.055	1.042	1.034	1.028	1.025	1.02'	1.019
2.1	.0686	.0179	1.363	1.197	1.137	1.106	1.087	1.060	1.046	1.037	1.031	1.027	1.024	1.021
2.2	.0752	.0206	1.391	1.213	1.149	1.118	1.094	1.065	1.050	1.039	1.034	1.029	1.026	1.023
2.3	.0822	.0235	1.420	1.231	1.161	1.124	1.102	1.071	1.054	1.044	1.037	1.032	1.028	1.025
2.4	.0895	.0268	1.449	1.248	1.176	1.134	1.110	1.077	1.059	1.047	1.040	1.034	1.030	1.027
2.5	.0972	.0303	1.480	1.266	1.187	1.145	1.119	1.083	1.063	1.051	1.043	1.037	1.033	1.029
2.6	.1051	.0340	1.511	1.285	1.200	1.155	1.128	1.088	1.068	1.055	1.046	1.040	1.035	1.032
2.7	.1133	.0381	1.542	1.303	1.213	1.166	1.137	1.095	1.073	1.059	1.050	1.043	1.038	1.034
2.8	.1219	.0426	1.573	1.322	1.228	1.178	1.146	1.100	1.078	1.063	1.053	1.046	1.041	1.036
2.9	.1307	.0472	1.606	1.341	1.242	1.189	1.155	1.108	1.083	1.067	1.057	1.049	1.043	1.039
3.0	.1399	.0524	1.637	1.361	1.256	1.199	1.165	1.115	1.088	1.072	1.061	1.053	1.046	1.041

3. The correct flow then = CxQ

   For example: V = 1 fps, Q = 6.31 cfs, H = 1 ft, then C = 1.022 and corrected Q = 1.022 x 6.31 = 6.45 cfs.

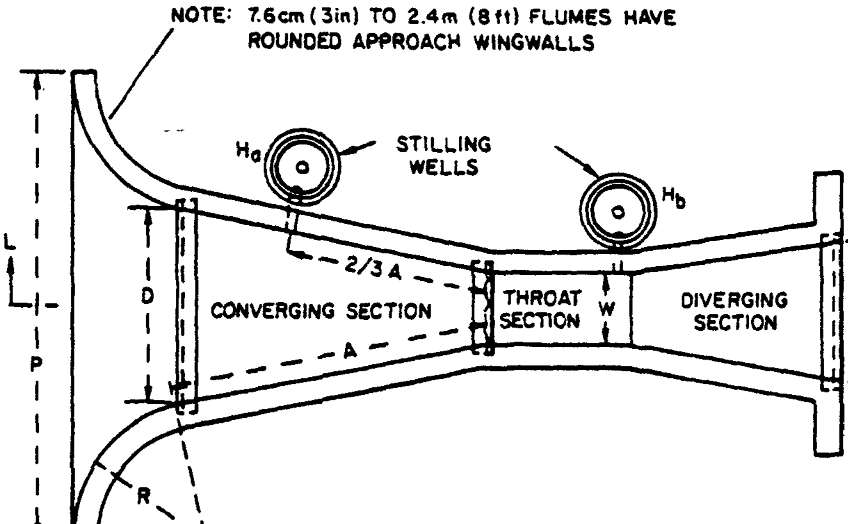
Note: Method and Table from Water Measurement Manual (1).

are self-cleaning in most applications. The accuracy of a Parshall flume in a good field installation is recognized to be approximately $\pm$ 5 percent (3,8,9,10).

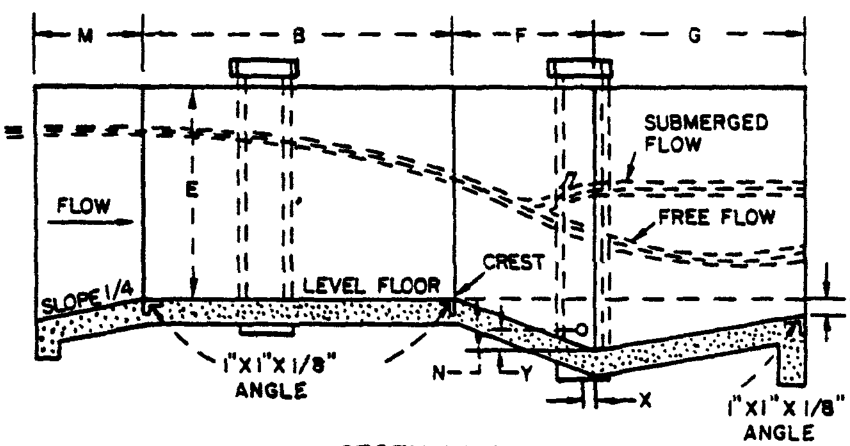
(1) Parshall Flume Structure and Nomenclature

A Parshall flume consists of a converging section, throat section, and diverging section, as shown in Figure VI-11. The size of the flume is determined by the width of the throat section. All dimensions for various Parshall flume sizes are given in the USDI Water Measurement Manual (1). Tolerances for Parshall flume dimensions, as given by this manual, are $\pm$ 1/64 inch for the throat width and $\pm$ 1/32 for the remaining sections.

The head (Ha) is measured at the point 2/3 of the length of the converging section (wingwall), upstream from the throat section. During conditions of free-flow, this is the only measurement required to determine flow. Occasionally, back water exists which causes some flooding of the diverging section of the flume. In those cases, it is necessary to check the head at an additional location (Hb) between the throat and diverging sections as shown in Figure VI-11. The ratio of the measured heads (Hb/Ha) is known as the submergence. Flumes can be used to accurately measure flow without correction until the following limits are reached for each indicated size of flume:



PLAN



SECTION L-L

LEGEND:

W	Size of flume, in inches or feet.
A	Length of side wall of converging section.
2/3A	Distance back from end of crest to gage point.
B	Axial length of converging section.
C	Width of downstream end of flume.
D	Width of upstream end of flume.
E	Depth of flume.
F	Length of throat.
G	Length of diverging section.
K	Difference in elevation between lower end of flume and crest.
N	Depth of depression in throat below crest.
R	Radius of curved wing wall.
M	Length of approach floor.
P	Width between ends of curved wing walls.
X	Horizontal distance to H_b gage point from low point in throat.
Y	Vertical distance to H_b gage point from low point in throat.

FIGURE VI-11

CONFIGURATION AND STANDARD NOMENCLATURE FOR PARSHALL FLUME (10)

Hb/Ha (%)	Flume Size
50	1, 2, 3 inches
60	6, 9 inches
70	1-8 feet
80	8-50 feet

When the submergence exceeds 95%, the flume is not usable for flow measurement purposes. A detailed description of submergence corrections is given in the USDI Water Measurement Manual (1).

Although the Parshall flume is relatively insensitive to approach velocities, influent flow should be evenly distributed across the channel as it enters the converging section. These flumes should not be installed immediately downstream from transition sections in order to assure such an even distribution. As a practical matter, a uniform channel should be provided upstream from the flume as far as is practical. A minimum distance of 15-20 channel widths or pipe diameters is recommended.

(2) Field Inspection and Flow Measurement

During compliance sampling inspections, flumes should be inspected to determine if entrance conditions provide a uniform influent flow distribution, the flume dimensions conform to those given in the USDI Water Measurement Manual (1), the flume converging throat section flow is level, and the throat section walls are vertical. Useful tools for checking Parshall flumes include a carpenter's level, framing square and tape. The flume should be closely examined to determine if it is discharging freely. If there is any question about free discharge, the downstream head (Hb) should be measured. A staff gage is useful for making head measurements. Any problems observed during the inspection should be noted on the field sheet.

A set of flume tables is necessary for calculating flows. Both the USDI Water Measurement Manual (1) and the Stevens Water Resources Data Book (11) contain a complete set of tables. The explanatory material accompanying these tables should be read and understood before they are used. In many cases, tabulated flow values are given for measured heads that are not within the usable measurement range.

The most frequently encountered problems with facility installed flumes include:

- Poor entrance and exit hydraulics that cause poor flow distribution or submergence,
- Improper installation, out of level, throat sidewalls not vertical, improper throat dimensions, or
- Improper location of head measuring points.

(ii) Palmer-Bowlus Flumes

Palmer-Bowlus flumes depend upon existing conduit slopes and a channel contraction (provided by the flume) to produce supercritical flow. Several different shapes of this flume are in use and are shown in Figure VI-12. These flumes are being increasingly used as primary flow devices for measuring flow in circular conduits. Their principal advantage lies in simplicity

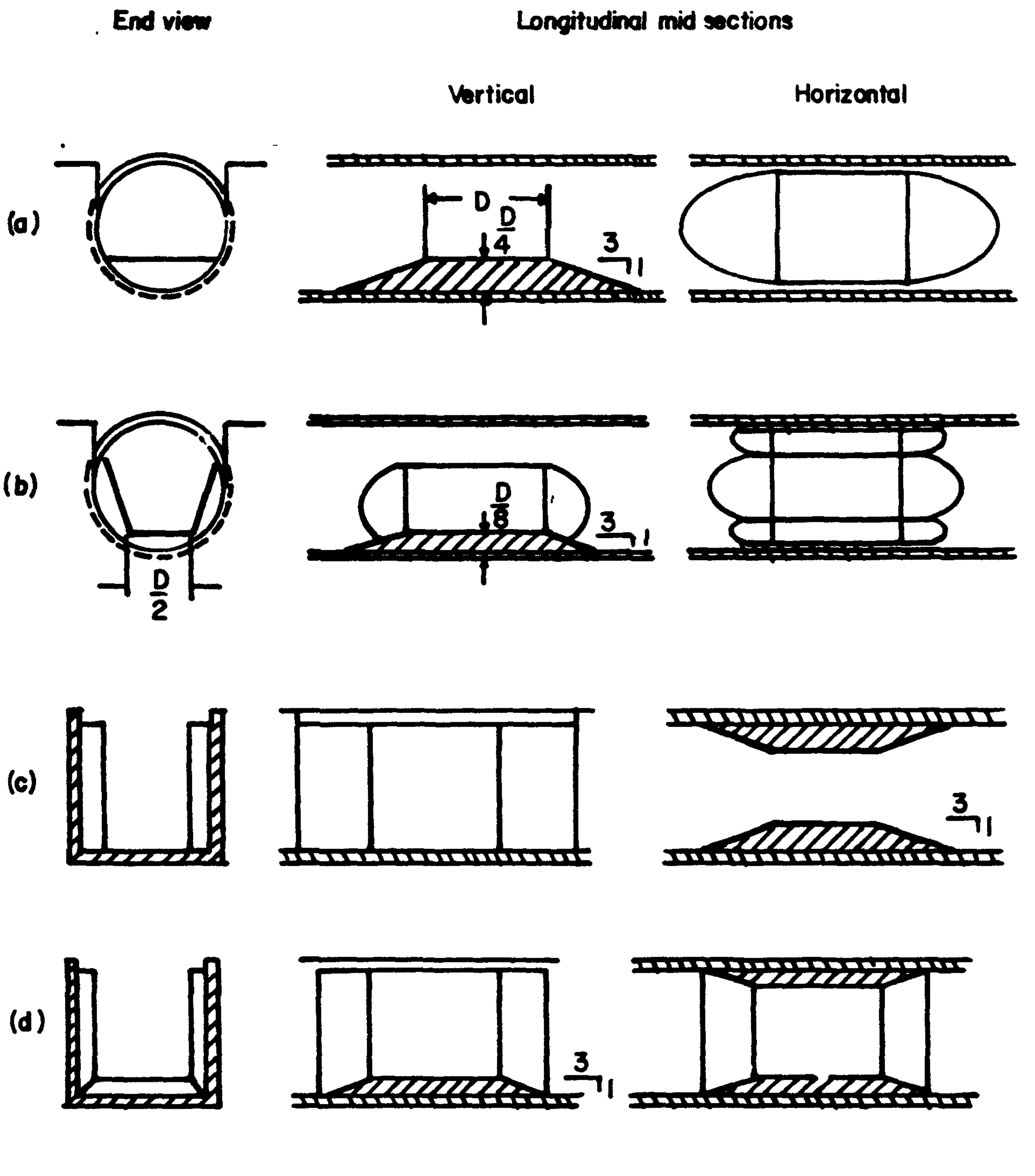


FIGURE VI - 12
VARIOUS CROSS - SECTIONAL SHAPES OF PALMER-BOWLUS FLUMES (15)

of construction and ease of installation through manholes. There is a paucity of data on the accuracy of this flume, although one reference reports that the performance of these flumes can be theoretically predicted to within 3 percent when used in U-shaped channels, so long as the upstream depth does not exceed 0.9D (where D is the diameter of the circular conduit leading into the flume) (3). A complete description of the theory of these flumes and their use is given in the references (3,10,12).

(iii) Other Flumes

A number of other flumes have been developed to solve specific flow measurement problems, including cutthroat, trapezoidal with bottom slope, critical depth, H, etc. (1,3,9,10). These flumes are seldom used for wastewater flow measurement purposes.

(d) Open Channel Flow Nozzles

The open channel flow nozzle is a combination of flume and sharp crested weir. Unlike sharp crested weirs, these devices operate well with wastewaters that contain high concentrations of suspended solids; however, they have poor head recovery characteristics. These devices are designed to be attached to the end of a conduit, flowing partially full, and must have a free fall discharge. Open channel flow nozzles are designed so there is a predetermined relationship between the depth of liquid within the nozzle and the flowrate. The Kennison nozzle has a cross-sectional shape such that the relationship between the flowrate and head is linear. These nozzles require a length of straight conduit immediately upstream from the nozzle, and the slope of the conduit must be within the limits of the nozzle calibration specifications. The profile of a parabolic and a Kennison type open flow nozzle is shown in Figure VI-13.

Open flow nozzles are factory calibrated and are ordinarily supplied as part of a flow measurement system. Calibration and installation data for each nozzle should be supplied by/or obtained from the manufacturer. The accuracy of these devices is reported to be often better than ± 5 percent of the indicated flow (10).

(e) Slope - Area Method

The slope-area method consists of using the slope of the water surface, in a uniform reach of channel, and the average cross-sectional area of that reach, to estimate the flowrate of an open channel. The flowrate is estimated from the Manning formula:

$$Q = 1.486/n \; AR^{2/3}S^{1/2} \qquad (7)$$

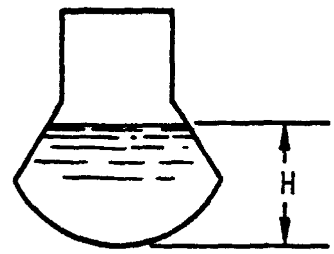
Where

Q = discharge in cfs

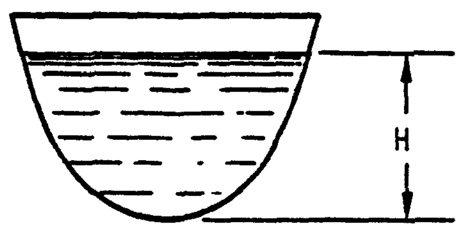
A = average area of the wetted channel cross-section in square feet

R = average hydraulic radius of the wetted channel in feet. (Average cross-sectional area divided by the average wetted perimeter.)

S = slope of the water surface, and



a. Linear (Kennison) Nozzle Profile ($Q \propto H$)



b. Parabolic Nozzle Profile ($Q \propto H^2$)

FIGURE VI-13
OPEN CHANNEL FLOW NOZZLE PROFILES (10)

n = a roughness factor depending on the character of the channel lining.

A long straight section of channel should be used for this estimation technique. Values of n may be obtained from hydraulic handbooks (6,7). It should be remembered that the slope in the equation is of the water surface and not the channel invert.

(f) Measurement by Floats

A crude but simple method of estimating flow in an open channel is by using floats. A straight reach of channel with uniform slope is necessary for this method. Three cross-sections are used. The purpose of the middle section is to provide a check on the velocity measurements between the beginning and end sections. The velocity is obtained by measuring the length of the reach and timing the passage of the float with a stopwatch. The flowrate is obtained by multiplying the resulting velocity by the average cross-sectional area of the section of channel used. Since surface velocities are higher than the average velocity of the channel, the velocities obtained by the float method should be corrected using the empirical factors presented in the USDI Water Measurement Manual (1).

4. Closed Conduit Flow Measurements

Closed conduit flow measurement systems present a special challenge to the field investigator. These systems, once installed, generally cannot be visually inspected, nor can the hydraulic responses of the systems be as easily evaluated as is the case with most open channel systems. One procedure for verifying the accuracy of closed conduit flow measurement systems in the field is to make an independent flow measurement at an acceptable location. The constant injection dilution technique, or the velocity area method, both of which were described earlier in this section, would be acceptable for this purpose. Another procedure includes inducing known pressures or voltages on the sensing system and verifying recorder response.

Some of the most commonly used closed conduit primary flow devices are presented and discussed briefly in this section. Several flow estimation techniques are also presented. The measurement accuracies quoted in this section apply only to the specific method or to the primary flow device being discussed. The total error involved in continuous flow measurement systems, which is the sum of the errors of each component, is beyond the scope of this discussion. The reader is referred to the list of references at the end of this chapter for such a discussion.

(a) Venturi Meter

The Venturi meter is one of the most accurate primary flow devices for measuring flowrates in pipes. Basically, the Venturi meter is a pipe segment (Figure VI-14) consisting of a converging section, a throat and a diverging section. A portion of the static head is converted in the throat section to velocity head. Thus, the static head in the throat of the Venturi is lower than in the converging section. This head differential is proportional to the flowrate. One of the advantages of the Venturi meter is that it has a low head loss.

The meter must be installed downstream from a straight and uniform section of pipe, at least 5-20 pipe diameters, depending upon the pipe diameter to throat diameter ratio. The accuracy of the Venturi is affected by changes in density, temperature, pressure, viscosity, and by pulsating flow. When used to measure flow in wastestreams containing high concentrations of suspended solids, special provisions must be made to insure that the pressure measuring taps are not plugged. The typical accuracy of Venturi meters is given at 1 to 2 percent (3,8,10).

There are a number of variations of the Venturi meter, generally called flow tubes, presently being used (10). Their principle of operation is similar to that of the Venturi, and they will not be discussed.

(b) Orifice Meters

The Orifice meter is one of the oldest flow measuring devices. Flow is measured by the difference in static head caused by the presence of the orifice plate. The differential pressure is related to the flowrate. The thin plate orifice is the most common variety, and consists of a round hole in a thin plate, which is generally clamped between a pair of flanges at a point in a pipe. The most common orifice plate consists of a sharp 90-degree corner on the downstream edge. Some orifice plates have a rounded edge facing into the direction of flow, and perhaps a short tube with the same diameter as the orifice

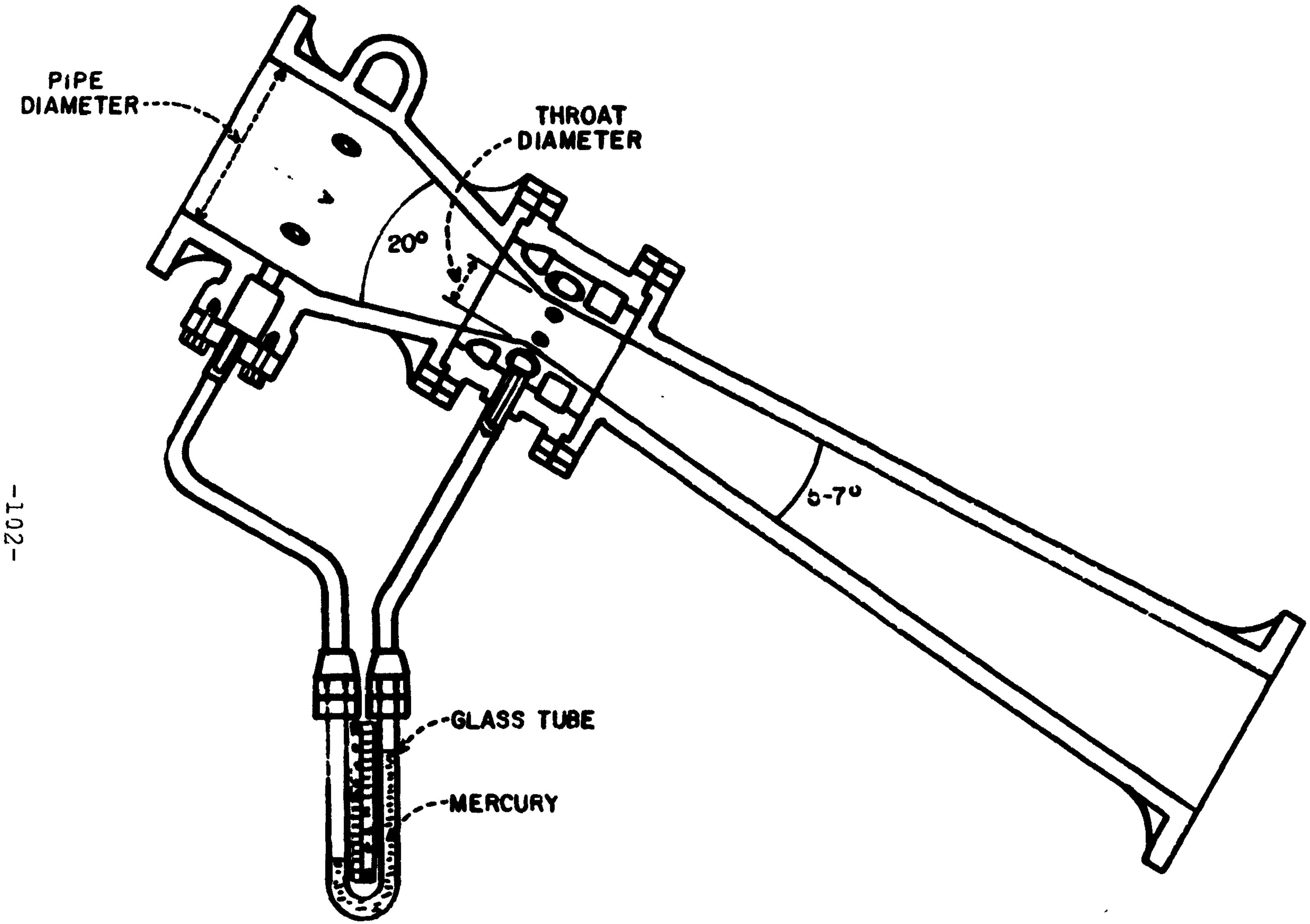


FIGURE VI - 14
VENTURI METER (15)

opening facing downstream. Pressure measuring taps are located upstream and downstream of the orifice plate to facilitate differential pressure measurements. Only one pressure tap is required if the orifice plate is located at the end of a pipe discharging at atmospheric pressure.

Orifice meters are of limited usefulness in measuring flowrates in wastestreams containing high suspended solids, since solids tend to accumulate upstream of the orifice plate. Orifice meters produce the highest head loss of any of the closed conduit flow devices, and are quite sensitive to upstream disturbances. It is not uncommon to need from 40 to 60 pipe diameters of straight pipe upstream of the installation. They can be quite accurate, 0.5%, although their usable range is small (5:1) unless rated in place (10).

(c) Flow Nozzles

A flow nozzle may consist of designs that approach the Venturi meter in one extreme and the orifice meter in the other. The basic principle of operation is the same as that of the Venturi meter. Typically, a flow nozzle has an entrance section and a throat, but lacks the diverging section of the Venturi (a typical flow nozzle is shown in Figure VI-15). A major advantage of the flow nozzle over the Venturi meter is that the flow nozzle can be installed between pipe flanges. They are intermediate in head loss between the Venturi and orifice meters. Like orifice meters, they are sensitive to upstream disturbances and 20 or more pipe diameters of straight pipe are required upstream from

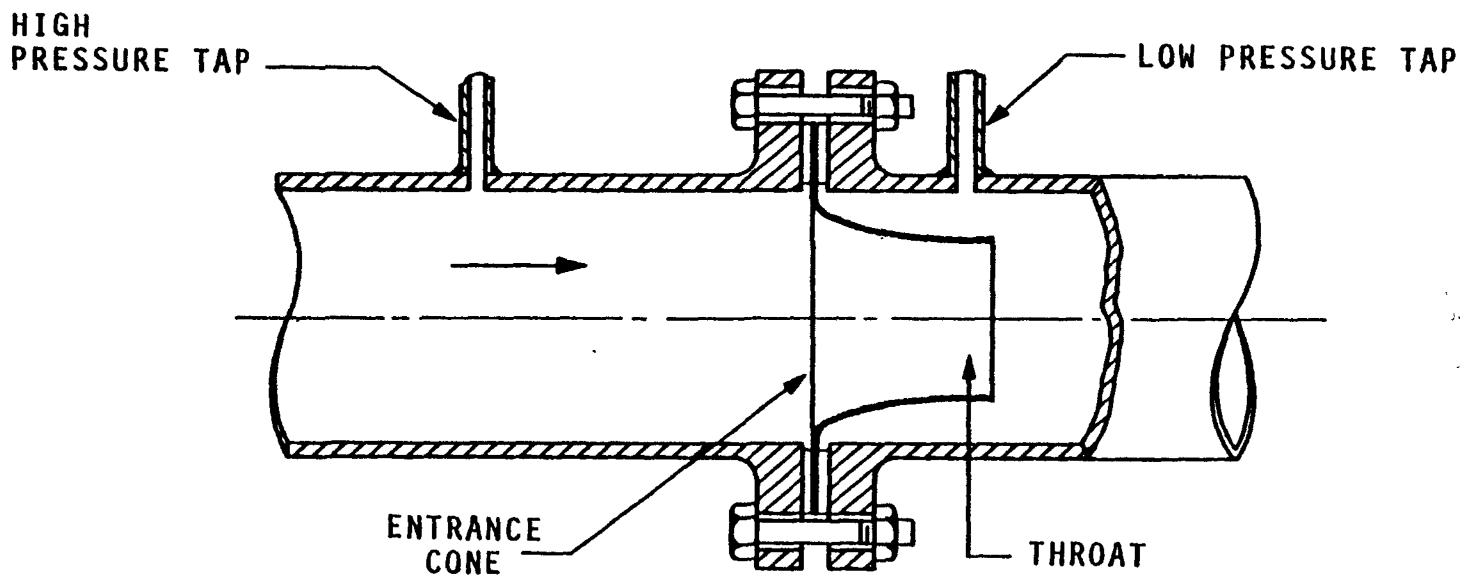


FIGURE VI-15
FLOW NOZZLE IN PIPE (10)

the flow nozzle for successful operation. Some flow nozzles are not recommended for use in measuring flowrates in high suspended solids wastestreams. Flow nozzle accuracies can approach those of Venturi meters (10).

(d) Electromagnetic Flowmeter

The electromagnetic flowmeter operates according to Faraday's Law of Induction. Namely, the voltage induced by a conductor moving at right angles through a magnetic field will be proportional to the velocity of the conductor through the field. In the electromagnetic flowmeter, the conductor is the liquid stream to be measured and the field is produced by a set of electromagnetic coils. A typical cross-section of an electromagnetic flowmeter is shown in Figure VI-16. The induced voltage is subsequently transmitted to a converter for signal conditioning.

Electromagnetic flowmeters have many advantages; they are very accurate (within ± 1 percent of full scale), have a wide flow measurement range, introduce a negligible head loss, have no moving parts, and the response time is rapid (10). However, they are expensive. Buildup of grease deposits or pitting by abrasive wastewaters can cause error. Regular checking and cleaning of the electrodes is necessary.

(e) Acoustic Flowmeters

Acoustic flowmeters operate on the basis of the difference in transit time between upstream and downstream directed sonic pulses. The difference in transit time is caused by the velocity

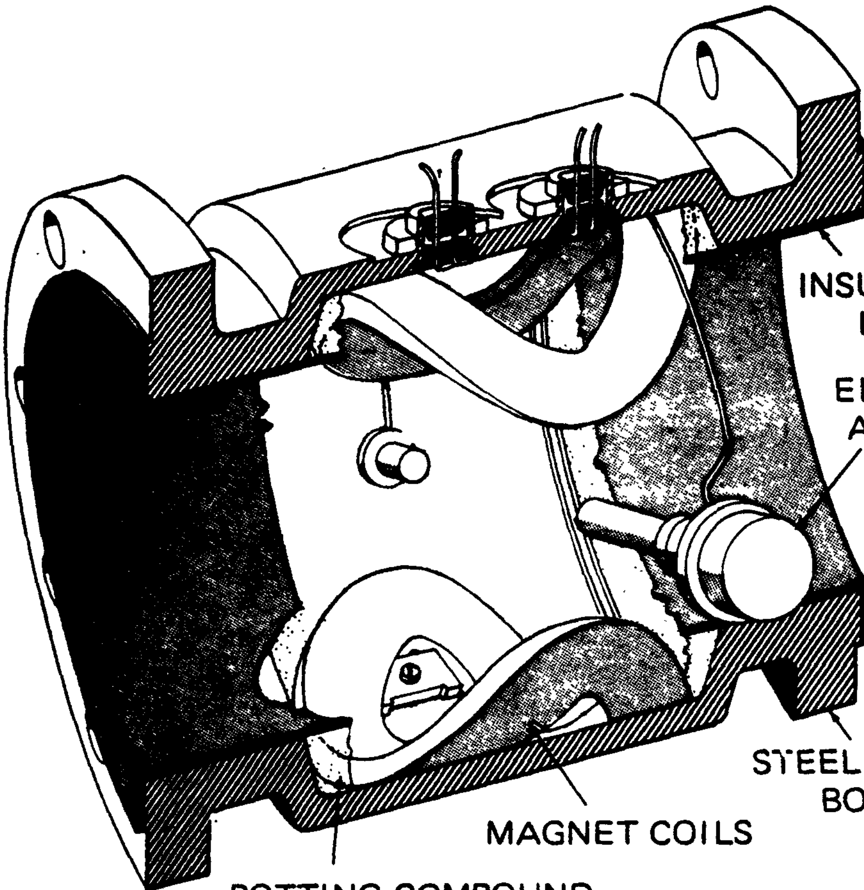


FIGURE VI-16
ELECTROMAGNETIC FLOW METER (15)

of the water in the conduit. This time lag is proportional to the velocity, and hence the flowrate. Manufacturers employ various methods to take advantage of this principle. Some flowmeters use the acoustic doppler principle. According to the manufacturers, accuracies of one percent of full scale are achievable (3,10).

(f) Trajectory Methods

A number of methods for estimating the flowrate from the end of a pipe with a free discharge are available. All of these methods, whether theoretically or empirically derived, have in common the measurement of the issuing stream coordinates (Figure VI-17) in the vertical and horizontal directions. It should be emphasized that all of these methods are estimates--none of them is accurate enough for NPDES compliance purposes.

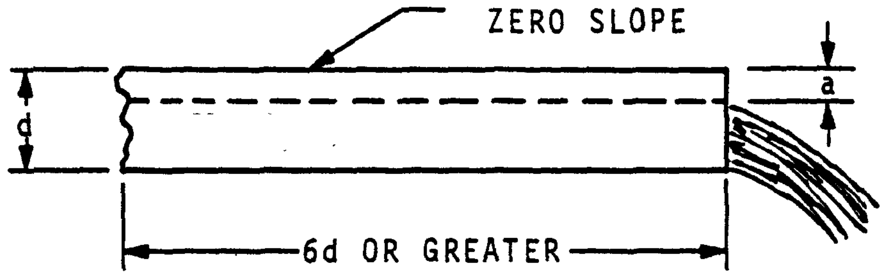
The California pipe method (Figure VI-17) uses a straight level section of pipe at least six pipe diameters in length as the primary flow device. The pipe must have a free discharge and must be only partially full. The distance from the crown of the pipe to the water surface (a) at the end of the pipe is related to the flowrate by the following equation:

$$Q = 8.69 \ (1-a/d)^{1.88} \ d^{2.48} \quad (8)$$

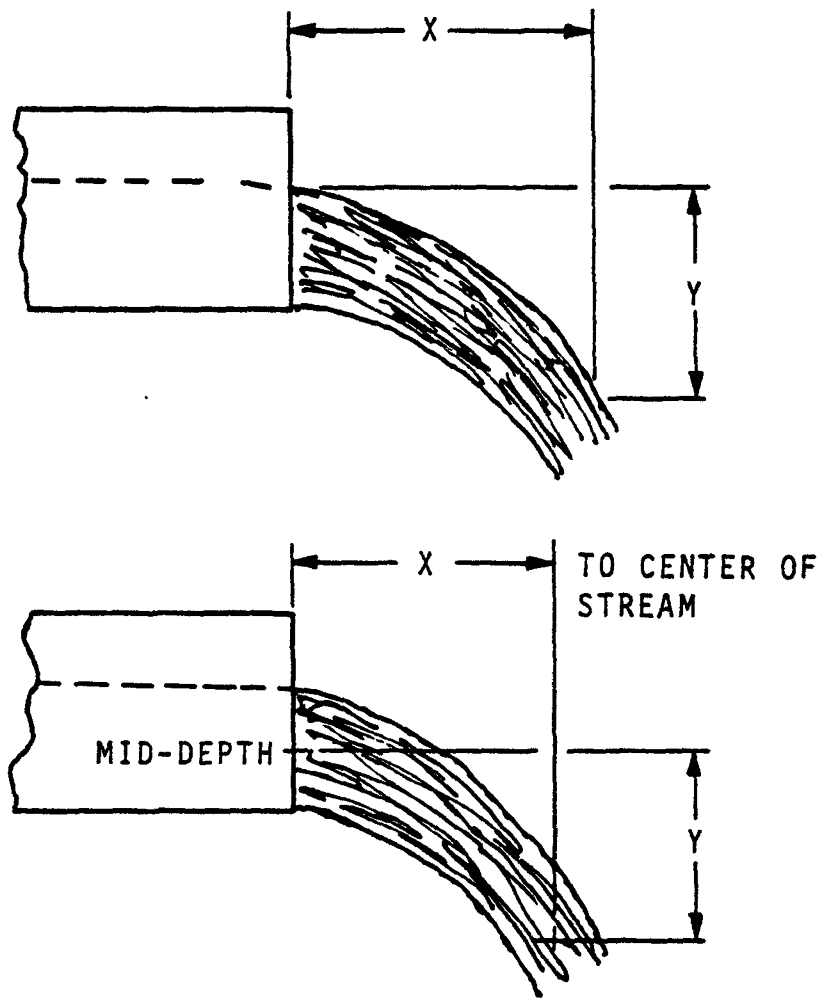
Where

Q = flowrate in cfs

d = diameter of pipe in feet



a. CALIFORNIA PIPE METHOD



b. PURDUE METHODS

FIGURE VI-17
TRAJECTORY METHODS (10)

It is recommended that a/d be restricted to values greater than 0.5. The experiments from which the above equation was derived used pipe diameters of from 3 to 10 inches (1,3,10).

The Purdue method involves the measurement of the horizontal (x) and the vertical (y) coordinates of the issuing stream at the end of a pipe, and the use of a set of curves that empirically relate these coordinates to the discharge. Curves for pipes 2, 3, 4, 5, and 6 inches are available (1,3).

If the water jet is treated as a freely falling body with constant horizontal velocity, the following equation results (3):

$$Q = A(g/2y)^{0.5}\, X \qquad (9)$$

Where

Q = flowrate in cfs

A = cross-sectional area of the issuing stream

X & Y = horizontal and vertical trajectory coordinates measured as shown in Figure VI-17

(g) Pump Curves

Pump curves, supplied by pump manufacturers, have been used extensively to estimate flows in closed conduits. Where pumps are operated on a cyclic basis, a timer hooked to a pump gives an estimate of the total flow. However, there are so many variables present in pump and piping installations that it is likely that most pump curves are not accurate enough for NPDES compliance purposes. When pump curves are used for NPDES compliance wastewater flow measurements, these curves should be verified by making an independent flow measurement.

(h) Use of Water Meters

Municipal and process water meters have been used to estimate industrial wastewater flows when all other methods have failed or are not usable. The use of water meters should be viewed with caution. All consumptive uses of water must be accounted for and subtracted from the meter readings. Also, water meters are often poorly maintained and their accuracy is questionable. When water meters have to be used, the municipality or utility that has responsibility for the meters should be consulted as to when the meters were last serviced or calibrated.

REFERENCES - SECTION VI

1. "Water Measurement Manual", Second edition, revised, United States Department of Interior, Bureau of Reclamation, 1974. Available from the U.S. Government Printing Office, Washington, D.C. 20402.

2. Smoot, C. W., "Orifice Bucket for Measurement of Small Discharges from Wells", Water Resources Division Bulletin, Illinois Water Survey, Champaign, Illinois, November 1963.

3. "A Guide to Methods and Standards for the Measurement of Water Flow", U.S. Department of Commerce, National Bureau of Standards, NBS Special Publication 421, May 1975.

4. "Fluorometric Facts, Flow Measurements", Monograph, 1976. Available from the Turner Designs Company, 2247A Old Middlefield Way, Mountainview, California 94043.

5. "Discharge Measurements at Gaging Stations", Hydraulic Measurement and Computation, Book I, Chapter 11, United Stated Department of Interior, Geological Survey, 1965.

6. King, H. W., and Brater, E. F., "Handbook of Hydraulics", Fifth Edition, McGraw-Hill, New York (1963).

7. Davis, C. V., and Sorenson, K. E., "Handbook of Applied Hydraulics", Third Edition, McGraw-Hill, New York (1969).

8. American Society of Testing Materials, "1976 Annual Book of ASTM Standards", Part 31 - Water, American Society of Testing Materials, 1916 Rose Street, Philadelphia, Pennsylvania 19103.

9. "Use of Weirs and Flumes in Stream Gaging", Technical Note No. 117, World Meteorological Organization, Technical Note No.117, United Nations, New York, N.Y. 1971.

10. "Sewer Flow Measurement A State-Of-The-Art Assessment", Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268.

11. "Stevens Water Resource Data Book", Second Edition, Leopold Stevens, Inc., P.O. Box 688, Beaverton, Oregon.

12. Wells, E.A. and Gotaas, H.B., "Design of Venturi Flumes in Circular Conduits", American Society of Civil Engineers, 82, Proc. Paper 928, April 1956.

13. "Fluid Meters--Their Theory and Application", Sixth Edition, 1971, American Society of Mechanical Engineers, New York, N.Y.

14. "Field Manual for Research in Agricultural Hydrology", Agricultural Handbook No. 224, Soil and Water Conservation Research Division, Agricultural Research Service, United States Department of Agriculture, Washington, D.C. 20402.

15. "Handbook for Monitoring Industrial Wastewater", Technology Transfer Publication, United States Environmental Protection Agency, 1973.

SECTION VII - QUALITY ASSURANCE

A. Purpose

The purpose of this section is to provide guidelines and procedures for establishing a field quality assurance program. It is intended to serve as a resource document for the design of quality assurance programs and to provide detailed operational procedures for certain measurement processes that can be used directly in implementing the field quality assurance program.

A quality assurance program for NPDES monitoring should address all elements from sample collection to data reporting, and at the same time allow flexibility.

B. Policy and Objectives

Quality assurance is necessary at each organizational level to insure high quality data. Each organization should have a written quality assurance policy. This policy should be distributed so that all organizational personnel know the policy and scope of coverage.

The objectives of quality assurance are to produce data that meet user requirements in terms of completeness, precision, accuracy, representativeness, and comparability. For compliance sampling inspections, an estimate of the resources required to support such a quality assurance program is 15 percent. It should be recognized, however, that many of these elements are already an integral part of the compliance monitoring program, but may not be specifically identified as quality assurance techniques.

To administer a field quality assurance program, the objectives must be defined, documented and issued for all activities that affect the quality of the data. Such written objectives are needed because they:

1. Unify the thinking of those concerned with quality assurance.
2. Stimulate effective action.
3. Provide an integrated, planned course of action.
4. Permit comparison of completed performance against stated objectives.

Precision and accuracy represent measures of data quality and data must be representative of the condition being monitored. Data available from numerous agencies and private organizations should be in consistent units and should be corrected to the same standard units to allow comparability of data among groups.

In addition, certain key assignments for carrying out the various operational aspects of the program should be made within the unit engaged in NPDES monitoring and monitoring support activities. The quality assurance plan should clearly identify the individuals and their responsibilities and document the unit's operating procedures.

C. Elements of a Quality Assurance Plan

Elements of a recommended quality assurance program, including necessary training, are contained in Part VI of the "Model State Water Monitoring Program"(1). Detailed specifications for laboratory quality assurance procedures are contained in EPA's "Handbook For Analytical Quality Control in Water and Wastewater"(2) and in "Quality Assurance Handbook For Air Pollution Measurement Systems"(3).

D. Quality Assurance In Sample Collection

Control checks should be performed by the inspector during the actual sample collection. These checks are used to determine the performance of the sample collection system. In general, the most common errors produced in monitoring are usually caused by improper sampling, poor preservation, or lack of adequate mixing during compositing and testing. The following checks will help the inspector and QA Coordinator to determine when the sample collection system is out-of-control:

1. Duplicate Samples

At selected stations on a random time frame, collect duplicate samples using the field equipment installed at the site. If automatic sampling equipment is not installed at the site, collect duplicate grab samples. This will provide a proficiency check for precision.

2. Split Samples

Aliquots of the collected sample may be given to the permittee, if requested, as a check on the permittee's laboratory procedures. Differences between agency and permittee's results can then be evaluated and the cause of the difference usually identified. Having the permittee analyze known performance samples will aid to identify discrepancies in the permittee's analytical techniques and procedures.

3. Spiked Samples

Known amounts of a particular constituent should be added to an actual sample or blanks of deionized water at concentrations where the accuracy of the test method is satisfactory. The amount added should be coordinated with the laboratory. This method will provide a proficiency check for accuracy of the field sampling procedures.

4. Sample Preservative Blanks

Acid and other chemical preservatives can become contaminated after a period of use in the field. The sampler should add the same quantity of preservative to a sample of distilled water as normally would be added to the wastewater sample. This preservative blank is sent to the laboratory for analysis and the blank is subtracted from the sample value. Liquid chemical preservatives should be changed every two weeks or sooner if contamination occurs.

5. Precision, Accuracy, and Control Charts

A minimum of seven sets each of comparative data for duplicates, spikes, split samples and blanks should be collected to define acceptable estimates of precision and accuracy criteria for data validation. See EPA's "Handbook for Analytical Quality Control in Water and Wastewater," (2) or W.J. Youden's "Statistical Techniques for Collaborative Tests," (4) for discussions of precision, accuracy, and quality control charts and their calculations.

E. Quality Assurance Procedures for Field Analysis & Equipment Calibration and Documentation Plan

A calibration plan should be developed and implemented for all field analysis test equipment and calibration standards to include: calibration and maintenance intervals; listing of required calibration standards; environmental conditions requiring calibration; and a documentation record system.

Written calibration procedures should be provided for all measuring and test equipment. A procedure should:

1. Specify where the procedure is applicable, e.g. free residual chlorine by amperometric titration at power plant cooling water effluents.
2. Provide a brief description of the calibration procedure, a copy of the manufacturer's instructions is usually adequate.

(c) List calibration standards, reagents, and accessory equipment required.

(d) Specify the documentation, including an example of the format used in the field quality assurance log book.

Field equipment should be labeled to indicate the calibration date, when calibration expires and when maintenance is due.

Table VII-1 summarizes quality assurance procedures for field analyses generally conducted duri[illegible] [illegible]ES compliance sampling inspections.

TABLE VII - 1

QUALITY ASSURANCE PROCEDURES FOR FIELD ANALYSIS AND EQUIPMENT

Parameter	General	Daily	Quarterly
1. Dissolved Oxygen			
a) Membrane Electrode	Enter the make, model, serial and/or ID number for each meter in a log book.	i) Calibrate meter using manufacturer's instructions or Winkler-Azide method.	Check instrument calibration and linerarity using a series of at least three dissolved oxygen standards.
	Report data to nearest 0.1 mg/l.	ii) Check membrane for air bubbles and holes. Change membrane and KCl if necessary.	
		iii) Check leads, switch contracts etc. for corrosion and shorts if meter pointer remains offscale.	
b) Winkler-Azide method	Record data to nearest 0.1 mg/l.	Duplicate analysis should be run as a precision check. Duplicate values should agree within ±0.2 mg/l.	
2. pH - Electrode Method	Enter the make model, serial and/or ID number for each meter in a log book.	i) Calibrate the system against standard buffer solutions of known pH value e.g., 4,7 and 9 at the start of a sampling run.	Take all meters to the laboratory for maintenance, calibration and quality control checks.

TABLE VII - 1
(Continued)

	Parameter	General	Daily	Quarterly
2.	pH (Continued)		ii) Periodically check the buffers during the sample run and record the data in the log sheet or book.	
			iii) Be on the alert for erratic meter response arising from weak batteries, cracked electrode, fouling, etc.	
			iv) Check response and linearity following highly acidic or alkaline samples. Allow additional time for equilibration.	
			v) Check against the closest reference solution each time a violation is found.	
			vi) Rinse electrodes thoroughly between samples and after calibration.	
3.	Conductivity	Enter the make, model, serial and/or ID number for each meter in a log book.	i) Standardize with KCl standards having similar specific conductance values to those anticipated in the samples. Calculate the cell constant using two different standards.	i) Take all meters to lab for maintenance, calibration and quality contntrol checks.

TABLE VII - 1
(Continued)

	Parameter	General	Daily	Quarterly
3.	Conductivity (Continued)		Cell Constant= Standard Value/ Actual Value Specific Conductance= Reading X Cell Constant	ii) Check temperature compensation. iii) Check date of last platinizing and replatinizing if necessary. iv) Analyze NBS or EPA reference standard and record actual vs. observed readings in the log.
			ii) Rinse cell after sample to prevent carryover.	
4.	Residual Chlorine Amperometric Titration	Enter the make, model, ID and/or serial number of each titration apparatus in a log book. Report results to nearest 0.01 mg/l.	Refer to instrument manufacturer's instructions for proper operation and calibration procedures.	Biweekly: Return instrument to lab for maintenance and addition of fresh, standardized reagents.
5.	Temperature a) Manual	Enter the make, model, serial number and/or ID number and temperature range for	i) Check for air spaces or bubbles in the column, cracks, etc. Compare with a known source if available.	Biweekly: Check at two temperatures against a NBS or equivalent thermometer. Enter data in log book.

TABLE VII - 1
(Continued)

Parameter	General	Daily	Quarterly
5. Temperature (Continued)	each thermometer. All standardization shall be against a NBS or NBS calibrated thermometer. Readings shall agree within ±1°C If enforcement action is anticipated, calibrate the thermometer before and after analysis. All data shall be read to the nearest 1°C. Report data beween 10 - 99°C to two significant figures.		Temperature readings shall agree within ±1°C or the thermometer shall be replaced or recalibrated.
		Initially & Biannually:	Accuracy shall be determined thoroughout the expected working range 0° to 50°C. A minimum of three temperatures within the range should be used to verify accuracy. Preferable ranges are: 5 - 10°, 15 - 25°, 35 - 45°C.
b) Thermistors; Thermographs etc.	Enter the make, model, serial and/or ID number of the instrument in a log book. All standardization shall be against a NBS or NBS calibrated thermometer. Reading should agree within ±1°C. If enforcement action is anticipated refer to the procedure listed in 5(a) above.	Check thermistor or sensing device for response and operation according to the manufacturer's instructions. Record actual vs. standard temperature in log book. Initially & Biannually:	Accuracy shall be determined throughout the expected working range 0° to 50°C. A minimum of three temperatures within the range should be used to verify accuracy. Preferable ranges are: 5 - 10°, 15 - 25°, 35 - 45°C.

TABLE VII - 1
(Continued)

	Parameter	General	Daily	Quarterly
6.	Flow Measurement	Enter the make, model, serial and/or ID number of each flow measurement instrument in a log book.	Install the device in accordance with the manufacturer's instuctions and with the procedures given in Section VI of this manual.	Annually: Affix record of calibration NBS, manufacturer or other, to the instrument log.
7.	Automatic Samplers	Enter the make, model, serial and/or ID number of each sampler in a log book.		Check intake velocity vs. head (minimum of three samples), and clock time setting vs. actual time interval.

F. Parameters Requiring Special Precautions

1. Organics

Preservatives, holding times, sampling procedures, and sample aliquots or volume for specific organic analysis should be determined prior to each survey after consultation with appropriate lab personnel. The survey leader should provide, if possible, the following information: raw products; chemical processes; and types of wastewater treatment. This will assist the laboratory in making their recommendations regarding sampling and handling procedures. Normally, a one to four liter grab sample, collected in a glass jar with a teflon or cleaned aluminium foil lined screw cap, will provide a sufficient sample volume. Normally, if biological activity cannot be stopped by addition of a preservative, samples should be iced until analysis and received in the laboratory within 24 hour.

2. Acidity - Alkalinity

Compositing of grab samples for acidity, alkalinity, and suspended solids analysis should not be done if a waste discharge varies outside the pH range specified in NPDES permits. Mixing acid grab samples with neutral or basic grab samples changes the acidity-alkalinity relationship and results in a composite sample which may not be representative of the discharge during the compositing period. The acid-base reaction may also dissolve a portion of the inorganic solids. Thus, a discharge which varies outside the pH range specified in the NPDES permit should be analyzed for acidity, alkalinity and suspended solids on an individual "grab" sample basis.

3. Miscellaneous Parameters

Based on present knowledge, the following parameters should not be collected using automatic samplers but should be preserved at the time of sample collection whether the sample is a grab sample or a composite of grab samples.

(a) Dissolved Parameters

Samples should be membrane filtered at the time of collection, if at all possible, and composited if necessary under acidified conditions. In any case, preservation should not be performed until after filtration.

(b) Mercury, Total

Samples for mercury analysis must be acidified at the time of collection. The addition of potassium dichromate will help stabilize dissolved mercury(5).

(c) Phenolics and Cyanides

Simple phenolic compounds and free cyanide may be significantly degrade if not preserved at the time of sample collection. If the sample contains residual chlorine, it is also necessary to dechlorinated the sample prior to preservation. Standard Methods (6) recommends the use of ferrous sulfate as a dechlorination agent for phenolics and ascorbic acid for cyanide.

(d) Sulfide and Sulfite

Table 2 of EPA's "Methods For Chemical Analysis Of Water & Wastes" (7) lists cooling to 4°C as the preservative for sulfide, while there is no acceptable preservative listed for sulfite and the sample must be analyzed at the time of collection.

REFERENCES - SECTION VII

1. "Model State Water Monitoring Program", U.S. Environmental Protection Agency, Office of Water and Hazardous Materials, Monitoring and Data Support Division, Washington, D.C. EPA-440/9-74-002, (1975).

2. "Handbook For Analytical Quality Control In Water And Wastewater Laboratories", U.S. Environmental Protection Agency, Technology Transfer, Washington, D.C. (6/72).

3. "Quality Assurance Handbook For Air Pollution Measurement Systems", Vol. I. Principles, U.S. Environmental Protection Agency, Office of Research and Development, Environmental Monitoring & Support Lab, Research Triangle Park, N.C., EPA-600/9-76-005, (3/76).

4. Youden, W.J., "Statistical Techniques For Collaborative Tests", Assn. of Official Analytical Chemists, Washington, D.C. (1973).

5. El-Awady, AA., R.B. Miller & M.J. Carter," Automated Method for the Determination of Total and Inorganic Mercury in Water and Wastewater Samples", Anal. Chem., Vol. 48, No. 1, 110-116, Jan. 1976.

6. <u>Standard Methods For The Examination Of Water And Wastewater</u>, 14th Ed., APHA, Washington, D.C. (1976).

7. "Methods For Chemical Analysis Of Water And Waste, 1974", U.S. Environmental Protection Agency, Office of Technology Transfer, Washington, D.C. (1974).

SECTION VIII - CHAIN OF CUSTODY PROCEDURES

A. Introduction

As in any other activity that may be used to support litigation, regulatory agencies must be able to provide the chain of possession and custody of any samples which are offered for evidence or which form the basis of analytical test results introduced into evidence in any water pollution case. It is imperative that written procedures be available and followed whenever evidence samples are collected, transferred, stored, analyzed, or destroyed. The primary objective of these procedures is to create an accurate written record which can be used to trace the possession and handling of the sample from the moment of its collection through analysis and its introduction as evidence.

A sample is in someone's "custody" if:

1. It is in one's actual physical possession; or
2. It is in one's view, after being in one's physical possession, or
3. It is in one's physical possession and then locked up so that no one can tamper with it; or
4. It is kept in a secured area, restricted to authorized personnel only.

B. Survey Planning and Preparation

The evidence gathering portion of a survey should be characterized by the conditions stipulated in the permit or the minimum number of samples required to give a fair representation of the wastewater quality. The number of samples and sampling locations, determined prior to the survey, must satisfy the requirements for NPDES monitoring or for establishing a civil or criminal violation.

A copy of the study plan should be distributed to all survey participants in advance of the survey date. A pre-survey briefing is helpful to reappraise survey participants of the objectives, sampling locations and chain of custody procedures that will be used.

C. Sampling Collection, Handling and Identification

1. It is important that a minimum number of persons be involved in sample collection and handling. Guidelines established in this manual for sample collection, preservation and handling should be used. Field records should be completed at the time the sample is collected and should be signed or initialed, including the date and time, by the sample collector(s). Field records should contain the following information:

(a) unique sample or log number;

(b) date and time;

(c) source of sample (including name, location & sample type);

(d) preservative used;

(e) analyses required;

(f) name of collector(s);

(g) pertinent field data (pH, DO, Cl residual, etc.);

(h) serial numbers on seals and transportation cases.

2. Each sample is identified by affixing a pressure sensitive gummed label or standardized tag on the container(s). This label should contain the sample identification number, date and time of sample collection, source of sample, preservative used and the collector(s') initial(s'). Analysis required should be identified. Where a label is not available, the same information should be affixed to the sample container with an indelible, water proof, marking pen. Examples of sample identification tags are illustrated in Figure VIII-1.

3. The sample container should then be placed in a transportation case along with the chain of custody record form, pertinent field records and analysis request form as needed. The transportation case should then be sealed or labeled. All records should be filled out legibly in pen.

★GPO IMPRINT

EPA,

Station No.	Date	Time	Sequence No.

Station Location

________Grab

________Comp.

________BOD
________Solids
________COD
________Nutrients

________Metals
________Oil and Grease
________D.O.
________Bact.
________Other

Remarks / Preservative:

Samplers:

U.S. E.P.A. REGION

GENERAL CHEMISTRY

Official Sample No.

SOURCE

Date and Time

Sampler's Signature *Office*

OTHER PARAMETERS:

PH Acid
Cond Alk
TS SO_4
DS Cl
SS F
BOD_2 Cr. +6
Turb BOD_5
Color

U.S. E.P.A. REGION

MICROBIOLOGY

Official Sample No.

SOURCE

Date and Time

Sampler's Signature *Office*

Tot. Colif.

Fecal Colif.

Fecal Strep.

Salmonella

U.S. E.P.A. REGION

PESTICIDES, ORGANICS

Official Sample No.

SOURCE

Date and Time

Sampler's Signature *Office*

Pesticides

PCB's:

Organics:

FIGURE VIII-1

SAMPLE IDENTIFICATION TAG EXAMPLES

The use of the locked and sealed chests will eliminate the need for close control of individual sample containers. However, there will undoubtedly be occasions when the use of a chest is inconvenient. On those occasions, the sampler should place a seal around the cap of the individual sample container which would indicate tampering if removed.

4. When samples are composited over a time period, unsealed samples can be transferred from one crew to the next crew. A list of samples will be made by the transferring crew and signed for by a member of the receiving crew. They will either transfer the samples to another crew or deliver them to laboratory personnel who will then acknowledge receipt in a similar manner.

5. Color slides or photographs taken of the sample outfall location and of any visible pollution are recommended to facilitate identification and later recollection by the inspector. A photograph log should be made at the time the photo is taken so that this information can be written later on the back of the photo or the margin of the slide. This should include the signature of the photographer, time, date, site location and brief description of the subject of the photo. Photographs and written records, which may be used as evidence, should be handled in such a way that chain of custody can be established.

D. <u>Transfer of Custody and Shipment</u>

1. When transferring the possession of the samples, the transferee must sign and record the date and time on the chain of custody record. Custody transfers, if made to a sample custodian in the field, should account for each individual sample, although samples may be transferred as a group. Every person who takes custody must fill in the appropriate section of the Chain of Custody Record. To prevent undue proliferation of custody records, the number of custodians in the chain of possession should be as few as possible.

2. The field custodian or field inspector, if a custodian has not been assigned, is responsible for properly packaging and dispatching samples to the appropriate laboratory for analysis. This responsibility includes filling out, dating, and signing the appropriate portion of the Chain of Custody Record. A Chain of Custody Record format containing the necessary procedural elements is illustrated in Figure VIII-2.

3. All packages sent to the laboratory should be accompanied by the Chain of Custody Record and other pertinent forms. A copy of these forms should be retained by the originating office (either carbon or photo copy).

4. Mailed packages can be registered with return receipt requested. If packages are sent by common carrier, receipts

FIGURE VIII-2

CHAIN OF CUSTODY RECORD

SURVEY	SAMPLERS: *(Signature)*

STATION NUMBER	STATION LOCATION	DATE	TIME	SAMPLE TYPE			SEQ. NO.	NO. OF CONTAINERS	ANALYSIS REQUIRED
				Water		Air			
				Comp.	Grab.				

Relinquished by: *(Signature)*		Received by: *(Signature)*	Date/Time
Relinquished by: *(Signature)*		Received by: *(Signature)*	Date/Time
Relinquished by: *(Signature)*		Received by: *(Signature)*	Date/Time
Relinquished by: *(Signature)*		Received by Mobile Laboratory for field analysis: *(Signature)*	Date/Time
Dispatched by: *(Signature)*	Date/Time	Received for Laboratory by:	Date/Time
Method of Shipment:			

Distribution: Orig. — Accompany Shipment
1 Copy — Survey Coordinator Field Files

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should be retained as part of the permanent chain of custody documentation.

5. Samples to be shipped must be so packed as not to break and the package so sealed or locked that any evidence of tampering may be readily detected.

E. <u>Laboratory Custody Procedures</u>

Chain of Custody procedures are also necessary in the laboratory from the time of sample receipt to the time the sample is discarded. The following procedures are recommended for the laboratory:

1. A specific person shall be designated custodian and an alternate designated to act as custodian in the custodian's absence. All incoming samples shall be received by the custodian, who shall indicate receipt by signing the accompanying custody forms and who shall retain the signed forms as permanent records.

2. The sample custodian shall maintain a permanent log book to record, for each sample, the person delivering the sample, the person receiving the sample, date and time received, source of sample, sample identification or log number, how transmitted to the laboratory and condition received (sealed,

unsealed, broken container, or other pertinent remarks). A standardized format should be established for log book entries.

3. A clean, dry, isolated room, building, and/or refrigerated space that can be securely locked from the outside shall be designated as a "sample storage security area."

4. The custodian shall ensure that heat-sensitive, light-sensitive samples, radioactive, or other sample materials having unusual physical characteristics, or requiring special handling, are properly stored and maintained prior to analysis.

5. Distribution of samples to the section chiefs who are responsible for the laboratory performing the analyses shall be made only by the custodian.

6. The laboratory area shall be maintained as a secured area, restricted to authorized personnel only.

7. Laboratory personnel are responsible for the care and custody of the sample once it is received by them and shall be prepared to testify that the sample was in their possession and view or secured in the laboratory at all times from the moment it was received from the custodian until the time that the analyses are completed.

8. Once the sample analyses are completed, the unused portion of the sample, together with all identifying labels, must be returned to the custodian. The returned tagged sample should be retained in the custody room until permission to destroy the sample is received by the custodian.

9. Samples shall be destroyed only upon the order of the Laboratory Director, in consultation with previously designated Enforcement officials, or when it is certain that the information is no longer required or the samples have deteriorated. The same procedure is true for tags and laboratory records.

F. Evidentiary Considerations

Reducing chain of custody procedures as well as the various promulgated laboratory analytical procedures to writing will facilitate the admission of evidence under rule 803(6) of the Federal Rules of Evidence (PL. 93-575). Under this statute, written records of regularly conducted business activities may be introduced into evidence as an exception to the "Hearsay Rule" without the testimony of the person(s) who made the record. Although preferable, it is not always possible to have the individuals who collected, kept, and analyzed samples testify in court. In addition, if the opposing party does not intend to contest the integrity of the sample or testing evidence, admission under the Rule 803(6) can save a great deal of trial time. For these reasons, it is important that the procedures followed in the collection and analysis of evidentiary samples be standardized and described in an instruction manual which, if need be, can be offered as evidence of the "regularly conducted business activity" followed by the lab or office in generating any given record.

In criminal cases however, records and reports of matters observed by police officers and other law enforcement personnel are not included under the business record exceptions to the "Hearsay Rule" previously cited (see Rule 803(8), P.L. 93-595). It is arguable that those portions of the compliance inspection report dealing with matters other than sampling and analysis results come within this exception. For this reason, in criminal actions records and reports of matter observed by field investigators may not be admissible and the evidence may still have to be presented in the form of oral testimony by the person(s) who made the record or report, even though the materials come within the definition of business records. In a criminal proceeding, the opposing counsel may be able to obtain copies of reports prepared by witnesses, even if the witness does not refer to the records while testifying, and if obtained, the records may be used for cross-examination purposes.

Admission of records is not automatic under either of these sections. The business records section authorizes admission "unless the source of information or the method or circumstances of preparation indicate lack of trustworthiness," and the caveat under the public records exception reads "unless the sources of information or other circumstances indicate lack of trustworthiness."

Thus, whether or not the inspector anticipates that his or her compliance inspection report will be introduced as evidence, he or she should make certain that the report is as accurate and objective as possible.

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