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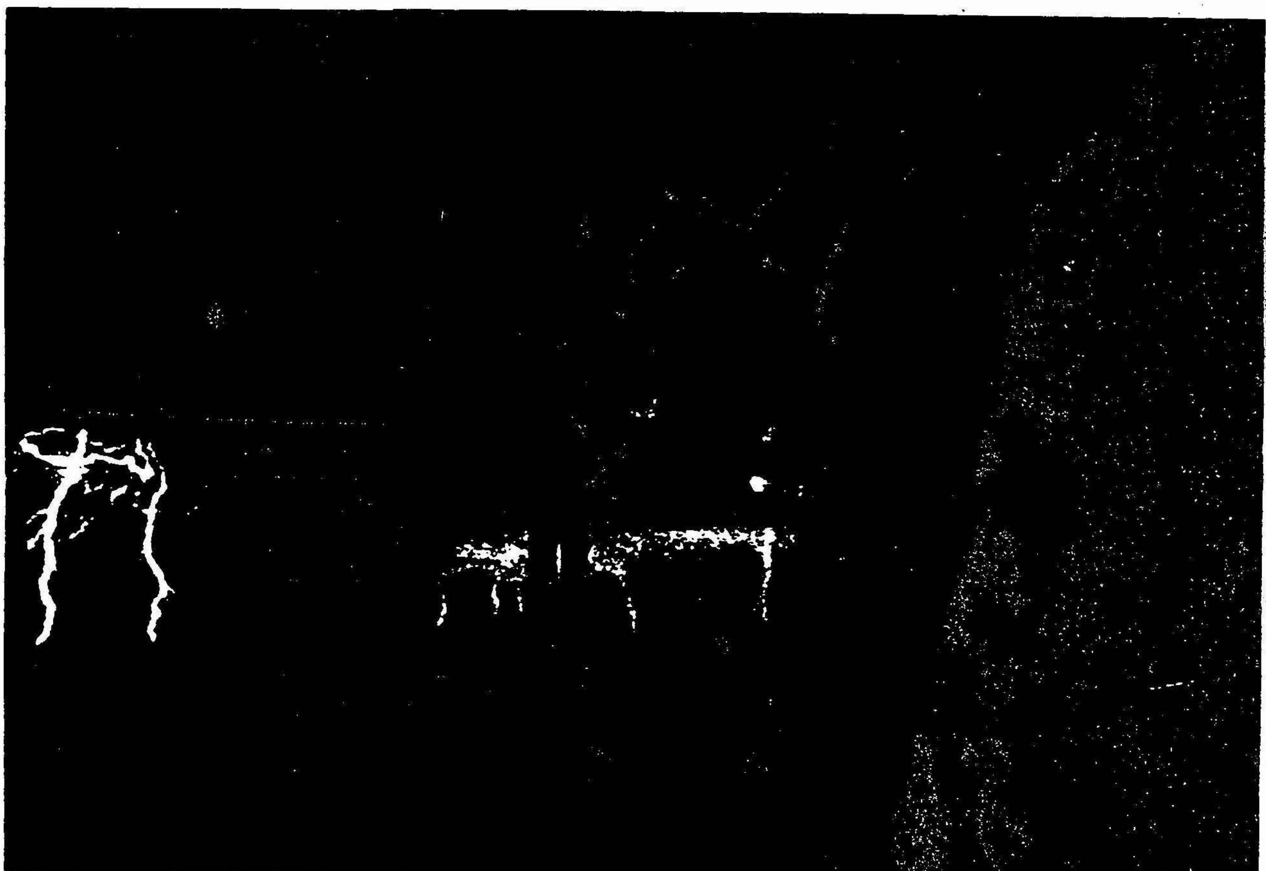
MONITORING REQUIREMENTS, METHODS, AND COSTS FOR THE NATIONWIDE URBAN RUNOFF PROGRAM



October 1979

Water Planning Division

U.S. Environmental Protection Agency

Washington, D.C. 20460

MONITORING

REQUIREMENTS, METHODS, AND COSTS

by

Philip E. Shelley, Ph.D.
EG&G Washington Analytical Services Center, Inc.
Rockville, Maryland 20850

Reprinted from the
AREAWIDE ASSESSMENT PROCEDURES MANUAL
EPA 600/9-76-014

for the
NATIONWIDE URBAN RUNOFF PROGRAM

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APPENDIX D

MONITORING REQUIREMENTS, METHODS, AND COSTS

D.1 Introduction

The nation's waters are as mixed and varied as its population and, just as there is no single measure of human health, there is no single measure of water quality. Furthermore, the nation's waters themselves (ground waters, streams, lakes, estuaries, and coastal waters) vary considerably in size, geological features, flow characteristics, climate and meteorological influences, and the type and extent of human impacts on them, and all these factors have a bearing on water quality.

Most definitions of water quality today are use-related, and each water use is sensitive to different pollution types and levels. For example, sufficient dissolved oxygen is critical to fish and other aquatic life but of little significance to drinking water supplies or swimming. On the other hand, coliform bacteria counts are a classical water pollution measure for human contact or ingestion but have little significance for most industrial uses or aquatic life. Even for the same parameter, the critical concentration for which one use begins to be impaired may be quite different from the level at which another use is affected. Thus, water quality monitoring - the collective activity that allows determination of the suitability of a particular water source for a specific use - is heavily use dependent. It is one thing to evaluate the lower Mississippi River as a drinking water supply and quite another to evaluate Lake Erie for swimming, a small stream in Michigan for trout fishing, or the South Platte River for irrigation. A different monitoring effort would be required for each.

D.1.1 How to Use This Appendix

In view of the foregoing, this Appendix cannot be a cookbook. Its overall objective is to provide the 208 planner with a range of information, considerations, and techniques that will allow him to design and implement a water quality monitoring program that is suited to his particular requirements. As indicated in Chapter 1 of this Manual, special emphasis is placed on equipment and methods suitable for storm-generated discharges.

The organization of this Appendix is indicated in Table D-1. By referring to it, the reader can locate information on the topic of immediate interest, e.g., where to look for available water quality data, how to select test catchments for stormwater model calibration and verification, how to choose an automatic sampler, etc. The topical organization is intended to support the chapters in the main body of this Manual by allowing quick reference to specific information, but it is recommended that this entire Appendix be read and understood thoroughly before implementation.

D.1.2 Purposes and Objectives of 208 Monitoring

The broad objective of a monitoring activity is to provide information upon which decision-makers can act. A more specific statement of objectives is required, however, for design and implementation of a monitoring effort. Examples of more specific monitoring objectives of interest to 208 agencies include:

1. Establishing baseline conditions
2. Determination of assimilative capacities of streams
3. Following the effects of a particular project or activity
4. Pollutant source identification
5. Long-term trend assessment
6. Waste load allocation
7. Projecting future water characteristics

TABLE D-1. ORGANIZATION OF APPENDIX D

TABLE D-1. ORGANIZATION OF APPENDIX D (Cont'd)

These monitoring objectives include both point and nonpoint source considerations involving variable and intermittent as well as continuous flows (see Chapter 1 of this Manual). In particular, Section 208 of PL 92-500 has focused money and attention on stormwater runoff and the need for urban runoff quality planning. The goals of such planning efforts are to define the runoff problem, identify potential solutions and costs, and measure the effectiveness of solution alternatives versus costs. Planning of this nature requires a method of evaluation that can provide comprehensive and areawide analysis, including the prediction of alternative futures. Mathematical models represent a developing tool that can be used by planners to meet these needs (see Appendix A). Such models require field data for their calibration and verification, and monitoring for this objective, along with problem assessment monitoring, will be emphasized in this Appendix.

A detailed listing of some USEPA uses for monitoring information is given in Table D-2. From a review of this table, it is readily apparent that a proper understanding of what is sought is paramount in the design and implementation of any given monitoring activity. Furthermore, the objectives should be reduced to writing, not only to ensure careful consideration of what they actually should be and help prevent misunderstandings by those involved, but also to set the limits, and thus discourage the pursuit of interesting but nonessential bypaths. These objectives will also provide a basis for measuring the extent to which the results of the effort meet the needs that justified the undertaking.

To illustrate the form such objective statements might take, several examples will be given. These were taken from actual 208 program efforts that are being designed and implemented now.

The stated objective for an instream sampling survey is to provide water quality and flow data for calibration and verification of a continuous water quality simulation model which will be used to simulate existing and future

TABLE D-2
SOME USEPA USES OF MONITORING INFORMATION

Develop/revise water quality standards

Develop/revise 303 basin plans

Develop/revise 208 areawide plans

Develop/revise 201 facilities plans

Document progress toward achievement/ maintenance of ambient standards and legislative goals

Monitor primitive areas for background levels and significant deterioration

Development of baseline information

Model validation/development

Develop health research/control techniques

Develop/evaluate Environmental Impact Statements

Develop/revise effluent standards

Formulate/revise discharge permits

Determine permit compliance

Develop/revise drinking water standards

Develop/revise pesticides monitoring plan

Develop/revise toxic standards

Develop/revise pretreatment standards

Investigate single pollution incidents (fish kills, oil spills)

Develop/assess/revise point source control strategies

Develop/assess/revise nonpoint source control strategies

Allocate resources

Report indices, trends, etc., to the public

Support enforcement actions

Develop/revise waste load allocations

conditions in selected streams and rivers in northeastern Illinois. Since organic pollutants and nutrients are considered the most general and widespread water quality problems in the region, the sampling and analysis program is designed to provide information necessary to simulate these parameters.

The stated objective for a land use runoff study is to determine nonpoint source pollution loading functions for homogeneous land uses. Transferability of data is required, since these loading functions will then be applied to other areas throughout the region.

The stated objective for a lake study is to determine, in terms of quantity and quality, the pollutional load from nonpoint sources that enters Lake Michigan during storm events. Note that this objective does not suggest that a complete survey of Lake Michigan be undertaken (a task of great magnitude) but, rather, seeks to determine what is going into the lake.

The three foregoing statements of objective were selected to illustrate that being specific and concise can go together (and should). As a final example, the following eight objectives are stated for an urban nonpoint source monitoring network:

- Collect basin rainfall and runoff data for 14 Philadelphia area drainage basins.
- Calibrate the USGS Dawdy parametric rainfall runoff model using 3 to 5 years of data.
- Using long-term Weather Service rainfall records as input to the calibrated model, develop flood frequency duration curves for 14 urban drainage basins.
- Measure physical basin characteristics of the 14 urban drainage basins.

- Relate physical basin characteristics to optimized model parameters.

- Using developed regression relationships between model and basin characteristics, develop flood-frequency duration curves for ungaged basins.

- Verify results with collected data on selected test basins.

- Collect average stream quality data for development of quality trends as related to type of development.

Once the objective statement has been clearly formulated, the survey design can begin, but not before.

D.1.3 Types of Monitoring Activities

There exist a number of types of monitoring activities that can be employed in meeting overall monitoring requirements. Their suitability and applicability will depend upon the purposes and objectives of the particular effort involved. Included are (1) reconnaissance surveys, (2) point source characterizations, (3) intensive surveys, (4) fixed station network monitoring networks, (5) ground water monitoring, and (6) biological monitoring. The last two types of monitoring activities are broken out separately only because they require skills, equipment, and techniques that are markedly different from those used in the first four. None of these should be considered as completely separate activities in actual practice. Comprehensive data interpretation will require that all monitoring data be considered together.

A brief description of these monitoring activities follows, with emphasis placed on typical objectives of each. By comparing them, the reader can see how they differ and how they may be combined to meet overall 208 monitoring objectives.

D.1.3.1 Reconnaissance Survey

A reconnaissance survey is a general or overall examination of a particular area. It is a visual or superficial qualitative (and sometimes quantitative) survey. Typical objectives of a reconnaissance survey include:

1. Getting the "lay of the land" in preparation for an intensive survey.
2. Identification of all waste sources in a particular catchment.
3. Identification of water uses in terms of types, locations, quantities, and frequencies.
4. Determination of general stream characteristics.
5. Obtaining information necessary for establishing the overall design of a fixed-station network.
6. Investigation of reported pollution incidents or spills.

D.1.3.2 Point Source Characterization

A point source characterization (or effluent monitoring) study is one conducted to determine the characteristics of an identifiable, discrete discharge (either continuous or intermittent) into a receiving body of water. Although several point sources are usually involved in a complete survey, the mechanics of execution are basically similar, and the same general considerations apply. It is also possible that more than one measurement site (i.e., sampling and flow determination) might be involved as, for example, in a treatment plant efficiency study. Mass loading discharges rather than simple parameter concentrations are usually sought. Some objectives are:

1. Determination of frequency, quantity, and strength of combined sewer overflows.
2. Characterization of storm sewer discharges.
3. Determination of treatment plant efficiency.
4. Verification of a permit application.
5. Infiltration/inflow determination at a given site.

6. Verification of self-monitoring data with regard to permit compliance.
7. Determination of pretreatment requirements or verification of compliance with pretreatment standards.
8. Verification of toxic substances sources.
9. Case preparation (as part of an enforcement action).

D.1.3.3 Intensive Survey

Intensive surveys are major elements in a monitoring program. The intensive survey: (1) bridges the gap between the data bases generated by effluent monitoring and fixed-station monitoring; (2) provides a definitive basis for understanding and describing receiving water quality and the mechanisms and processes that affect water quality; (3) provides the documentation required to explain the trends observed at fixed network stations; and (4) is a tool for determining the ultimate fate of pollutants in the water environment.

Some generalizations concerning the overall nature of intensive surveys and their planning and execution follow.

1. Repetitive measurements of water quality are made at each station (sources and receiving water). The stations will typically comprise a short, very dense, sampling network throughout the duration of the field effort.

2. The duration of an intensive survey is dictated by the objectives of the survey, with 3 to 14 days being typical for freshwater streams, lakes, and reservoirs. Surveys in tidal bodies are typically more complex and longer in duration as are nonpoint source surveys (e.g., for calibrating a stormwater management model).

3. The measurements taken during an intensive study vary. A study may be oriented towards one particular type of data (chemical, biological, sediment, etc.) or it may involve the collection of many types of data.

4. Continuous and intermittent point and nonpoint sources within the survey area are usually monitored during the study.

Some major objectives of intensive surveys are:

1. Determining quantitative cause-and-effect relationships of water quality for making load allocations, assessing the effectiveness of pollution control programs, or for developing alternative solutions to pollution problems.

2. Setting priorities for establishing or improving pollution controls.

3. Supporting and setting priorities for enforcement actions.

4. Identifying and quantifying nonpoint sources of pollution and assessing their impact on water quality.

5. Assessing the biological, chemical, physical, and trophic status of publicly-owned lakes and reservoirs.

6. Providing data for the classification or reclassification of stream segments as being either effluent limited or water quality limited.

7. Evaluating the locations and distribution of fixed monitoring stations.

8. Calibrating and verifying stormwater management models.

Such objectives should be considered mutually compatible. The incremental cost of expanding a single-purpose survey into a multipurpose survey should always be evaluated prior to conducting the survey.

D.1.3.4 Fixed Station Monitoring Networks

The fixed monitoring network is a system of fixed stations that are sampled in such a way that well-defined histories of the physical, chemical, and biological conditions of the water and sediments can be established. In general, other monitoring data will be needed to explain, in detail, the trends observed at the fixed stations. Thus, a high level of coordination between the fixed-station monitoring network and other monitoring activities is essential for developing a useful data base. The basic objectives of fixed monitoring networks are to provide data and information that, when taken in combination with other data, will:

1. Characterize and define trends in the physical, chemical, and biological condition of surface waters, including significant publicly-owned lakes and impounded waters.

2. Establish baselines of water quality.

3. Provide for a continuing assessment of water pollution control programs.

4. Identify and quantify new or existing water quality problems or problem areas.

5. Aid in the identification of stream segments as either effluent limited or water quality limited.

6. Act as a triggering mechanism for intensive surveys, enforcement proceedings, or other actions.

D.1.3.5 Ground Water Monitoring

Because of the increasing threat to the quality of ground water posed by some waste management practices and a general lack of comprehensive information on the origins, scope, and nature of existing ground water pollution problems, it is important that programs be established and maintained to monitor ground water quality. Some objectives of ground water monitoring are:

1. Obtaining data for the purpose of determining baseline conditions in ground water quality and quantity.

2. Providing data for the early detection of ground water pollution or contamination, particularly in areas of ground water use.

3. Identifying existing and potential ground water pollution sources and maintaining surveillance of these sources, in terms of their impact on ground water quality.

4. Providing a data base upon which management and policy decisions can be made concerning the surface and subsurface disposal of wastes and the management of ground water resources.

Ground water monitoring has been extensively treated in a recent series of USEPA reports (1-5) and will not be discussed further in this Appendix. It is only mentioned here to point up its importance to the 208 planning process.

D.1.3.6 Biological Monitoring

Aquatic organisms and communities act as natural pollution monitors. Some organisms tend to accumulate or magnify toxic substances, pesticides, radionuclides, and a variety of other pollutants. Organisms also can reflect the synergistic and antagonistic interactions of point and nonpoint source pollutants within the receiving water system. Some objectives of a biological monitoring program are to gather biological data in such a manner as to:

1. Determine suitability of the aquatic environment for supporting abundant, useful, and diverse communities of aquatic organisms.

2. Provide information adequate to detect, evaluate, and characterize changes in water quality through the study of biological productivity, diversity, and stability of aquatic systems.

3. Detect the presence and buildup of toxic and potentially hazardous substances in aquatic biota.

4. Provide information adequate to periodically update the eutrophic condition classification of freshwater lakes.

D.1.4 Coordination With Other Monitoring Programs

An attempt to put 208 monitoring somewhat in perspective is presented in Figure D-1, taken from the National Water Monitoring Panel (6). It is obvious that if each functional purpose is to be productive, the proper information must be provided by the monitoring program. It also should be clear that persons responsible for monitoring must maintain a frequent and substantive contact with those programs requiring information. Finally, there is abundant need for coordination among all aspects of a monitoring program.

The importance of this last statement regarding coordination among monitoring activities can be emphasized by considering the following. At the federal level, legislative authority for monitoring is contained in at least six Acts:

- The Federal Water Pollution Control Act
- The Safe Drinking Water Act
- The Refuse Act
- The Marine Protection, Research and Sanctuaries Act
- The Federal Insecticide, Fungicide, and Rodenticide Act
- The Solid Waste Disposal Act

When combined with State and local legislation, the legislative mandates form an almost staggering dimension. The activities responsible for monitoring implementation form an equally large dimension. At the federal level alone,

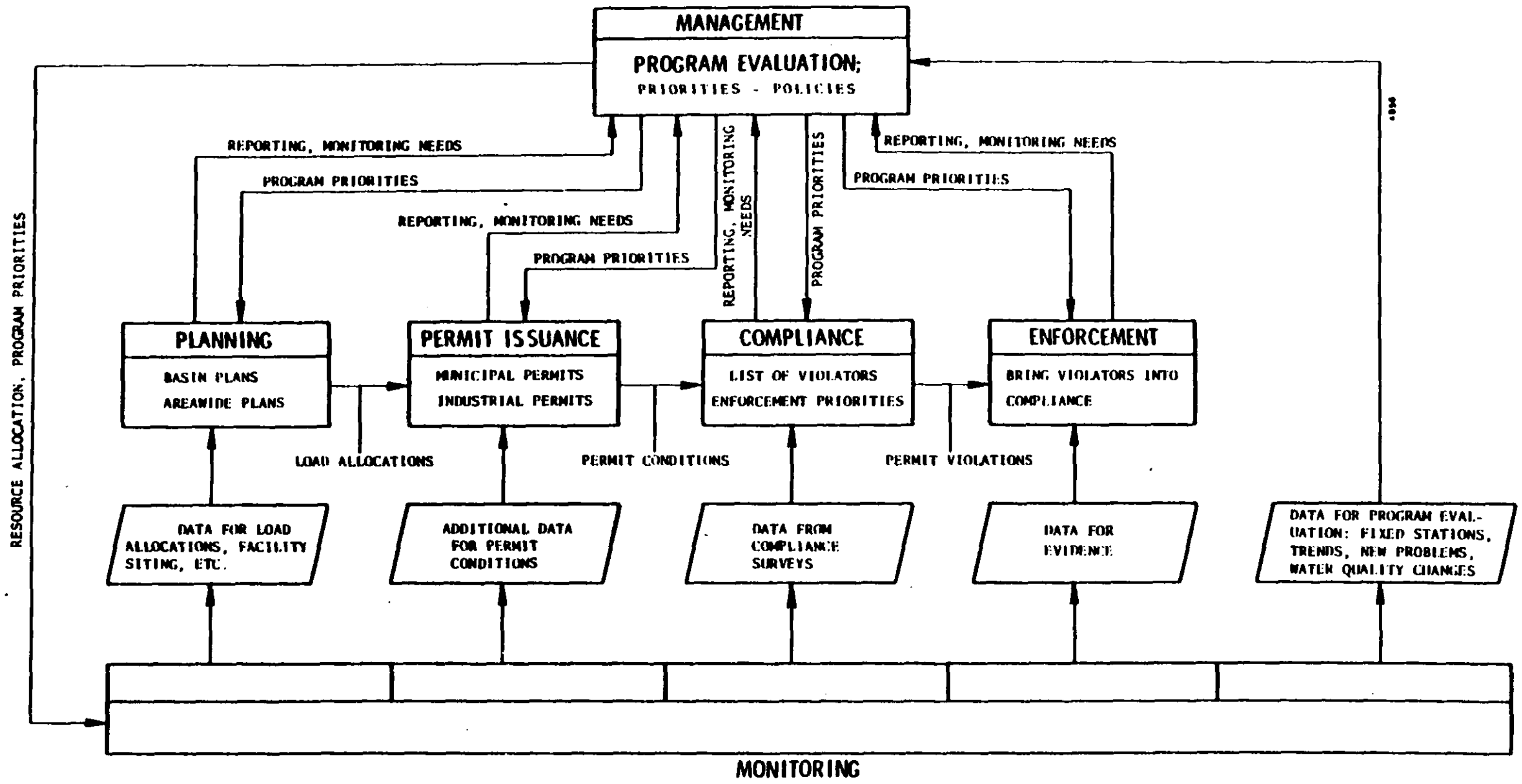


FIGURE D-1
MONITORING IN PERSPECTIVE

they include the U.S. Environmental Protection Agency; the U.S. Geological Survey; the U.S. Department of Agriculture; the Bureau of Reclamation; the Department of Defense, including the Army Corps of Engineers and the Naval Facilities Engineering Command; the Bureau of Mines; the National Aeronautics and Space Administration; the Occupational Safety and Health Administration; the Food and Drug Administration; the Energy Research and Development Administration; and others, not to mention special purpose monitoring efforts conducted by federal activities such as the National Science Foundation, the Council on Environmental Quality, the Office of Manpower and Budget, the Office of Technology Assessment, and so on. These efforts must be combined with those of the states, designated agencies, and all pollutant dischargers operating under effluent permits. Typically, monitoring efforts are far from centralized. For example, in the USEPA alone, monitoring responsibilities - encompassing both the collection and use of information - are found in 16 Headquarters offices under 5 assistant administrators. Similarly, USEPA field responsibilities are dispersed among the 10 regional offices and 13 research laboratories.

D.1.5 Available Data Sources

The prudent use of resources dictates that the maximum use practicable be made of existing data. For 208 planning, these can be grouped into three categories: meteorological, geographical, and water quality. Available data sources for each category will be discussed in turn. One caveat more or less applicable to each must be mentioned, however. All prior data may not be of acceptable quality (i.e., truthfulness, suitability, accuracy). Where at all possible, attempt to determine the original source and some indication of the "goodness" of the data. For example, USGS stream gage records are annotated with a somewhat subjective indication of the quality of the record, e.g., poor, fair, good, etc. Unfortunately, this is the exception rather than the rule. Be especially chary of water quality records; attempt to determine how the samples were taken, whether or not they were handled properly, and how the analyses were run.

D.1.5.1 Meteorological Data

The best source of long-term rainfall data in the United States is the National Weather Service (NWS). Data can be obtained from the NWS either on tape files or through published daily and hourly summaries. Tapes can be obtained by contacting:

U.S. Department of Commerce
National Climatic Center
NOAA Environmental Data Service
Federal Building
Ashville, N.C. 28801

Telephone (704) 258-2850

Data are available on two record files: Deck 448-USWB HOURLY PRECIPITATION and Deck 345-WBAN SUMMARY OF DAY. Most first-order stations are covered. The period of record is usually from August 1949 to the current data with some gaps. Long-term 5-minute data are also available from the NWS for over 50 major U.S. cities, and can be generated for most cities having a NWS city or airport office.

One word of caution; be sure to determine if there is a high aerial variability of rainfall for the region in question. For example, the total rainfall measured at the NWS station at Philadelphia International Airport was 44.47 inches for 1975. The totals for individual gaged catchments within the city for the same period ranged from 40 to over 60 inches, with a city-wide average of 51.37 inches.

Other meteorological data available from NOAA include snowfall, temperature, wind, sunshine and sky cover, evaporation, and humidity. Local data sources and the possible existence of data from previous studies should also be investigated.

D.1.5.2 Geographical Data

In this context, the term geographical is used in its broadest meaning. Chief among this category are land use data, but other physical, cultural, and demographic data will also be desired (e.g., catchment slopes and terrain, soil types, sewer maps, population distributions, etc.). Sources of such data are described in detail in Appendix C of this Manual, but generally include:

- U.S. Census Bureau
- Metropolitan Sanitary Districts
- State and local planning agencies
- Office of the County Surveyor (or equivalent)
- U.S. Coast and Geodetic Survey
- U.S. Department of Housing and Urban Development
- USDA Soil Conservation Service
- Standard Metropolitan Statistical Area Data
- Previous basin (303e) or facilities (201) plans

D.1.5.3 Water Quality Data

The STORET system of the USEPA is the largest source of water quality data in the nation. The system is operated as a utility serving states, areawide agencies, and other organizations. Data are stored in the system by the data collecting organization for their own purposes as well as for sharing with others. The STORET system should be queried for existing data during the initial design phase of the 208 areawide monitoring effort. USEPA headquarters and regional offices may be contacted for assistance in the use of STORET.

Other existing water quality data are widespread, but the recent establishment of the National Water Data Exchange (NAWDEX) should considerably assist users in locating and acquiring needed data. Unlike STORET, NAWDEX is not a large depository of water data. Rather, its objective is to provide the user with sufficient information to define what data are available, where these data may be obtained, in what form the data are available, and some of the major characteristics of the data.

The U.S. Geological Survey has the lead-role responsibility for NAWDEX. In this capacity, it has established the NAWDEX Program Office at its National Center in Reston, Virginia. This office became active in November 1975 and provides the central management for NAWDEX. It also has the responsibility for coordinating all operational activities within the program. This includes serving as liaison between NAWDEX members and users of the system.

The service capabilities of NAWDEX will be supported by a nationwide network of Local Assistance Centers established in the offices of NAWDEX members to provide local and convenient access to NAWDEX and its services. This network will initially be established in late 1976 in the 46 district offices of the U.S. Geological Survey. These offices are located in 45 states and Puerto Rico. Most are equipped with computer terminals, thereby providing an extensive telecommunication network for access to the computerized directory and indexes being developed for the NAWDEX program. As the NAWDEX membership increases, additional centers will be added in large population areas and areas of high user interest to provide improved access to NAWDEX and its services.

The NAWDEX Program Office is currently developing a Water Data Sources Directory. This directory will identify organizations that collect water data, locations within these organizations from which water data may be obtained, the geographic areas in which water data are collected by these organizations, the types of water data collected, alternate sources for acquiring the organization's data, and the media in which the data are available. This directory is scheduled for release in 1977.

A computerized Master Water Data Index is also being prepared which is scheduled for nationwide use in November 1976. This index will identify individual sites for which water data are available, the locations of these sites, the organizations collecting the data, the hydrologic disciplines represented by the data, the periods of record, water data parameters, the frequency of measurement of the parameters, and the media in which the data are available. More than 350,000 water data sites are currently being indexed from information contributed by 19 federal agencies and more than 300 non-Federal agencies.

Through its Water Data Sources Directory, Master Water Data Index, and indexes and other reference sources made available by its participating members, NAWDEX assists its users in locating data of special interest. These data include water data in computerized and in both published and unpublished forms. The user is then referred to the organization(s) having the needed data. NAWDEX thus serves as a central point of contact for locating water data that may be held by several different organizations. Data search assistance may be obtained from the NAWDEX Program Office or from any of the Local Assistance Centers.

To expedite locating existing data, NAWDEX and STORET should be queried at the same time. In addition to referring the user to STORET, NAWDEX will provide information on other data sources for the area under consideration in many instances.

Requests for services or additional information related to NAWDEX and STORET may be directed to:

National Water Data Exchange
U.S. Geological Survey
421 National Center
Reston, VA 22092

Telephone (703) 860-6031

STORET (WH-553)
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

Telephone (202) 426-7792

Local points of contact for the USEPA STORET system and state water quality agencies are given in Chapter 2 of this Manual (Tables 2-4 and 2-7). Selected federal sources for water quality information are given in Table D-3. A call to the Federal Information Center, (202) 755-8660, with its staff of trained information specialists, will assist the user in finding the appropriate contact within any of these federal agencies.

TABLE D-3
SELECTED FEDERAL SOURCES FOR WATER QUALITY INFORMATION

Department of Agriculture

- Forest Service
- Soil Conservation Service

Department of Commerce

- National Oceanic and Atmospheric Administration
- National Bureau of Standards

Department of Defense

- Army Corps of Engineers
- Army Civil Engineering Research Laboratory
- Navy Facilities Engineering Command
- Air Force Civil Engineering Research Center

Department of Health, Education, and Welfare

- Public Health Service

Department of Interior

- Bureau of Reclamation
- Bureau of Land Management
- Bureau of Indian Affairs
- Bureau of Mines
- Bureau of Sport Fisheries and Wildlife
- Bureau of Outdoor Recreation
- Geological Survey
- Office of Saline Water
- Fish and Wildlife Service
- Office of Water Resources Research

Department of Transportation

- Coast Guard

Energy Research and Development Administration

Environmental Protection Agency

National Aeronautics and Space Administration

Nuclear Regulatory Commission

Water Resources Council

Council on Environmental Quality

D.2 Measurement Site, Parameter, and Frequency Selection

D.2.1 Site Selection

The location of measurement sites is critical to obtaining good quality data and properly interpreting them. The following discussion covers overall site location guidance, site selection for waste load allocation surveys, catchment selection for stormwater model calibration and verification, and specific local site selection criteria.

D.2.1.1 Overall Site Location Guidance

For overall background and problem assessment the following locations are recommended for the chemical and physical sampling of the water column. Biological and sediment stations should also be established at these locations, as appropriate.

1. At critical locations in water quality limited areas. Stations should be located within areas that are known or suspected to be in violation of water quality standards, ideally at the site of the most pronounced water quality degradation. The data from these stations should gage the effectiveness of pollution control measures being required in these areas.

2. At the major outlets from and at the major or significant inputs to lakes, impoundments, estuaries, or coastal areas that are known to exhibit eutrophic characteristics. These stations should be located in such a way as to measure the inputs and outputs of nutrients and other pertinent substances into and from these water bodies. The information from these stations will be useful in determining cause/effect relationships and in indicating appropriate corrective measures.

3. At critical locations within eutrophic or potentially eutrophic lakes, impoundments, estuaries, or coastal areas. These

stations should be located in those areas displaying the most pronounced eutrophication or considered to have the highest potential for eutrophication. The information from these stations, when taken in combination with the pollution source data, can be used to establish cause/effect relationships and to identify problem areas.

4. At locations upstream and downstream of major population and/or industrial centers which have significant waste discharges into flowing surface waters. These stations should be located in such a way that the impact on water quality and the amounts of pollutants contributed can be measured. The information collected from these stations should gage the relative effectiveness of pollution control activities.

5. Upstream and downstream of representative land use areas and morphologic zones within the area. These stations should be located and sampled in such a manner as to compare the relative effects of different land use areas (e.g., cropland, mining area) and morphologic zones (e.g., piedmont, mountain) on water quality. A particular concern for these stations is the evaluation of nonpoint sources of pollution and the establishment of baselines of water quality in sparsely populated areas.

6. At the mouths of major or significant tributaries to mainstem streams, estuaries, or coastal areas. The data from these stations, taken in concert with permit monitoring data and intensive survey data, will determine the major sources of pollutants to the area's mainstem water bodies and coastal areas. By comparison with other tributary data, the relative magnitude of pollution sources can be evaluated and problem areas can be identified.

7. At representative sites in mainstem rivers, estuaries, coastal areas, lakes, and impoundments. These stations will provide data for the general characterization of the area's surface

waters and will provide baselines of water quality against which progress can be measured. The purpose of these stations is not to measure the most pronounced areas of pollution, but rather to determine the overall quality of the water. Biological monitoring will be a basic tool for assessing the overall water quality of an area.

8. In major water use areas, such as public water supply intakes, commercial fishing areas, and recreational areas. These stations serve a dual purpose: the first is public health protection and the second is for the overall characterization of water quality in the area. Determining the presence and accumulation of toxic substances and pathogenic bacteria and their sources are primary objectives of these stations.

Sediment sampling sites should be located [illegible] areas as determined by intensive surveys, reconnaissance surveys, and historical data. A major concern of sediment monitoring will be to assess the accumulation of toxic substances, and locations for sediment sampling should be chosen with this in mind. Sediment mechanics and the hydrological characteristics of the water body must be considered. Refer also to Chapter 4 of this Manual.

In general, biological monitoring stations should be established as follows:

1. At key locations in water bodies that are of critical value for sensitive uses such as domestic water supply, recreation, and propagation and maintenance of fish and wildlife.

2. In major impoundments near the mouths of major tributaries.

3. Near the mouths of major rivers where they enter an estuary.

4. At locations in major water bodies potentially subject to inputs of contaminants from areas of concentrated urban, industrial, or agricultural use.

5. At key locations in water bodies largely unaffected by man's activities.

For purposes of biological monitoring, a station will normally encompass areas, rather than points, within a reach of river or area of lake, reservoir, or estuary adequate to represent a variety of habitats typically present in the body of water being monitored. Unless there is a specific need to evaluate the effects of a physical structure, it is advisable to avoid areas that have been altered by a bridge, weir, within a discharge plume, etc. Thus, biological sampling stations may not always exactly coincide with water column or sediment stations.

To the extent possible, all monitoring stations should be located in such a manner as to aid cause/effect analyses. Some station requirements may be such that, with careful station siting, one particular station could meet the criteria of a number of types of stations. Caution should be exercised, however, to avoid compromising the worth of a station for the sake of false economy. In general, the quality of a monitoring program is not judged solely by the number of stations. A few critically located stations may be extremely valuable, while a large number of randomly selected stations may yield meaningless data. Resource constraints will limit the total number of stations. Figure D-2, taken from (6), shows some examples of station locations.

The stations shown on Figure D-2 are described as follows:

1. At a water supply intake; upstream station of a pair bracketing a municipal and industrial center.

2. At a critical location in a water quality limited segment; downstream station of a pair bracketing a municipal and industrial center; mouth of a significant input to a reservoir known to exhibit eutrophic characteristics.

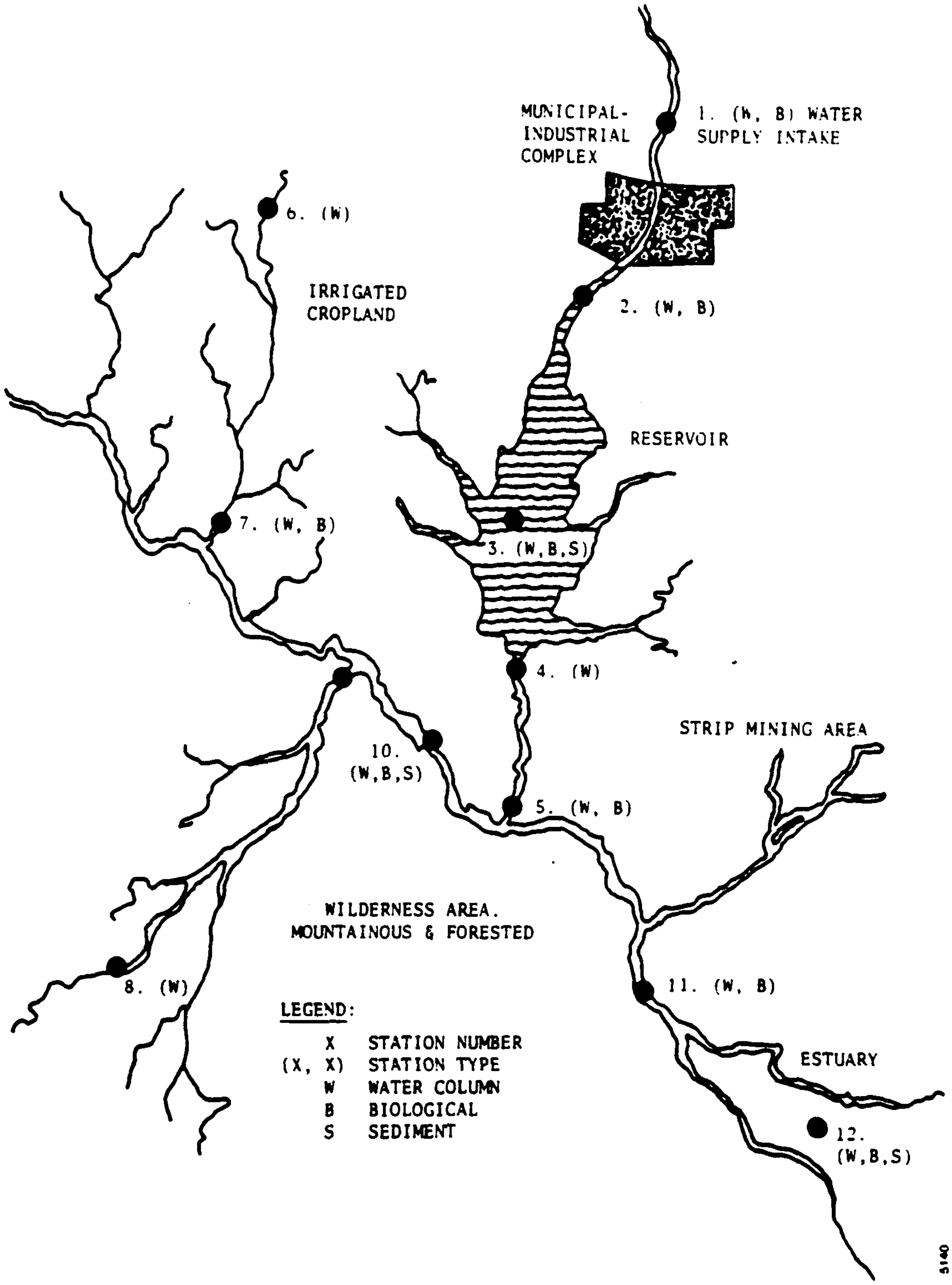


FIGURE D-2
STATION LOCATIONS

3. At a critical location in a reservoir known to exhibit eutrophic characteristics; in an area of recreation.

4. Upstream of a major land use area (strip mining); major outlet from a eutrophic reservoir.

5. Downstream of a land use area (strip mining); mouth of a significant tributary to mainstem river.

6. Upstream of a major land use area (irrigated cropland).

7. Downstream of a land use area (irrigated cropland); mouth of a significant tributary; representative site for other streams passing through same land use.

8. Upstream of a major land type area (wilderness).

9. Downstream of a major land type area (wilderness); mouth of significant tributary to mainstem river.

10. Representative site in mainstem river.

11. Representative site in mainstem river, mouth of major input to a potentially eutrophic estuary.

12. Representative site in estuary, recreational area, shellfish harvesting area.

D.2.1.2 Site Selection for Waste Load Allocation Surveys

Intensive surveys for waste load allocation will form an important part of a 208 agency's monitoring program. Since water quality problems don't manifest themselves on demand and we can't afford to wait around for the 10-year dry spell, the use of mathematical models for problem assessment will be required. These models will require monitoring data from intensive surveys for calibration and verification. By and large, at least two intensive surveys will be required for each waste load allocation study. The first, or preliminary, survey should be performed during slightly higher flow conditions than the second, or primary, survey which should be conducted when flow conditions are as low as possible.

For the case where only one outfall impacts upon the water quality of a stream, measurement sites should be located as follows:

A - directly upstream of the outfall.

B - effluent from the outfall.

C - mix point (i.e., where effluent is thoroughly mixed with stream flow).

D_i - intermediate points between the mix point and the DO sag point or a tributary, if one enters the stream ahead of the sag point. Spacing of 0.1 mile or less is usually warranted.

E - directly upstream of any tributaries.

F - tributary.

G_i - intermediate points between tributaries (if more than one) or between tributary and sag point.

H - sag point.

I_i - points downstream from the sag point. Measure at least every 0.1 mile until there is a definite recovery in the DO profile.

Where more than one outfall discharges into the stream, these sources must also be measured, and the above site locations altered accordingly.

The problem of determining the mix point deserves special mention. The common practice of locating the mix point either by visual inspection of the stream or by simply assuming that the stream is well mixed a certain distance downstream is simply inadequate. A more rigorous method must be used. One technique that has successfully been employed is to follow the concentration of chlorides downstream. The steps in this procedure are:

1. Measure chloride concentration upstream of the outfall.

2. Measure chloride concentration in the effluent.

3. Perform a mass balance calculation to determine the mixed chloride concentration.

4. Measure chloride concentrations at increasing distances downstream from the outfall.

5. Locate the mix point where the measured chloride concentration is equal to the calculated value.

D.2.1.3 Catchment Selection for Stormwater Model Calibration and Verification

Field data will be required for calibration and verification of stormwater models, with details dependent upon the actual model selected (see Appendix A). However, it must be emphasized at the outset that instrumentation of a large, multiuse drainage basin can only generate data for verification of urban planning models. Calibration of these models requires data from small catchments of uniform land use to provide information for adjusting model parameters for each individual land use. Since it will not be practicable to instrument all catchments within a planning area, the effectiveness of the planning models will depend to a large degree on the ability to estimate parameters for catchments that have no calibration data. This implies the selection of catchments that have a high potential for data transferability as "benchmark" stations and instrumenting them accordingly. Each instrumented catchment must therefore be viewed as a "sample" of the planning area's catchments. Selection of representative and (to the extent possible) uniform "samples" is necessary in order to arrive at a set of transferable model parameters that cover the variations among catchments for the entire planning area.

Catchment selection begins with an inventory of catchments in the planning area. Minimum characterization includes size; present and projected land use; drainage type (non-sewered, degrees of partial sewer service, fully sewered, and sewer types); physical catchment characteristics; and relationship to major streams, lakes, or estuaries within the area of interest. Catchments in urban areas are small and numerous, emphasizing the need for selecting a small, representative subset. The size will affect the relative importance of runoff flow and water quality constituent routing. Very small (e.g., less than 0.1 square mile) catchments should be avoided as their (typically) extremely rapid response times may make runoff characterization impossible. It is unlikely that the requirement for uniformity of land use will allow utilization of large (e.g., over 5 square miles) catchments in urban areas.

The extent of sewering will have a significant impact on catchment runoff, affecting routing, length of overland flow, and the relative importance of infiltration. In urban areas, the ratio of sewer length to drainage area typically falls between 8 and 18. The corresponding ratio for natural river and stream channels would be less than 2. The physical catchment characteristics such as percent imperviousness, ground slope, soil characteristics, and infiltration potential will obviously affect runoff and must be considered in selecting representative catchments for instrumentation.

The recommended procedure is to prepare a matrix inventory characterizing each catchment within the area of interest. These should then be categorized using land use as the factor, since parameters in currently available models are largely functions of land use. One should not feel constrained to use only the conventional single-family residential, multi-family residential, commercial, industrial, and open-space land use types. Use types reflecting the local conditions are more meaningful. For example, it may be desirable to distinguish between single-family residential areas near the center of a city and those in the suburbs; review of the catchment inventory may indicate a number of small suburban shopping centers and the desirability of a mixed residential/commercial category. Other locally important factors for determining land use types might be traffic volume, population density, age of development, family income, percent of streets with curb and gutter, type of industry, and so on. Although local conditions will determine the exact number of land use categories to be employed, fewer than five will probably not allow satisfactory data transfer and more than ten will increase field data collection costs beyond reason. See Appendix C of this Manual for further guidance.

The problem of site selection from among those catchments in each land use category now remains. Budgetary constraints will mandate selection of only one catchment for instrumentation in each land use category for the most part and, therefore, the "best" must be selected. Although random selection may be expedient, a more rigorous and comprehensive approach is usually desirable. On the other hand, a sophisticated multiple regression analysis with serial and/or factor differentiation of catchment variables is probably not warranted. The technique of weighted suitability ratings often employed in land use planning will be adequate in most instances. It has the advantage that the selection criteria can easily be illustrated on a single chart for relative catchment comparison. Although the procedure is necessarily subjective in the selection of factors, suitability values, and weights, so was the basic selection of land use types.

D.2.1.4 Specific Site Selection Criteria

Given an identified catchment, stream reach, or other general location where measurements are desired, there are some general criteria that can aid in selecting the specific measurement site. They include:

1. Maximum accessibility and safety. Manholes on busy streets should be avoided if possible; shallow depths with manhole steps in good condition are desirable. Sites with a history of surcharging or submergence by surface water, or both, should be avoided if possible.

2. Be sure that the site provides the information desired. Familiarity with the sewer system is necessary. Knowledge of the existence of inflow or outflow between the measurement point and point of data use is essential.

3. Make certain the site is far enough downstream from tributary inflow to ensure mixing of the tributary with the main stream.

4. Locate in a straight length of channel, at least six widths below bends.

5. Locate at a point of maximum turbulence, as found in sections of greater roughness and of probable higher velocities. Locate just downstream from a drop or hydraulic jump, if possible.

6. In all cases, consider the cost of installation, balancing cost against effectiveness in providing the data needed.

The success or failure of selected equipment or methods, with respect to accuracy and completeness of data collected as well as reasonableness of cost, depends very much on the care and effort exercised in selecting the site. A requirement with regard to flow measurement that appears to be obvious, but which is frequently not sufficiently considered, is that the site selected be located to give the desired flow measurement. Does flow at the site provide information actually needed to fulfill given needs? Sometimes influent flows, diversions, or storage upstream or downstream from the selected site would bias the data in a manner not understood without a thorough study of the proposed site. Such study would include reference to surface maps and to sewer maps and plans. Sometimes groundwater infiltration or unrecorded connections may exist. For these reasons, a thorough field investigation should be made before establishing a flow measurement site.

A basic consideration in site selection is the possible availability of measurements or records collected by others. At times, data being collected by the USGS, by the state, or by other public agencies can be used. There are locations where useful data, although not currently being collected, may have been collected in prior years. Additional data to supplement those earlier records may be more useful than new data collected at a different site.

Requirements that apply to all measurement sites are accessibility, personnel and equipment safety, and freedom from vandalism. If a car or other vehicle can be driven directly to the site at all times, the cost in time required for installation, operation, and maintenance of the equipment will be less, and it is possible that less expensive equipment can be selected. Consideration should be given to access during periods of adverse weather conditions and during periods of flood stage. Sites on bridges or at manholes where heavy traffic occurs should be avoided unless suitable protection for men and equipment is provided. If entry to sewers is required, the more shallow locations should be selected where possible. Manhole steps and other facilities for sewer access must be carefully inspected, and any needed repairs made. Possible danger from harmful gases, chemicals, or explosion should be investigated. With respect to sites at or near streams, historical flood marks should be determined and used for placement of access facilities and measurement equipment above flood level where this is possible. Areas of known frequent vandalism should be avoided.

In this last regard, the problem of vandalism can be serious and costly, both in terms of equipment damage and data loss. The selection of sites in open, rather than secluded, areas may help reduce vandalism as may illumination at night. Attempts to hide or camouflage equipment have been generally unsuccessful. Instrumentation should be sheltered to the extent possible, trading off the cost of protective facilities, the latitude afforded by the site, and the need for easy access. Occasionally, solid masonry or steel shelters surrounded by heavy fencing may be required for measurement sites, and these additional costs must be included in such instances. Finally, warning signs are generally unsuccessful; they may only encourage vandalism regardless of the type of threat -- high voltage, radiation hazard, fine, or imprisonment.

D.2.2 Parameter Selection

A review of the Parameter Handbook points out that the list of possible water quality parameters that might be of interest to the 208 planner is almost endless. Parameter selection must be based on the specific objectives of the study and a knowledge of general pollution source characteristics. For example, nonmunicipal effluent limitations guidelines for existing point sources, standards of performance for new sources, and pretreatment standards for new and existing sources discharging to publicly-owned waste treatment facilities have been published for 28 point source categories (40 CFR 405-432). Effluent limitations establish the mass of specific pollutants that may be discharged per unit of production or raw material input. Limitations are established for a maximum production day and for the 30-day average. Table D-4 summarizes the effluent parameters included in each of the published effluent guidelines.

For publicly-owned treatment works in existence on July 1, 1977, or approved for a Federal construction grant prior to June 30, 1974, effluent limitations

TABLE D-4
EFFLUENT PARAMETERS BY INDUSTRIAL CATEGORIES

INDUSTRY CATEGORY	BOD_5	TSS	pH	COLOR	COD	PHENOLS	OIL AND GREASE	SURFACTANTS	TOC	NH_3	SULFIDE	Cr TOTAL	Cr 6	ZINC	K. NITROGEN	FECAL COLIFORM	NO_3-N	ORGANIC N	T. PHOSPHORUS	FLUORINE	HEAT	COPPER	ALUMINUM	CYANIDE	MANGANESE	NICKEL	ARSENIC	CHLORINE	IRON	LEAD	MERCURY	T. DISSOLVED SOLIDS
1. PULP, PAPER AND PAPERBOARDS	X	X	X	X																												
2. BUILDERS PAPER AND BOARD	X	X	X																													
3. TIMBER PRODUCTS	X	X	X		X	X	X																									
4. SOAP AND DETERGENTS	X	X	X		X		X	X																								
5. DAIRY PRODUCTS	X	X	X																													
6. ORGANIC CHEMICALS	X	X	X		X	X																										
7. PETROLEUM REFINING	X	X	X		X	X	X		X	X	X	X	X																			
8. LEATHER TANNING AND FISHING	X	X	X				X				X	X			X	X																
9. CANNED AND PRESERVED FRUITS AND VEGETABLES	X	X	X													X																
10. NONFERROUS METALS		X	X		X					X										X		X	X									
11. GRAIN MILLS	X	X	X																													
12. SUGAR PROCESSING	X	X	X													X					X											
13. FERTILIZERS		X	X				X			X							X	X	X	X												
14. ASBESTOS		X	X		X																											
15. MEAT PRODUCTS	X	X	X				X			X						X																
16. FERROALLOYS		X	X			X						X	X								X			X		X						
17. GLASS	X	X	X		X	X	X												X													
18. ELECTROPLATING		X	X									X	X	X								X		X		X						
19. PHOSPHATE MANUFACTURING		X	X																X	X							X					X
20. FEEDLOTS	X															X																
21. CEMENT MANUFACTURING		X	X																		X											X
22. RUBBER PROCESSING	X	X	X		X		X																									
23. PLASTICS AND SYNTHETICS	X	X	X		X	X						X		X																		
24. INORGANIC CHEMICALS		X	X		X				X			X	X							X				X					X	X	X	
25. IRON AND STEEL		X	X			X	X			X				X			X			X			X		X						X	
26. TEXTILES	X	X	X	X	X	X	X					X				X																
27. STEAM ELECTRIC GENERATING EQUIPMENT		X	X				X														X	X						X	X			
28. SEAFOOD PROCESSING	X	X	X				X																									
TOTALS:	18	27	27	2	11	8	12	1	2	5	2	7	4	3	1	6	2	1	3	5	4	3	2	3	1	2	1	1	2	1	2	2

are based upon an effluent standard of secondary treatment. Secondary treatment is defined in 40 CFR 133.102 and consists of:

Parameter	7-day Average	30-day Average
BOD_5	45 mg/ℓ	30 mg/ℓ
Suspended Solids	45 mg/ℓ	30 mg/ℓ
Fecal Coliform Bacteria (geometric mean)	400/100 mℓ	200/100 mℓ
Removal Efficiency		85 percent
pH	6.0 - 9.0	

The recommended procedure is to examine the sources and processes involved in the study area and, on the basis of need-to-know and reasonable expectation, select measurement parameters accordingly. Flow should always be included. Parameters should not be limited to those that are known to be a problem, but should also include those that can reasonably be expected to become a problem. The 208 monitoring program should identify new problems as well as track existing ones. The results of early analyses should be used to assess parameter coverage and assist in determining whether an increase or decrease is warranted. Resist the temptation to "look at the whole world." Analyses cost money, and wise resource management dictates that only parameters, the knowledge of which directly supports specific study objectives, should be included. Put in writing a justification for each parameter selected. Use the Parameter Handbook for guidance.

D.2.2.1 Parameters for Storm-Generated Discharges

Parameter selection will be facilitated by initially considering water quality characteristics in gross categories rather than as specific compounds or elements. As an example, the following treats the quality characteristics considered important for storm-generated discharges. See Wullschleger et al. (7) for elaboration.

D.2.2.1.1 Oxygen Demand

One of the most important quality characteristics in a receiving body of water is the dissolved oxygen concentration. The dissolved oxygen concentration has a direct bearing on the quality and natural balance of much of the aquatic biota. Dissolved oxygen concentration can also have an effect on the recreational and aesthetic uses of a body of water. Storm-generated discharges that contain organic and inorganic compounds that exert a demand for the oxygen dissolved in water can be considered pollutional discharges in the same sense as dry-weather municipal wastewaters.

Oxygen demand is exerted by (1) organic compounds that undergo biochemical oxidation as a result of microbial activity and (2) by the immediate demand exerted by the chemical oxidation of inorganic reduced compounds. However, storm-generated discharges have certain characteristics different from municipal sewage that affect not only the DO level in the receiving waters, but also the conventional tests used to measure oxygen demand. Since combined sewer overflows have a variety of sources other than just municipal sewage, the discharges may contain materials that cause special problems. During dry weather, when flow through a combined sewer system is low, solids settle out. At the start of a storm, the first flush of water through the system may have a high concentration of solids that affects the demand characteristics of the waste. It has been found that the fraction of BOD in the particulate form can range from 69 to 87 percent, which is considerably higher than the 30 to 50 percent present in most municipal wastewaters. Also, combined sewer overflows from industrial areas and urban runoff may contain oils, toxic materials and chemicals which are foreign to the natural environment and interfere with traditional oxygen demand tests. Finally, storm-generated discharges contain a large amount of natural materials such as silt, vegetation, wood, and other materials such as plastic that may not exert an immediate demand but will eventually use the oxygen required for decomposition. These characteristics cause these discharges to be different from that waste normally encountered in sanitary analyses.

There are numerous tests available for use as potential oxygen demand indicators, including BOD_5, BOD_{20}, BOD_X, ΔCOD, COD, TOC, and TOD. The desired test should have a well established, standardized test procedure and provide a measurement of the total oxygen demand on the environment. No single analytical test can meet both of these criteria. Therefore, two parameters are recommended to indicate oxygen demand for storm-generated discharges, TOD and BOD_5. TOD reflects the long-term demand, allowing correct determination of discharge effects, and lacks the serious interference problems of other tests, notably COD. BOD_5 is recommended, despite its numerous disadvantages, because of its widespread and historical use. Also, because of toxicity effects on the BOD_5 test, comparison of BOD_5 and TOD results can yield information about the degree of toxicity and its possible effect on the natural environment.

D.2.2.1.2 Particulate Concentration

The solid matter present in storm-generated discharges can be divided into two major categories; namely, particulate solids and dissolved solids. Particulate solids are important in combined sewer overflows and storm runoff applications because they usually represent a large fraction of the total solids. Also, these solids are generally removed from the flow by physical treatment processes such as sedimentation, screening, flotation, and filtration--the type of processes most commonly used for storm-generated discharges. It is, in fact, the relatively high concentration of particulate solids in these flows which makes such processes attractive.

The recommended parameter for indicating particulate concentration in storm-generated discharges is nonfilterable residue (suspended solids). The analysis is routine and not as time consuming and cumbersome as some of the other particulate tests and, with a few additional steps, both the volatile and fixed portions can be determined, yielding another useful piece of information in most instances. Where settleable residue is desired, the gravimetric method is recommended, not the Imhoff cone. Turbidity measurements provide little comparable data about particulate matter or concentration and are not recommended for this purpose.

D.2.2.1.3 Pathogenic Microorganism Potential

Any discharge that includes waters which have come into contact with excrement from warm-blooded animals of any type should be considered as having the potential for conveying pathogenic bacteria, viruses, protozoa, and other contagions. It is extremely difficult, if not logistically impossible, to monitor these discharges for the many pathogens themselves. This problem was recognized in the water supply field many years ago and has led to the almost universal usage of the coliform group of bacteria as the indicator or measure of the sanitary quality of water. The coliforms themselves are not necessarily pathogenic, but their presence should infer the possible presence of pathogens. However, for a number of reasons the coliform group is not necessarily the most sensitive indicator as far as storm-generated discharges are concerned.

The recommended indicator parameters are fecal coliform and fecal streptococcus. Furthermore, it is recommended that the membrane filter (MF) technique be used rather than the multiple tube fermentation procedure where results are expressed as the most probable number (MPN) statistic.

D.2.2.1.4 Eutrophic Potential

In addition to sunlight and carbon dioxide, aquatic plants require nutrients and trace salts. The principal nutrients are compounds which contain the elements phosphorus, nitrogen, and potassium. The proliferation of aquatic plants in most water bodies is undesirable. The term "eutrophic" refers to a condition in a water body where copious plant growth has resulted in an undesirable or unsightly situation of accelerated lake deterioration. Although eutrophication is a natural process, it can be accelerated by man's activities.

Nitrogen and phosphorus are measures of the eutrophic potential of storm-generated discharges. It is recommended that two nitrogen analyses be conducted, nitrate plus nitrite (run by reducing nitrate to nitrite and measuring the latter) and Kjeldahl. Of the 14 different phosphorus fractions, total phosphorus is the recommended parameter.

D.2.2.1.5 Toxic and Related Substances

A large number of compounds of varying toxicity and concentration are likely to be found in combined sewer overflows and storm runoff. However, the toxicants of major concern can be divided into the general categories of heavy metals, pesticides, and herbicides.

When studying the quality of storm flows, it is recommended that a composite sample of the flow be analyzed for lead, zinc, copper, chromium, mercury, cadmium, arsenic, nickel, and tin four times a year (seasonally). Based upon the results of these tests, a decision can be made as to how often certain heavy metals will have to be analyzed thereafter. It is expected that lead, zinc, copper, and chromium may be measured routinely. In certain combined sewer areas serving known industries, or in certain storm sewer discharges from areas of heavy vehicular traffic, it may be necessary to do more frequent analysis.

Because of the wide variability of pesticides in use, the periodic nature of their application depending upon season and nature of the drainage area, and the complexity of the laboratory analyses, no pesticides or associated compounds are recommended for routine analysis. However, it is recommended that, when evaluating the quality of a storm-generated discharge, a study of the drainage area should be made to determine the likelihood of pesticide application (and the type) and if it is probable that the storm flow may contain pesticides. At least one discharge should be analyzed to see if that pesticide is present. Depending upon this result, a decision can be made as to whether more analyses are needed.

D.2.2.1.6 Other Parameters

There are a host of other parameters that can be used to characterize storm-generated discharges. In the absence of site specific concerns, however, only pH is recommended for routine measurement.

D.2.2.2 Parameters for a National Water Quality Monitoring Program

As a further aid in parameter selection, the proposed minimum parameter list for a national water quality monitoring program will be discussed. Temperature, pH, and dissolved oxygen are included because they are the primary constituents in most chemical reactions that occur within the water-body. They are also the essential factors that govern whether the ecosystem will maintain aquatic life. A conductivity measurement is included to determine the degree to which dissolved solids contribute to the water quality. This is a most reliable measurement and can be done on site. Salinity is measured in estuaries and bays.

Fecal coliform is included because it is, at present, the most reliable test for indicating the possible presence of pathogenic microorganisms in the system. Trace metals were limited to those that are of high priority and are toxic. Since the concern of the program is to measure the total load, total metals instead of dissolved forms are measured.

In order to determine the extent of total nutrient contribution, total phosphorus, total Kjeldahl nitrogen, and nitrite and nitrate are measured. Since the basic concern of the program is the total nutrient load, total phosphorus is measured instead of the other various forms of phosphorus.

This is also more economically sound. In determining the contribution of nitrogen to the system, the concern of the program is also to arrive at some understanding of the stage of nitrification within the system. Therefore, total Kjeldahl nitrogen is included as a measurement of organic nitrogen and ammonia, and nitrate and nitrite are included to determine the extent of oxidized nitrogen.

A total suspended solids measurement is included to measure the contribution of solid material to the system and to give some indication of water clarity and the probability of chemical adsorption.

A chemical oxygen demand (COD) measurement is included to get an indication of the oxygen demand placed on the system. Chemical oxygen demand was chosen over biochemical oxygen demand (BOD) and total organic carbon (TOC) because it is more reliable than BOD, does not involve problems with holding time and sample transport as do BOD samples, and does not require the sophisticated equipment required of a TOC measurement. COD is not measured in lakes and impoundments because it is usually found only in such low concentrations that it renders the measurement meaningless. TOC is measured in estuaries because the COD measurement does not yield satisfactory results in salt water due to chloride interference.

The trace organics included in the program were chosen because they appear most frequently on several USEPA priority lists relating to toxic substances; for example, measurements required for the permit program, measurements required for the drinking water program, the Section 307(a) list, and several listings proposed by the Office of Toxic Substances.

The effects of contaminants on aquatic organisms are complex. Synergistic chemical/physical reactions, biomagnification, and other natural events cannot be easily quantified. For these reasons and for the purposes of the program, the best approach to determine the presence and potential health threat of toxic substances in the ecosystem appears to be the chemical analysis of fish and shellfish tissue. This has, therefore, been included in the monitoring program.

D.2.2.3 Parameters for Waste Load Allocations

As an example of possible parameter coverage for waste load allocation surveys, Tables D-5 and D-6 indicate minimum parameters for the preliminary and primary intensive surveys discussed in Section D.2.1.2. The measurement locations indicated in the tables are those described in Section D.2.1.2. In addition to the indicated parameters, it will usually be desirable to perform a metals and pesticide scan on at least one sample from the preliminary survey and, based on the results, consider additional parameters for the primary low flow survey.

D.2.3 Measurement Frequency Selection

Monitoring frequencies are established by the variations of the system (sources and receiving water) and the nature of the pollutants (conservative and nonconservative). Frequencies selected should be adequate to account for variations in the flows and quality of pollution sources, the variations in stream flow, and tidal action. This establishes a spectrum ranging from a periodic grab sample (suitable for the rare steady-state condition) to continuous collection over a suitable time period.

D.2.3.1 Frequency for Background and Trend Data

Background and trend data must be representative of the variations in water quality and changes in pollution occurring over the course of a year, and the measurement frequency must be less than the shortest anticipated frequency of pollutant variation. To aid in such sampling frequency determination, Tables D-7, D-8, and D-9 present the proposed sampling frequencies for the national water quality monitoring program for rivers and streams, lakes and impoundments, and estuaries and bays.

The sampling frequencies given in the foregoing represent the bare minimum and, depending upon the anticipated variability, considerations should be given to utilizing more frequent intervals. If at all possible, new stations should be sampled on a weekly or biweekly basis for the first 6 months to

TABLE D-5
PARAMETERS FOR PRELIMINARY SURVEY

Location	DO	Temp	Distance Downstream	Travel Time	Flow Measurement	BOD_{20}	BOD_{20} Inh	Nitrogen Compounds
A	x	x			x		x	x
B	x	x			x	x	x	x
C	x	x	x	x	x			
D_i	x	x	x	x*				
E	x	x	x		x			
F	x	x	x		x			
G_i	x	x	x	x*				
H	x	x	x	x				
I_i	x	x	x	x*	x*			

* Measurements need be taken at only one of the multiple locations designated by each of D_i, G_i, or I_i.

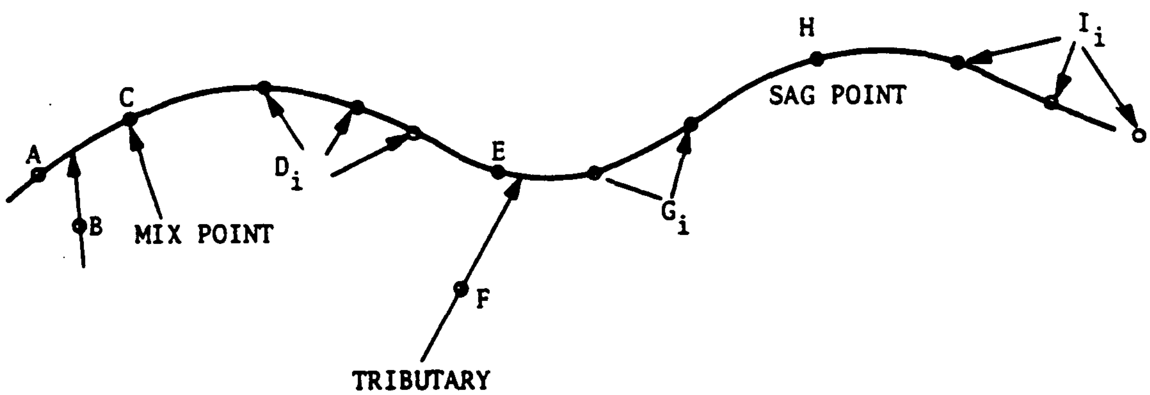


TABLE 6
PARAMETERS FOR PRIMARY SURVEY

Location	DO	pH	Temp	Distance Downstream	Travel Time	Flow Measurement	Continuous DO	Nitrogen Compounds	BOD_5	BOD_5 Inh	BOD_{20} Inh
A	x	x	x			x		x			x
B	x	x	x			x		x	x	x	x
C	x	x	x	x	x	x	x	x			x
D_i	x	x	x	x	x			x		x	
E	x	x	x	x	x	x				x	
F	x	x	x	x		x		x			x
G_i	x	x	x	x	x			x		x	
H	x	x	x	x	x		x	x			x
I_i	x	x	x	x	x	x*		x		x	

* Measurements need be taken at only one of the multiple locations designated by I_i.

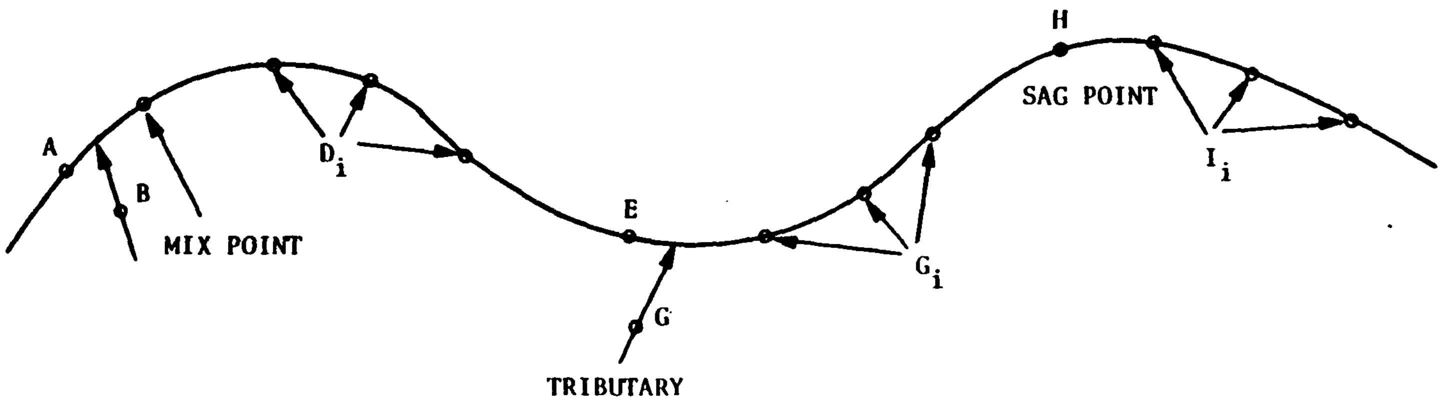


TABLE D-7
PARAMETER LIST AND SAMPLING FREQUENCY
FOR THE NATIONAL MONITORING PROGRAM

Rivers and Streams	
Parameter (Units) (STORET Parameter Code)	Sampling Frequency
Temperature (C°) (00010)	Monthly
Dissolved oxygen (mg/ℓ) (00300)	Monthly
pH (Standard Units) (00400)	Monthly
Conductivity (UMHOS/cm @ 25°C) (00095)	Monthly
Fecal Coliform (No./100mℓ) (31616)	Monthly
Total Kjeldahl nitrogen (mg/ℓ) (00625)	Monthly
Nitrate + nitrite (mg/ℓ) (00630)	Monthly
Total phosphorus (mg/ℓ) (00665)	Monthly
Chemical oxygen demand (mg/ℓ) (00335)	Monthly
Total suspended solids (mg/ℓ) (00530)	Monthly
Representative fish/shellfish tissue analysis (see Table D-9)	Annually
Flow (CFS) (00060)	Monthly

TABLE D-7
PARAMETER LIST AND SAMPLING FREQUENCY
FOR THE NATIONAL MONITORING
PROGRAM (Cont'd)

Lakes and Impoundments, Including the Great Lakes	
Parameter (Units) (STORET Parameter Code)	Sampling Frequency
pH (Standard Units) (00400)	Seasonally
Temperature (°C) (00010)	Seasonally
Dissolved oxygen (mg/ℓ) (00300)	Seasonally
Conductivity (UMHOS/cm @ 25°C) (00095)	Seasonally
Fecal Coliform (No./100mℓ) (31616)	Seasonally
Total phosphorus (mg/ℓ) (00665)	Seasonally
Total Kjeldahl nitrogen (mg/ℓ) (00625)	Seasonally
Nitrate + nitrite (mg/ℓ) (00630)	Seasonally
Total suspended solids (mg/ℓ) (00530)	Seasonally
Representative fish/shellfish tissue analysis (see Table D-9)	Annually
Transparency Secchi Disk (Meters) (00078)	Monthly

TABLE D-7
PARAMETER LIST AND SAMPLING FREQUENCY
FOR THE NATIONAL MONITORING
PROGRAM (Cont'd)

Estuaries and Bays	
Parameter (Units) (STORET Parameter Code)	Sampling Frequency
Temperature (°C) (00010)	Monthly
Dissolved oxygen (mg/ℓ) (00300)	Monthly
Total organic carbon (mg/ℓ) (00680)	Monthly
pH (Standard Units) (00400)	Monthly
Salinity (°/oo) (00480)	Monthly
Fecal Coliform (No./100mℓ) (31616)	Monthly
Transparency Secchi Disk (Meters) (00078)	Monthly
Total Kjeldahl nitrogen (mg/ℓ) (00625)	Monthly
Total phosphorus (mg/ℓ) (60665)	Monthly
Nitrate + nitrite (mg/ℓ) (00630)	Monthly
Total suspended solids (mg/ℓ) (00530)	Monthly
Representative shellfish tissue analysis (see Table D-9)	Annually

TABLE D-8
TRACE ORGANICS AND METALS ANALYSES FOR WATER COLUMN[1]

Parameter (STORET), (μg/1)	
PCBs (39516)	Endrin (39390)
Aldrin (39330)	Methoxychlor (39480)
Dieldrin (39380)	Hexachlorobenzene (39700)
o,p-DDE (39327)	Pentachlorophenol (39032)
p,p'-DDE (39320)	Hexachlorocyclohexane
o,p-DDD (39315)	α-BHC (39334)
p,p'-DDD (39310)	γ-BHC (39810)
o,p-DDT (39305)	Arsenic (01002)
p,p'-DDT (39300)	Cadmium (01027)
Chlordane	Chromium (01042)
cis isomer (39062)	Copper (01034)
trans isomer (39065)	Mercury (71900)
cis nonachlor (39068)	Lead (01051)
trans nonachlor (39071)	

(1) For water column analysis when applicable (24).

TABLE D-9
TRACE ORGANICS AND METALS ANALYSES FOR FISH/SHELLFISH TISSUE AND SEDIMENT

Parameter (STORET:tissue, STORET:sediment), (μg/g tissue, μg/kg sediment)	
PCBs (39520,39519)	Endrin (39397, 39393)
Aldrin (39334, 39333)	Methoxychlor (39482, 39481)
Dieldrin (39387, 39383)	Hexachlorobenzene (39703, 39701)
o,p-DDE (39329, 39328)	Pentachlorophenol (39060, 39061)
p,p'-DDE (39322, 39321)	Hexachlorocyclohexane
o,p-DDD (39325, 39316)	α-BHC (39074, 39076)
p,p'-DDD (39312, 39311)	γ-BHC (39075, 39811)
o,p-DDT (39318, 39306)	Arsenic (01004, 01003)
p,p'-DDT (39302, 39301)	Cadmium (71940, 01028)
Chlordane	Chromium (71939, 01029)
cis isomer (39063, 39064)	Copper (71937, 01039)
trans isomer (39066, 39067)	Mercury (71930, 71921)
cis nonachlor (39069, 39070)	Lead (71936, 01052)
trans nonachlor (39072, 39073)	

1 year of operation or until the data indicate that less frequent sampling is warranted.

Fish samples should be collected annually in the fall, since contaminant concentrations are at their maximum at this time of year. Only fish samples that will be most representative of the water quality in the area of interest should be collected for tissue analysis. Migratory species should be discounted. Two replicate whole fish composite samples of a representative bottom feeder and one whole fish composite sample of a predator species should be collected at each station. Commercially or recreationally important species should be collected wherever possible. Each composite should include at least five fish, each of approximately the same size. Because of their sedentary existence and great water-filtering capabilities, shellfish are excellent concentrators of contaminants. Therefore, wherever possible, shellfish samples should be collected and analyzed, especially in estuarine environments.

Where incidents of fish kill occur, the appropriate information should be recorded. This should include the date of occurrence (or period if it persists), the location or affected area, the species affected, estimates of the magnitude of the kill (i.e., number of fish), and any other information that would be useful. The frequency and magnitude of such events should decrease as a result of implementing the areawide plans, and this can be a dramatic way of indicating progress.

D.2.3.2 Frequency for Waste Load Allocation Surveys

Samples could be taken at any convenient time if stream conditions did not vary. The necessary number of samples would be only that dictated by the desired degree of precision of the results, taking into account the precision of the laboratory analytical methods. In theory, the times of collection and numbers of samples are dictated by the need to ensure both an acceptable measure of the variations in stream conditions and an acceptable precision of laboratory analysis. In practice, these considerations are tempered by inescapable limitations of budget, personnel, and facilities, and frequently by the amount of time available.

There is no fixed number of samples that will yield results within selected limits of precision in all situations. The number of samples needed for any point on a stream varies with the variability in water quality at that point. A preliminary estimate of the variability can be calculated after a limited number of analytical results has been obtained. A preliminary prediction of the number of samples needed to ensure final results within selected confidence limits can be based on the preliminary estimate of variability. The prediction can be refined as the number of analytical results is increased until the point is reached at which a firm prediction of the number of samples required becomes possible. Data from a previous study under comparable conditions may be used to determine variability and predict the number of samples required.

In the absence of better information, daily grab samples should be taken from each stream measurement site over at least a 14-day period. Furthermore, the time of sampling at each site should be varied as much as possible to indicate any diurnal variations. Try to collect at least one set of samples at night to indicate photosynthetic effects. Review the analytical results from the early samples, and adjust the frequency accordingly.

For continuous point source discharges, the sampling frequency will also be dependent upon anticipated pollutant variability. If knowledge about the time-varying characteristics of the discharge is required, collect a sequential discrete sample series. Hourly time steps will be adequate for most continuous discharges, but in some instances either shorter time periods or flowmeter pacing will be required. If only average daily loadings are required, twenty-four-hour, flow proportional composite samples represent the best approach. These should be taken over a minimum of five consecutive days, and longer if variability indicates.

D.2.3.3 Frequency for Storm Generated Discharges

For intermittent storm related discharges, measurement frequencies must be quite short, especially for model calibration and verification where knowledge of temporal variations is very important. The measurement interval required is related to catchment size, shape, slope, and percent imperviousness. During sampling of the first few storms in a catchment, it is prudent to estimate sampling intervals on the short side. They can be increased later if the data warrant. Model input frequency requirements must also be considered. Suggested minimum measurement intervals are given in Table D-10. The first sample should be collected as close to the beginning of the storm-generated runoff as possible. This can be accomplished by triggering an automatic sampler at a predetermined indication of stage or rate of rise. Subsequent samples can be paced by timer settings or a flowmeter with flow increments selected so that the rising limb is well characterized. It may not be necessary to analyze all samples on the falling limb. Early data analysis will indicate if some can be eliminated or composited and still allow adequate discharge characterization.

D.3 Flow Measurement Considerations, Equipment, and Procedures

Although flow can be thought of as simply another parameter, it is so often neglected that it should properly be considered as an essential component of a monitoring program. Flow measurements are absolutely necessary for mass discharge calculations, stream and runoff studies, and model calibration and verification.

D.3.1 General Considerations

Concentrations of natural constituents, such as alkalinity, hardness, and minerals, generally vary inversely with stream flows. Total loads, or quantities, of natural constituents carried by a stream, on the other hand, increase as flow increases. The increasing water carried by the stream more than balances the decreasing concentration to yield a greater load in terms of a unit of total quantity, such as pounds per day. Other factors come into play with unstable constituents. Time-of-water travel increases as flow decreases, and this serves to accomplish natural purification in shorter distances. Higher densities of bacteria, for example, occur just below the

TABLE D-10
MAXIMUM MEASUREMENT INTERVALS

		Desirable Maximum Measurement Interval (min)	
Catchment Size	Variable	Highly Impervious Catchment	Highly Pervious Catchment
50 acres	Rainfall	2	3
	Flow	2	3
	Water Quality	3	4
100 acres	Rainfall	3	5
	Flow	3	5
	Water Quality	4	7
600 acres	Rainfall	5	12
	Flow	5	12
	Water Quality	7	20
3000 acres	Rainfall	12	20
	Flow	12	20
	Water Quality	15	30

point of discharge at lower flows, but they die off in shorter distances because of the longer time of travel. Likewise, BODs are higher near the point of discharge but stabilize in shorter distances at low discharges.

The natural flow of uncontrolled streams usually varies over a wide range. Stream flows follow precipitation patterns except in the colder areas of the country, where precipitation falls as snow in winter and much of the surface water is frozen. There can be wide differences in stream flow throughout the year and in the annual flow cycle from year to year. Flow in most areas tends to be high in late winter and to taper off to minimum quantities in the fall. High flows usually occur in colder areas when relatively warm spring rains melt the winter accumulation of ice and snow. However, the natural cycle may be altered to a considerable extent in streams controlled by impoundments. Thus, stream flows must be considered in selecting periods for stream study because of the considerable variations in water quality that accompany changes in flow. The objectives of the study are important in this selection, as they are in other decisions.

In manmade conduits, the effects of flow variation are probably greatest in storm sewers. Although storm sewers are basically designed to carry storm runoff, during periods of no rainfall they often carry a small but significant flow (dry weather flow). This may be flow from ground water, or "base flow," which gains access to the sewer from unpaved stream courses. Much of the dry weather flow in storm sewers is composed of domestic sewage or industrial wastes or both. Where ordinances concerning connections to sewers are lax or are not rigidly enforced, unauthorized connections to storm sewers will appear. In some cases, the runoff from septic tanks is carried to them. Connections for the discharge of swimming pools foundation drains, sump pumps, cooling water, and pretreated industrial process water to storm sewers are permitted in many municipalities and contribute to flow during periods of no rainfall. In some areas, sewers classed as storm sewers are, in fact, sanitary or industrial waste sewers due to the unauthorized or inappropriate connections made to them. This may become so aggrevated that a continuous flow of sanitary or industrial wastes, or both, discharges into the receiving stream. Furthermore, this "dry-weather" portion of storm sewer flow may vary significantly with time.

Storm runoff is the excess rainfall which runs off the ground surface after losses resulting from infiltration to ground water, evaporation, transpiration by vegetation, and ponding occur. In general, storm runoff is intermittent in accordance with the rainfall pattern for the area. It is also highly variable from storm to storm and during a particular storm. The time-discharge relationship, or hydrograph, of a typical storm, with its synchronous time-precipitation relationship, or hyetograph, is illustrated in Figure D-3. The meanings of various parameters given in the figure are:

R_p - Rainfall retained on the permeable portion of the drainage basin, and not available for runoff.

P_e - Precipitation in excess of that infiltrated into the ground, plus that retained on the surface. (Equals the volume of flood runoff.)

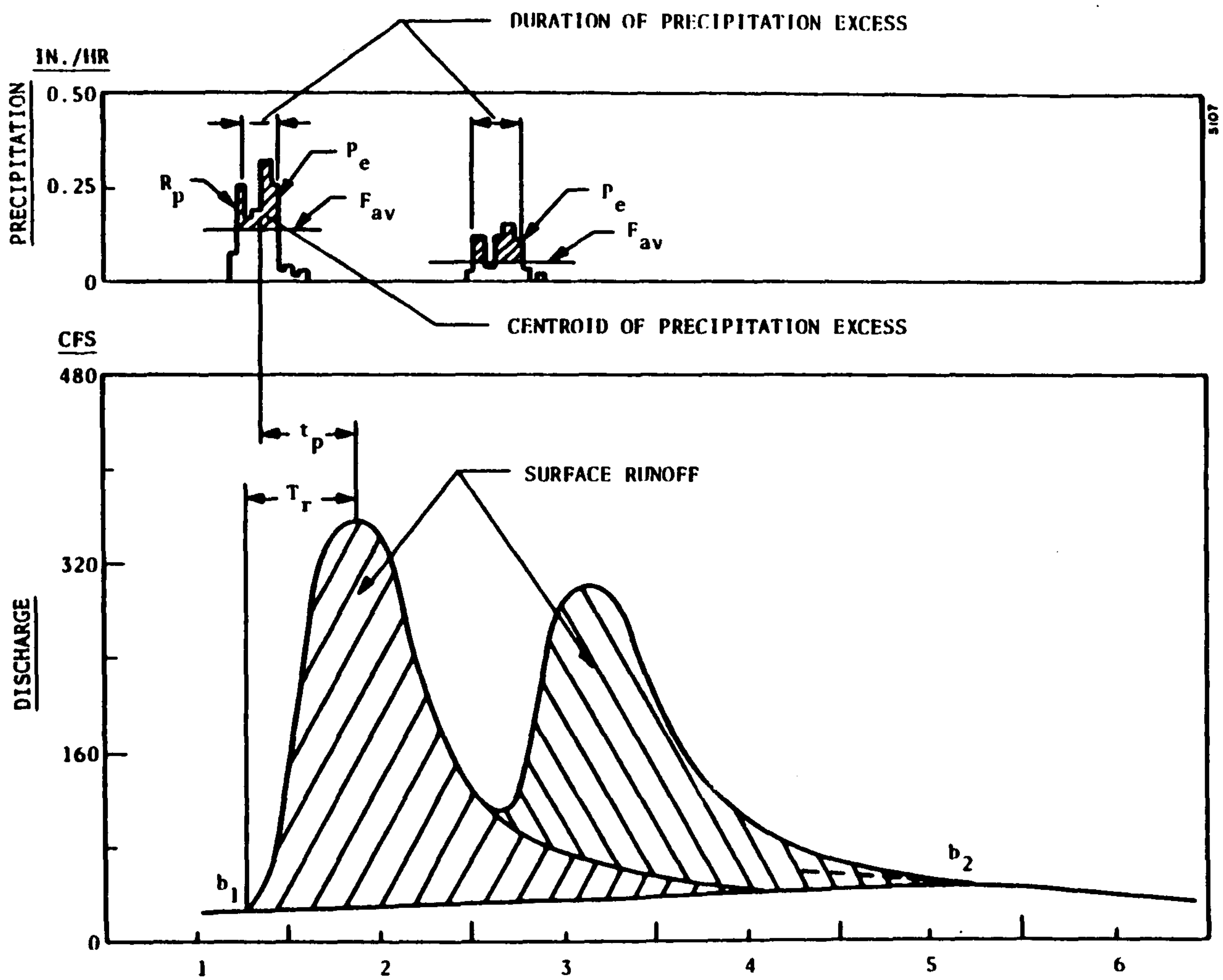
F_{av} - Average infiltration of the ground during the storm.

T_r - Period of rise from the beginning of storm runoff to peak of the hydrograph.

T_p - Time from center of gravity of rainfall excess to the hydrograph peak (lag time).

b_1, b_2 - Baseline separating groundwater discharge from surface runoff.

The total volume of runoff for a particular storm is represented by the areas between the baseline and the hydrograph.



NOTE: 1 INCH = 2.54 CM
1 CUBIC FOOT = 28.3 LITERS

FIGURE D-3
TYPICAL STORM HYETOGRAPH AND HYDROGRAPH

To illustrate some of the problems in measuring storm runoff in small basins, peak flows exceeding 85 cubic meters per second per 260 hectares (3000 cfs per square mile) have been observed. Lag times (t_p) of 15 minutes to a hydrograph peak of about 28 cubic meters per second (1000 cfs) from a 600-hectare (2.3 sq mi) area are not uncommon. With such rapid changes in the flow, only highly responsive flow measurement methods can be used. The high rates of flow, with accompanying high velocities, further limit the usable flow measuring methods.

All flow data must be synchronized with time, at least on a watch time basis, to have any useful meaning. A particular need for attention to the time element occurs in the measurement of flows from small urban storm sewers in order to define the hydrograph and to provide data for the development and verification of rainfall-runoff-quality models. Peak flows, storm runoff volumes, daily flows, or other flow parameters are often correlated with similar flows at other points on a storm sewer or stream, or with flows of other storm sewers or streams, to provide a means for flow estimation. Correlations with temperature, soil moisture, or antecedent precipitation may be made at times. In most cases, it is essential that the correlated variables be synchronous, so accurate timing of the data is often required. It is mandatory if time-series analysis is contemplated.

Timing of measured flows and collection of quality samples can be useful in determining sources of pollution. For example, they can be related to time of release of pollutants from industrial plants, or to the time of accidental spills of pollutants. The time of travel of pollutants along a stream or storm sewer can be estimated from the time of travel of small rises or other flow changes in the channel.

D.3.2 Flow Measurement Equipment

This brief discussion is intended to provide an overview to aid the 208 planner in the selection of equipment for the quantitative measurement of flows. For further reading, see Shelley and Kirkpatrick (8), ASME (9), Replogle (10), McMahon (11), USDI Bureau of Reclamation (12), Leupold and Stevens (13), and any of the many standard texts on hydraulics and fluid mechanics.

Any flow measurement system consists of two distinct parts, each having a separate function to perform. The first, or primary element, is that part of the system which is in contact with the fluid, resulting in some type of interaction. The secondary element is that part of the system which translates this interaction into the desired readout or recording. While there is almost an endless variety of secondary elements, primary elements are related to a more limited number of physical principles, being dependent upon some property of the fluid other than, or in addition to, its volume or mass such as kinetic energy, inertia, specific heat, or the like. These primary element physical principles form a natural classification system for flow-measuring devices as presented in Table D-11.

D.3.2.1 Desirable Equipment Characteristics

Not all types of flow meters are suitable for measuring wastewater flows. The severe conditions and vagaries of many of these flows place a number of very stringent design requirements on flow measurement equipment if it is to function satisfactorily. No single design can be considered ideal for all flow measurement activities in all flows of interest. Despite this, one can set forth some equipment "requirements" in the form of primary design considerations and some desirable equipment features in the form of secondary design considerations.

The following are primary design considerations for equipment that is to be used to measure more difficult wastewaters such as storm and combined sewer flows:

1. Range. Since flow velocities may range from 0.03 to 9 m/s (0.1 to 30 fps), it is desirable that the unit have either a very wide range of operation; be able to automatically shift scales; or otherwise cover at least a 100 to 1 range.

TABLE D-11
FLOW METER CATEGORIZATION

Division	Classification	Type	Subtype
Quantity	Gravimetric	Weigher	
Quantity	Gravimetric	Tilting Trap	
Quantity	Gravimetric	Weight Dump	
Quantity	Volumetric	Metering Tank	
Quantity	Volumetric	Reciprocating Piston	
Quantity	Volumetric	Oscillating or Ring Piston	
Quantity	Volumetric	Nutating Disc	
Quantity	Volumetric	Sliding Vane	
Quantity	Volumetric	Rotating Vane	
Quantity	Volumetric	Gear or Lobed Impeller	
Quantity	Volumetric	Dethridge Wheel	
Rate	Differential Pressure	Venturi	
Rate	Differential Pressure	Dall Tube	
Rate	Differential Pressure	Flow Nozzle	
Rate	Differential Pressure	Rounded Edge Orifice	
Rate	Differential Pressure	Square Edge Orifice	Concentric
Rate	Differential Pressure	Square Edge Orifice	Eccentric
Rate	Differential Pressure	Square Edge Orifice	Segmented
Rate	Differential Pressure	Square Edge Orifice	Gate or Variable Area
Rate	Differential Pressure	Centrifugal	Elbow or Long Radius Bend
Rate	Differential Pressure	Centrifugal	Turbine Scroll Case
Rate	Differential Pressure	Centrifugal	Guide Vane Speed Ring
Rate	Differential Pressure	Impact Tube	Pitot-Static
Rate	Differential Pressure	Impact Tube	Pitot Venturi
Rate	Differential Pressure	Linear Resistance	Pipe Section
Rate	Differential Pressure	Linear Resistance	Capillary Tube
Rate	Differential Pressure	Linear Resistance	Porous Plug
Rate	Variable Area	Gate	
Rate	Variable Area	Cone and Float	
Rate	Variable Area	Slotted Cylinder and Piston	
Rate	Head-Area	Weir	Sharp Crested
Rate	Head-Area	Weir	Broad Crested
Rate	Head-Area	Flume	Venturi
Rate	Head-Area	Flume	Parshall
Rate	Head-Area	Flume	Palmer-Bowlus
Rate	Head-Area	Flume	Diskin Device
Rate	Head-Area	Flume	Cutthroat
Rate	Head-Area	Flume	San Dimas
Rate	Head-Area	Flume	Trapezoidal
Rate	Head-Area	Flume	Type HS, H, and HL
Rate	Head-Area	Open Flow Nozzle	
Rate	Flow Velocity	Float	Simple
Rate	Flow Velocity	Float	Integrating
Rate	Flow Velocity	Tracer	
Rate	Flow Velocity	Vortex	Vortex-Velocity
Rate	Flow Velocity	Vortex	Eddy-Shedding
Rate	Flow Velocity	Turbine	
Rate	Flow Velocity	Rotating Element	Horizontal Axis
Rate	Flow Velocity	Rotating Element	Vertical Axis
Rate	Force-Displacement	Vane	
Rate	Force-Displacement	Hydrometric Pendulum	
Rate	Force-Displacement	Target	
Rate	Force-Displacement	Jet Deflection	
Rate	Force-Displacement	Ball and Tube	
Rate	Force-Momentum	Axial Flow Mass	
Rate	Force-Momentum	Radial Mass	
Rate	Force-Momentum	Gyroscopic	
Rate	Force-Momentum	Mangus Effect	
Rate	Thermal	Hot Tip	
Rate	Thermal	Cold Tip	
Rate	Thermal	Boundary Layer	
Rate	Other	Electromagnetic	
Rate	Other	Acoustic	
Rate	Other	Doppler	
Rate	Other	Optical	
Rate	Other	Dilution	
Rate	Other	Electrostatic	
Rate	Other	Nuclear Resonance	

2. Accuracy. For most purposes, an accuracy of ±10 percent of the reading at the readout point is necessary, and there will be applications where an accuracy of ±5 percent is highly desirable. Repeatability of better than ±2 percent is desired in almost all instances.

3. Flow Effects on Accuracy. The unit should be capable of maintaining its accuracy when exposed to rapid changes in flow; e.g., depth and velocity changes in an open channel flow situation. There are instances where the flows of interest may accelerate from minimum to maximum in as short a time period as 5 minutes.

4. Gravity and Pressurized Flow Operation. Because of the conditions that exist at many measuring sites, it is sometimes desirable that the unit have the capability (within a closed conduit) of measuring over the full range of open channel flow as well as the conduit flowing full and under pressure.

5. Sensitivity to Submergence or Backwater Effects. Because of the possibility of changes in flow resistance downstream of the measuring site due to blockages, rising river stages including possible reverse flow, etc., it is highly advantageous that the unit be able to continue to function under such conditions or, at a minimum, be able to sense the existence of such conditions which would lead to erroneous readings.

6. Effects of Solids Movement. The unit should not be seriously affected by the movement of solids such as sand, gravel, debris, etc., within the fluid flow.

7. Flow Obstruction. The unit should be as nonintrusive as possible to avoid obstruction or other interference with the flow, which could lead to flow blockage or physical damage to some portion of the device.

8. Head Loss. To be usable at a maximum number of measurement sites, the unit should induce as little head loss as possible.

9. Manhole Operation. To allow maximum flexibility in utilization, the unit should have the capability of being installed in confined and moisture-laden spaces such as sewer manholes.

10. Power Requirements. The unit should require minimum power at the measuring site to operate; the ability to operate on batteries is a definite asset for many installations.

The following secondary design considerations are desirable features for flow measuring equipment.

Site Requirements. Unit design should be such as to minimize site requirements, such as the need for a fresh water supply, a vertical drop, excessive physical space, etc.

Installation Restrictions or Limitations. The unit should impose a minimum of restrictions or limitations on its installation and be capable of use on or within sewers of varying size.

Simplicity and Reliability. To maximize reliability of results and operation, the design of the unit should be as simple as possible, with a minimum of moving parts, etc.

Unattended Operation. For the majority of applications, it is highly desirable that the equipment be capable of unattended operation.

Maintenance Requirements. The design of the equipment should be such that routine maintenance is minimal and troubleshooting and repair can be effected with relative ease, even in the field.

Adverse Ambient Effects. The unit should be unaffected by adverse ambient conditions such as high humidity, freezing temperatures, hydrogen sulphide or corrosive gases, etc.

Submersion Proof. The unit should be capable of withstanding total immersion without significant damage.

Ruggedness. The unit should be of rugged construction and as vandal and theft proof as possible.

Self Contained. The unit should be self contained insofar as possible in view of the physical principles involved.

Precalibration. In order to maximize the flexibility of using the equipment in different settings, it is desirable that it be capable of precalibration; i.e., it should not be necessary to calibrate the system at each location and for each application.

Ease of Calibration. Calibration of the unit should be a simple, straightforward process requiring a minimum amount of time and ancillary equipment.

Maintenance of Calibration. The unit should operate accurately for extended periods of time without requiring recalibration.

Adaptability. The system should be capable of: indicating and recording instantaneous flow rates and totalized flows; providing flow signals to associated equipment (e.g., an automatic sampler); implementation of remote sensing techniques or incorporation into a computerized urban data system, including a multisensor single readout capability.

Cost. The unit should be affordable both in terms of acquisition and installation costs as well as operating costs, including repair and maintenance.

It is not necessary that all of these primary and secondary design considerations be achieved for all applications. For example, flow measurement devices used to calibrate others need not necessarily be self-contained, nor would unattended operations be required. Furthermore, meeting all of the listed design considerations for all installations and settings would be difficult, if not impossible, to achieve in a single design. Nonetheless, the primary and secondary design considerations can be used to formulate a set of evaluation parameters against which a given design or piece of equipment can be judged. Since application details may make certain parameters more or less important in one instance or another, no attempt has been made to apply weighting factors or assign numerical rank. The evaluation factors should prove useful, as a check list among other things, for the 208 planner who has a flow measurement requirement and who may require assistance in the selection of his equipment. The evaluation parameters together with qualitative scales, are presented in the form of a flow measurement equipment checklist in Table D-12.

D.3.2.2 Evaluations of Some Promising Devices

A slightly modified form of the flow measurement equipment checklist given in Table D-12 has been used to evaluate the various flow-measuring devices and techniques of Table D-11, and a matrix summary is given as Table D-13. It must be emphasized that these evaluations are made with a highly variable wastewater application such as storm or combined sewer flow measurement in mind and will not necessarily be applicable for other types of flows.

Only a few of the evaluation parameters normally have numbers associated with them. To assist the reader in interpreting the ratings, the following general guidelines were used. If the normal range of a particular device was considered to be less than about 10 to 1, it was termed poor; if it was considered to be greater than around 100 to 1, it was termed good. The intermediate ranges were termed fair. The accuracy that might reasonably be anticipated in measuring storm or combined sewer flows was considered rather than the best accuracy achievable by a particular device. For example, although a sharp-crested weir may be capable of achieving accuracies of ±1.5 percent or better in clear irrigation water flows, accuracies of much better than ±4 to 7 percent should not necessarily be anticipated for a sharp-crested weir measuring stormwater or combined sewer discharges. If the accuracy of a particular flow-measuring device or method was considered to be better than around ±1 to 2 percent, it was termed good; if it was considered

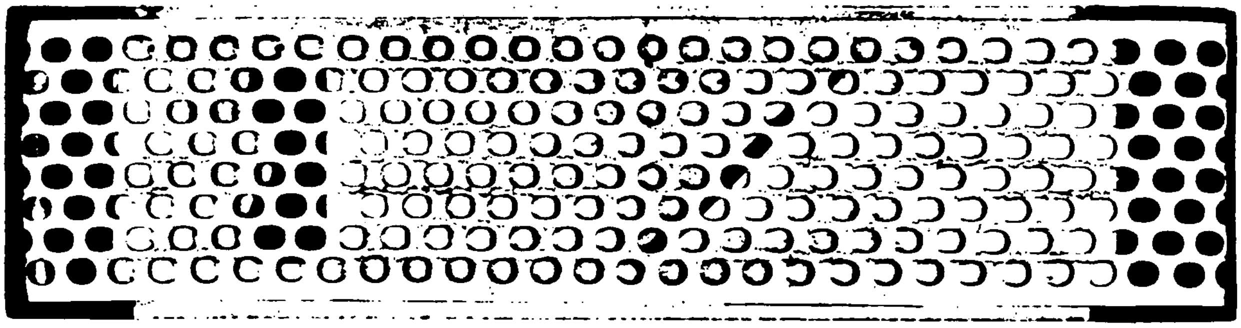


TABLE D-12
FLOW MEASUREMENT EQUIPMENT CHECKLIST

Designation: ______________________________

	Evaluation Parameter	Scale			Weight and Score
1	Range	☐ Poor	☐ Fair	☐ Good	
2	Accuracy	☐ Poor	☐ Fair	☐ Good	
3	Flow Effects on Accuracy	☐ High	☐ Moderate	☐ Slight	
4	Gravity & Pressurized Flow Operation	☐ No		☐ Yes	
5	Submergence or Backwater Effects	☐ High	☐ Moderate	☐ Low	
6	Effect of Solids Movement	☐ High	☐ Moderate	☐ Slight	
7	Flow Obstruction	☐ High	☐ Moderate	☐ Slight	
8	Head Loss	☐ High	☐ Medium	☐ Low	
9	Manhole Operation	☐ Poor	☐ Fair	☐ Good	
10	Power Requirements	☐ High	☐ Medium	☐ Low	
11	Site Requirements	☐ High	☐ Moderate	☐ Slight	
12	Installation Restrictions or Limitations	☐ High	☐ Moderate	☐ Slight	
13	Simplicity and Reliability	☐ Poor	☐ Fair	☐ Good	
14	Unattended Operation	☐ No	☐	☐ Yes	
15	Maintenance Requirements	☐ High	☐ Medium	☐ Low	
16	Adverse Ambient Effects	☐ High	[illegible]		
17	Submersion [illegible]				

5116 6

to be worse than around ±10 percent, it was termed poor. The intermediate accuracies were termed fair.

The flow-measuring devices and techniques were not rated on two evaluation parameters, submersion proof and adaptability, because these factors are so dependent upon the design details of the secondary element selected by the user.

In comparison with Table D-13, Table D-14 offers a different (and even more subjective) comparison of the most promising primary devices or techniques. Each method is numerically evaluated in terms of its percent of achievement of several desirable characteristics. Dilution techniques as a class appear to be most promising of all. In view of the current state-of-the-art, however, their usefulness is probably greatest as a tool for in-place calibration of other primary devices. They have also been extremely useful for general survey purposes and have found some application as an adjunct to other primary devices during periods of extreme flow such as pressurized flow in a conduit that is normally open channel.

Acoustic open channel devices are also quite promising; but, because of their dependency upon the velocity profile and the frequently resulting requirement for several sets of transducers, they are presently only justifiable for very large flows in view of the expense involved. The usefulness of the Parshall flume is evidenced by its extreme popularity. The requirement for a drop in the floor is a disadvantage, and submerged operation may present problems at some sites. Known uncertainties in the head-discharge relations (possibly up to 5 percent) together with possible geometric deviations make calibration in place a vital necessity if high accuracy is required. Palmer-Bowlus type flumes are very popular overall. They can be used as portable as well as fixed devices in many instances, are relatively inexpensive, and can handle solids in the flow without great difficulty.

All point velocity measuring devices have been lumped together in the current meter category. In the hands of a highly experienced operator, good results can be obtained (the converse is also true, unfortunately), and they are

TABLE D-13
FLOWMETER EVALUATION SUMMARY

	Range	Accuracy	Flow Effects on Accuracy	Gravity & Pressurized Flow Operations	Submergence or Backwater Effects	Effect of Solids Movement	Flow Obstruction	Head Loss	Manhole Operation	Power Requirements	Site Requirements	Installation Restrictions or Limitations	Simplicity and Reliability	Unattended Operation	Maintenance Requirements	Adverse Ambient Effects	Submersion Proof	Ruggedness	Self Contained	Precalibration	Ease of Calibration	Maintenance of Calibration	Adaptability	Cost	Portability
Gravimetric-all types	G	G	H	Y	L	H	H	H	P	M	H	H	P	Y	H	M	-	F	Y	Y	G	F	-	H	N
Volumetric-all types	P	G	H	Y	L	H	H	M	P	L	H	H	F	Y	H	M	-	F	Y	Y	G	F	-	H	N
Verturi Tube	P	G	S	N	L	S	S	L	P	L	H	H	G	Y	M	M	-	G	Y	Y	G	G	-	H	N
Dall Tube	P	G	S	N	L	M	S	L	P	L	H	M	G	Y	M	M	-	G	Y	Y	G	F	-	H	N
Flow Nozzle	P	G	S	N	L	S	S	M	P	L	H	M	G	Y	L	M	-	G	Y	Y	G	G	-	M	N
Orifice Plate	P	F	S	N	L	H	H	H	P	L	H	S	G	Y	H	M	-	F	Y	Y	G	P	-	L	Y
Elbow Meter	P	F	S	N	L	S	S	L	P	L	H	S	G	Y	L	M	-	G	Y	N	F	G	-	L	N
Slope Area	F	P	H	N	H	S	S	L	G	L	M	S	G	Y	L	M	-	G	Y	N	F	G	-	H	N
Sharp-Crested Weir	F	F	M	N	M	H	H	H	F	L	M	M	G	Y	H	M	-	G	Y	Y	G	P	-	L	Y
Broad-Crested Weir	F	F	S	N	H	H	M	M	G	L	M	M	G	Y	L	M	-	G	Y	N	F	F	-	L	N
Subcritical Flume	F	F	S	N	L	S	S	L	F	L	M	S	G	Y	L	M	-	G	Y	Y	G	G	-	M	N
Parshall Flume	G	F	S	N	M	S	S	L	F	L	M	M	G	Y	L	M	-	G	Y	Y	G	G	-	M	Y
Palmer-Bowlus Flume	F	F	S	N	M	S	S	L	G	L	S	S	G	Y	L	M	-	G	Y	Y	G	G	-	L	Y
Diskin Device	F	F	S	N	M	M	H	L	G	L	S	S	G	N	H	H	-	F	Y	Y	F	F	-	L	Y
Cutthroat Flume	G	F	S	N	L	S	S	L	P	L	S	S	G	Y	L	M	-	G	Y	Y	G	G	-	L	N
San Dimas Flume	G	F	D	N	L	S	S	L	F	L	S	S	G	Y	L	M	-	G	Y	Y	G	G	-	L	N
Trapezoidal Flume	G	F	S	N	L	S	S	L	F	L	S	S	G	Y	L	M	-	G	Y	Y	G	G	-	L	N
Type HS, H & HL Flume	G	F	S	N	H	M	S	H	G	L	M	M	G	Y	M	M	-	G	Y	Y	G	F	-	L	Y
Open Flow Nozzle	G	F	S	N	H	M	S	H	G	L	M	M	G	Y	M	M	-	G	Y	Y	G	F	-	L	Y
Float Velocity	G	P	H	N	L	S	S	L	G	L	S	S	G	N	L	H	-	G	N	-	-	-	-	L	Y
Tracer Velocity	F	F	M	Y	L	S	S	L	G	M	S	S	F	Y	M	S	-	F	N	N	G	G	-	H	Y
Vortex Velocity	P	F	S	N	L	H	H	L	P	L	H	H	F	Y	H	S	-	F	Y	Y	F	F	-	H	N
Eddy-Shedding	F	F	S	Y	L	M	M	L	G	L	S	S	F	Y	M	S	-	F	Y	Y	G	F	-	M	Y
Turbine Meter	P	F	S	N	L	H	H	M	P	L	H	M	F	Y	H	S	-	F	Y	Y	G	F	-	H	N
Rotating-Element Meter	F	F	S	Y	L	H	M	L	F	L	S	S	G	N	H	N	-	G	N	Y	G	G	-	L	Y
Vane Meter	P	F	S	N	L	M	H	L	F	L	S	M	G	Y	M	M	-	G	Y	Y	F	F	-	L	N
Hydrometric Pendulum	P	P	S	N	L	M	M	L	G	L	S	S	G	N	L	H	-	G	N	Y	F	F	-	L	Y
Target Meter	P	F	S	N	L	M	H	M	P	M	S	M	F	Y	H	S	-	P	Y	Y	G	F	-	H	N
Force-Momentum	P	G	S	N	L	M	M	L	P	H	H	H	P	Y	H	S	-	P	Y	Y	G	G	-	H	N
Hot-Tip Meter	F	P	S	Y	L	H	M	L	F	M	M	M	F	Y	H	M	-	F	Y	Y	G	F	-	H	N
Boundary Layer Meter	G	G	S	Y	L	S	S	L	P	M	M	M	F	Y	M	S	-	G	Y	Y	G	G	-	H	N
Electromagnetic Meter	F	G	S	Y	L	S	S	L	P	H	M	M	F	Y	M	S	-	F	Y	Y	G	G	-	H	N
Acoustic Meter	G	G	S	Y	L	M	S	L	F	M	M	M	F	Y	M	S	-	F	Y	Y	G	G	-	H	N
Doppler Meter	P	G	S	Y	L	H	S	L	F	M	M	M	F	Y	M	S	-	F	Y	Y	G	G	-	H	N
Optical Meter	F	P	S	N	L	S	S	L	F	L	S	S	G	N	L	H	-	G	N	Y	G	G	-	L	Y
Dilution	G	G	M	Y	L	S	S	L	G	M	S	S	F	Y	M	S	-	F	N	N	G	G	-	H	Y

Legend:

- F - Fair
- G - Goal
- H - High
- L - Low
- M - Medium or Moderate
- N - No
- P - Poor
- S - Slight
- Y - Yes

TABLE D-14
COMPARISON OF MOST POPULAR PRIMARY DEVICES OR TECHNIQUES

Primary Device or Technique	Desirable Characteristic (% of Achievement)								Comments
	Range	Uncalib. Accuracy	Head Loss	Free From Upstream Effects	Free From Downstream Effects	Solids Bearing Liquids	Portability	Unattended Operation	
Dilution	100	100	100	100	100	100	100	80	Especially useful as a calibration tool.
Acoustic (Open Channel)	100	100	100	60	90	95	80	100	Good in large flows but expensive.
Parshall Flume	90	95	80	90	80	90	70	100	Requires drop in floor.
Palmer Bowlus Flume	80	90	85	90	85	90	90	100	Good overall.
Current Meter	90	95	100	100	100	90	100	0	Results are very operator dependent.
Electromagnetic	50	100	100	100	100	100	0	100	Generally requires pressure flow.
Acoustic (Pressure Flow)	100	100	100	60	90	95	0	100	Wetted transducers recommended.
Open Flow Nozzle	60	95	70	80	75	80	80	95	Good if head drop is available.
Sharp-Crested Weir	60	95	70	80	80	50	80	90	Will require frequent cleaning.
Flow Tube	50	100,	95	40	100	95	0	100	Pressurized flow only.
Venturi Tube	20	100	90	70	100	90	0	100	Pressurized flow only.
Trajectory Coordinate	80	70	50	100	70	100	100	0	Requires free discharge.
Slope Area	80	50	100	20	100	100	100	0	Use as last resort.

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often used to calibrate primary devices in place or for general survey work. They are generally not suited for unattended operation, however.

Electromagnetic flowmeters show considerable promise where pressurized flow is ensured, as do closed pipe acoustic devices. Neither can be considered portable if one requires that the acoustic sensors be wetted, a recommended practice for most wastewater applications.

Open flow nozzles and sharp-crested weirs are often used where the required head drop is available. Weirs will require frequent cleaning and are best used as temporary installations for calibration purposes. Flow tubes and venturis are only suitable for pressurized flow sites such as might be encountered, for example, at the entrance to a treatment plant.

Trajectory coordinate techniques, such as the California pipe or Purdue methods, require a pipe discharging freely into the atmosphere with sufficient drop to allow a reasonably accurate vertical measurement to be made, a situation not often encountered in sewers. Slope area methods (e.g., Manning, formula) must generally be considered as producing estimates only, and consequently should be considered as the choice of last resort (despite their apparent popularity).

D.3.2.3 Review of Commercially Available Equipment and Costs

The number of commercial firms that offer liquid flow-measuring equipment in the marketplace today is astoundingly large, probably well in excess of 200. Many manufacturers offer more than one type of primary device (and these typically in numerous models) and, when combined with secondary device choices, the number is virtually overwhelming. Thus, no attempt to cover all available equipment can be made here. We simply note that two or more firms offer all devices that were described except for sharp-crested weirs, which are usually fabricated directly by (or for) the user in accordance with specifications for the particular measuring site.

The firms offering flow-measuring equipment as at least a part of their product line range from very large, well-known manufacturers that have offered a wide range of flow-measuring equipment for over a century to relatively small organizations with a limited product line that has only recently been introduced. This latter category should not be excluded from consideration solely because of their seemingly novitiate status. The principals involved frequently have many years of experience, and their designs often reflect the most up-to-date expressions of the state-of-the-art.

The revolution in the electronics industry, especially as regards solid-state designs and integrated circuitry, has not gone unnoticed by most flowmeter manufacturers; as a result, many new, sophisticated secondary devices have recently appeared, and older equipment is frequently being upgraded in design to reflect the more modern technologies. Furthermore, many of these new secondary devices are of digital (rather than analog) design and are frequently computer compatible as supplied, offering tremendous possibilities for system structure.

A listing, by no means complete, of some manufacturers who offer flow-measuring equipment in the categories listed in Table D-14 is presented in Table D-15. Under the heading "Company," the name, address, and telephone number have been provided. Under the heading "Products" only those products bearing on the flow measurement categories of Table D-14 have been listed, even though the particular company may have a much more extensive flow measurement product line. The product emphasis was placed on primary devices, with secondary devices (in the form of level gages) indicated only where they are offered as "flowmeters." It can be generally assumed that each manufacturer offers a complete line of secondary elements for use with his primary devices.

Table D-15 can be used to obtain direct, up-to-date information on all of the types of equipment discussed from at least two suppliers. Reference can be made to Shelley and Kirkpatrick (8) for descriptions of the offerings of these and a number of other manufacturers.

TABLE D-15
SOME FLOW MEASUREMENT EQUIPMENT MANUFACTURERS

Company	Products	Company	Products
American Chain and Cable Company, Inc. ACCO Bristol Division Waterbury, Connecticut 06720 Telephone (203) 756-4451	Combination depth and velocity measuring device in a single unit	Carl Fisher and Company Division of Formulabs, Inc. 529 West Fourth Avenue P. O. Box 1056 Escondido, California 92025 Telephone (714) 745-6423	Fluorescent dyes
Badger Meter, Inc. Instrument Division 4545 West Brown Deer Road Milwaukee, Wisconsin 53223 Telephone (414) 355-0400	Flow tubes, open flow nozzles, Parshall flumes	Flumet Co. P. O. Box 575 Westfield, New Jersey N. Y. Office: Telephone (212) 227-6668	Palmer-Bowlus flumes
Badger Meter, Inc. Precision Products Division 6116 East 15th Street Tulsa, Oklahoma 74115 Telephone (918) 836-4631	Acoustic (open channel)	The Foxboro Company Foxboro, Massachusetts 02035 Telephone (617) 543-8750	Electromagnetic, level gages
BIF - A Unit of General Signal 1600 Division Road West Warwick, R.I. 02893 Telephone (401) 885-1000	Flow tubes, open flow nozzles, Parshall flumes, "universal" venturi tubes	Hinde Engineering Company of California P. O. Box 56 Saratoga, California 95070 Telephone (408) 378-4112	Palmer-Bowlus flumes
Brooks Instrument Division Emerson Electric Company 407 West Vine Street Hatfield, Pennsylvania 19440 Telephone (215) 247-2366	Electromagnetic	Interocean Systems, Inc. 3510 Kurtz Street San Diego, California 92110 Telephone (714) 299-4500	Current meters, level gages
Controlotron Corporation 176 Control Avenue Farmingdale, L.I., New York 11735 Telephone (516) 249-4400	Acoustic (pressure flow)	Kahl Scientific Instrument Corporation P. O. Box 1166 El Cajon, California Telephone (714) 444-2158	Current meters, fluorescent dyes
Cushing Engineering Inc. 3364 Commercial Avenue Northbrook, Illinois 60062 Telephone (312) 564-0500	Electromagnetic	F. B. Leopold Company Division of Sybron Corporation 227 S. Division St. Zelienople, Pennsylvania 16063 Telephone (412) 452-6300	Open flow nozzles, Palmer-Bowlus flumes, Parshall flumes
C.W. Stevens, Inc. P. O. Box 619 Kennett Square, Pennsylvania 19348 Telephone (215) 444-0616	Acoustic level gage	Leupold & Stevens, Inc. P. O. Box 588 600 N. W. Meadow Drive Beaverton, Oregon 97005 Telephone (503) 646-9171	Float level gages
Drexelbrook Engineering Company 205 Keith Valley Road Horsham, Pennsylvania 19044 Telephone (215) 674-1234	Electronic level gage	Manning Environmental Corp. 120 Du Bois Street P. O. Box 1356 Santa Cruz, California 95061 Telephone (408) 427-0230	Acoustic and "dipper" level gages
Environmental Measurement Systems A Division of Wesmar 905 Dexter Avenue North Seattle, Washington 98109 Telephone (206) 285-1621	Acoustic (open channel)	Martig Bub-L-Air 2116 Lakemoor Drive Olympia, Washington 98502 Telephone (206) 943-2390	Bubbler level gage
Epic Inc 150 Nassau Street Suite 1430 New York, New York 10038 Telephone (212) 349-2470	Current meters, level gages	Metritape, Inc. 77 Commonwealth Avenue West Concord, Massachusetts 01742 Telephone (617) 369-7500	Electronic level gage
Fischer & Porter Co. Warminster, Pennsylvania 18974 Telephone (215) 675-6000	Electromagnetic, flow tubes, open flow nozzles, Parshall flumes, level gages	NB Products, Inc. 35 Beulah Road New Britain, Pennsylvania 18901 Telephone (215) 345-1879	Portable V-notch weirs, level gages

TABLE D-15
SOME FLOW MEASUREMENT EQUIPMENT MANUFACTURERS (Cont'd)

Company	Products	Company	Products
N-Con Systems Company 308 Main Street New Rochelle, New York 10801 Telephone (914) 235-1020	Float and "dipper" level gages	Sigmamotor, Inc. 14 Elizabeth Street Middleport, New York 14105 Telephone (716) 735-3616	Bubbler level gage
Nusonics, Inc. 9 Keystone Place Paramus, New Jersey 07652 Telephone (201) 265-2400	Acoustic (pressure flow)	Singer-American Meter Division 13500 Philmont Avenue Philadelphia, Pennsylvania 19116 Telephone (215) 637-2100	Palmer-Bowlus flumes, Parshall flumes, level gages
Ocean Research Equipment, Inc. Falmouth, Massachusetts 02541 Telephone (617) 548-5800	Acoustic (open channel)	Sirco Controls Company 8815 Selkirk Street Vancouver 14, British Columbia, Canada Telephone (604) 261-9321	Acoustic level gage
The Permutit Company Division of Sybron Corporation E49 Midland Avenue Paramus, New Jersey Telephone (201) 262-8900	Flow tubes, open flow nozzles, Parshall flumes, venturi tubes	Taylor Sybron Corporation Taylor Instrument Process Control Division Telephone (716) 235-5000	Electromagnetic
Plasti-Fab, Inc. 11650 S. W. Ridgeview Terrace Beaverton, Oregon 97005 Telephone (502) 644-1428	Palmer-Bowlus flumes, Parshall flumes, V-notch weir boxes	Tri-Aid Sciences, Inc. 161 Norris Drive Rochester, New York 14610 Telephone (716) 461-1660	Acoustic level gage
Plocon, Inc. An Affiliate of Carl F. Buettner & Associates, Inc. 5106 Hampton Avenue St. Louis, Missouri 63109 Telephone (314) 353-5993	Open channel flow tube	Universal Engineered Systems, Inc. 7071 Commerce Circle Pleasanton, California 94566 Telephone (415) 462-1543	Palmer-Bowlus flumes
PORTAC Min-Ell Company, Inc. 1689 Blue Jay Lane Cherry Hill, New Jersey 08003 Telephone (609) 429-0421	Current meter flow tube	Vickery-Simms, Inc. P. O. Box 459 Arlington, Texas 76010 Telephone (817) 261-4446	Parshall flumes, venturi
Robertshaw Controls Company P. O. Box 3523 Knoxville, Tennessee 37917 Telephone (615) 546-0524	Parshall flumes, level gages	Wallace-Murray Corporation Carolina Fiberglass Plant P. O. Box 580 510 East Jones Street Wilson, North Carolina 27893 Telephone (919) 237-5371	Parshall flumes
Saratoga Systems, Inc. 10601 South Saratoga-Sunnyvale Road Cupertino, California 95014 Telephone (408) 247-7120	Acoustic (pressure flow)	Wesmar Industrial Systems Division 905 Dexter Avenue North Seattle, Washington 98109 Telephone (206) 285-2420	Acoustic level gages
Scarpa Laboratories, Inc. 46 Liberty Street, Brainy Boro Station Metuchin, New Jersey 08840 Telephone (201) 549-4260	Acoustic (pressure flow)	Westinghouse Electric Corporation Oceanic Division P. O. Box 1488, Mail Stop 9830 Annapolis, Maryland 21404 Telephone (301) 765-5658	Acoustic (open channel)

In these days of inflation, little can be said about equipment costs except in a very cursory fashion. For example, one manufacturer is anticipating a 30-percent increase in the cost of basic flow tube forgings, catalog pricing is giving way to individual quotes for larger systems, and some manufacturers are quoting tentative estimates subject to adjustment at delivery. Desired features such as remote readouts, digital outputs, recorder types, battery parts, etc., add another diversion to total system costs. The following discussion is more indicative them precise, and all costs must be increased if many accessories are desired.

Dilution flow measurement systems can be put together for under $3K. The chemicals (salt, dye, etc.) are inexpensive. Acoustic open channel devices start at around $5K, and larger systems are quoted on an installation basis only, with $15-40K being a typical charge for a four-path system and some large, complex installations approaching $100K in cost. Parshall flumes run from $300 to over $2K in portable versions, depending upon size, and from $500 to $5K for fixed installations, not counting secondary devices. Palmer-Bowlus flumes without a level gage will cost between $300 and $3K depending upon size. Construction materials also affect flume prices.

Simple current meters start at around $300 for basic Price or Ott types and may run as high as $1,500. Electromagnetic current meters cost from $2K to $3K. Electromagnetic pipe meters start at around $2K for small (2 in.) sizes and run to over $30K in the largest practicable sizes. Acoustic pipe meters run from $2K to $20K depending upon size. These prices are for complete systems including secondary devices.

Open flow nozzles, flow tubes, and Venturi tubes are comparably priced with forging costs and machining accounting for the major portion. In small sizes (3 in.) they run under $1K, and range up to $15-20K in large sizes (48 in.). These prices do not include secondary devices.

The liquid level gage market is intensely competitive at the present time, and prices are similar regardless of technique (e.g., electronic, bubble, acoustic, dipper, etc.). They run from just under $1K for a basic device with visual read-out to over $2K with flow converters, recorders, transmitters, etc., as accessories.

As a closing note, construction, installation, and (importantly) projected maintenance and repair costs must be considered in addition to the equipment acquisition costs given above to arrive at true cost of ownership, which is the only real basis for comparison.

D.3.2.4 Review of Recent Field Experience

A brief review of flow measurement experiences, with emphasis on recent projects in the storm and combined sewer area, will be given to allow a better appreciation of the application of some of the flow-measuring devices and techniques in an actual field setting. The various experiences are presented by primary device or technique as listed in Table D-14. It should be pointed out that, although the following discussion focuses more on the negative experiences, instances of good results were encountered with all types of flow measurement.

Dilution methods were successfully used to calibrate primary devices in several instances. In one installation, this technique was used to measure flows in a sewer under surcharged conditions. A Palmer-Bowlus flume was employed for normal flow conditions. When the secondary device indicated that the sewer line was nearly filled, a signal was given to begin chemical injection. An automatic sampler was used to obtain samples for concentration analysis at a site downstream from the injection equipment. Some other attempts to use dilution methods were less successful, and it was abandoned by several projects. Erroneous effects due to exposed sludge banks, insufficient turbulence to ensure mixing, and poor equipment operation (especially samplers) were among difficulties cited.

Open channel acoustic devices had rather little use in the projects examined because of their recent origin. Although successful installations exist, their use has been abandoned at other locations. The primary difficulties have to do with particles, notably air bubbles, in the flow causing improper readings, the complex velocity patterns requiring a number of transverse sensors, and simple shakedown difficulties typical of early designs of many complex electronic devices. Acoustic level gages were plagued by wind (in an open application), foam, standing ripples on the water surface, and false echoes from manhole structures or other confined areas. More recent indications are that such problems are being overcome, and satisfaction with these devices appears to be increasing.

Parshall flumes were used in many projects, and they performed well when dimensions were faithfully followed, standard approach conditions were present, and (especially) when calibrated in place. Unfortunately, far too many Parshall flume installations are nonstandard, reflecting difficulties in making precise structures from poured concrete, the improper use of a lightweight plastic flume liner as a form, etc.

Palmer-Bowlus type flumes were successfully used in a number of instances, including portable versions intended for short-time application at any given site. Other than their loss of accuracy as the pipe fills and surcharges, no general negative comments about the devices themselves were encountered. There were numerous complaints concerning secondary devices used in conjunction with Palmer-Bowlus flumes, however, especially bubblers. Instances of their collecting debris and otherwise requiring frequent cleaning and maintenance abound. In one project, their use was abandoned altogether, and they were replaced with another type of level sensor.

Current meters were almost exclusively used to spot check flows and verify or rate existing structures. There were flows where they could not be used at all, however, because they immediately became fouled by rags, plastic sheets, and other debris.

Electromagnetic devices were not encountered, except where they had already been installed for other purposes. They appeared to work well, but the need for periodic inspection and verification of any fixed flow-measuring device was illustrated at one installation. As a part of a general flowmeter inspection in one district an apparently well performing electromagnetic flowmeter was found to be in error by over 50 percent. The cause was a piece of utility pole resting in the meter proper.

No projects examined used pressure flow acoustic meters, but their use in industrial plant applications has apparently been successful in many instances. Open flow nozzles performed rather well where sites allowed their use. Frequent inspection and cleaning were required at several installations, however, to ensure proper readings.

Sharp-crested weirs were among the most commonly used (and misused) primary devices encountered. Problems ranged from failure to properly account for approach velocity, improper sizing, backwater elevations causing surcharging and flooding, to almost continual cleaning being required in very trashy flows.

Flow tubes and venturi tubes were seldom encountered, except where they had existed for other purposes. They generally seemed to produce complete and accurate records.

Trajectory coordinate estimates were uncommon, owing to the lack of suitable sites.

Slope-area methods (Manning in particular) were far and away the most frequently encountered. They ranged from proper applications yielding reasonable discharge estimates to totally unsuitable applications, as in one case where the combined sewer discharge was found to considerably exceed the measured precipitation event. Difficulties ranged from accurately measuring slopes to estimating the proper friction coefficient (n) to use, in the best instances, to unknowledgeable attempts and improper applications in the worst. Apparently, far too many persons think that all that has to be done is to measure stage and plug into a handy formula to obtain flow. It is long past time that that situation be corrected.

D.3.3 Flow Measurement Field Procedures

For flow measurement in natural streams and channels, it is recommended that USGS assistance be obtained. They will establish gaging stations (temporary or permanent) at reasonable cost upon request and provide ratings to convert stage to discharge. Often a culvert or some other control structure for which a theoretical rating can be developed will be used. In some instances, weirs or flumes will have to be used. It is prudent to spot check the ratings of new gaging stations periodically. Be alert to changes in channel characteristics that would affect the established rating, e.g., sedimentation, erosion, deposition of large stones or boulders, etc.

Follow the manufacturer's recommendations for the installation, calibration, and operation of the liquid level gages used to record stage. Where stilling wells are employed, the connecting pipe should be checked for obstruction on each visit, as should the float and cable operation. Note any instances that could affect readings in the field log and the corrective action taken. It is also prudent to verify chart time at each visit if record length exceeds visit frequency (e.g., weekly flow charts but daily sampling). If a manual sample is taken, a mark made on the flow chart can assist in subsequent data analysis.

For manually gaging natural streams at the time of sampling, follow the guidance given by the Bureau of Reclamation (12). Do not take a stream gaging until all required samples for the site have been collected. Try to minimize or avoid walking in the stream until sampling is completed. Stirring up the bottom may result in nonrepresentative samples. A complete flow record is more desirable, however, and flow determinations made manually at the time of sampling should be considered as a last choice.

For flow measurement in man-made channels and conduits, the use of an appropriate primary device (refer to discussion in section D.3.2) is recommended. These should be properly installed, following manufacturer's recommendations in the case of commercial devices. The Bureau of Reclamation

Manual (12) provides much helpful information. An independent verification of the installation (i.e., by someone not on the installation team) will be prudent in most instances. This is especially true where existing flow-metering stations are to be used. Checklists for each type of primary device should be prepared to facilitate field inspection. As an example, a check-list for a contracted rectangular weir is presented in Table D-16.

Comments made above for secondary devices apply here as well. In closed conduits that are subject to occasional surcharging, try to install the level gage so that it will indicate when this condition occurs. Although the degree of surcharging cannot be indicated by most designs, knowledge of the period of time over which the surcharge condition exists may be helpful in subsequent data analysis. Such sites are best avoided wherever possible, however.

On each visit, the flow-measuring equipment should be inspected to ensure proper functioning. Visual verification of stage readings with a staff gage is recommended at each visit, and results should be noted in the field log, along with any anomalies discovered (e.g., a rag caught in the notch of a weir, a stuck float, a clogged stilling well connection tube, etc.) and any corrective actions taken. The possible buildup of sediment behind a weir should be checked (the staff gage can be used) and any accumulation removed. An occasional in-place calibration check is recommended to ensure that subtle changes that could affect the record have not occurred.

One word of caution as regards the use of sewer maps is in order. Typically, such maps (elevations especially) reflect intentions rather than installations. Even so-called as-built drawings may only indicate average invert slopes from manhole to manhole and tell little about variations in true slope. It is generally a prudent practice to verify pipe slopes entering and leaving manholes where flow measurements are to be made.

Flow measurement at outfall sites can present some unique difficulties. Where there is a drop from the discharge pipe invert to the upper level of the receiving stream, the site will probably be acceptable, and a temporary

TABLE D-16
CHECKLIST FOR CONTRACTED RECTANGULAR WEIR

1.	What is the maximum measurable head?	______
2.	Is upstream face of bulkhead smooth?	☐
3.	Is upstream face of bulkhead vertical? (check for plumb with level)	☐
4.	Is upstream face of weir plate smooth, straight, and flush with upstream face of bulkhead?	☐
5.	Is weir axis perpendicular to channel axis? (check with line and carpenter's square)	☐
6.	Is entire crest level?	☐
7.	What is thickness of crest in flow direction? (should be between 0.03 and 0.08 inch)	______
8.	Is upstream corner of crest sharp and at right angles to upstream face?	☐
9.	Are both side edges truly vertical and of same thickness as crest?	☐
10.	Are downstream edges of notch chamfered? (angle should be 45° or more to crest surface)	☐
11.	What is distance of crest from bottom of approach channel? (should be at least twice the depth above the crest and never under one foot)	______
12.	What is distance from sides of weir to sides of approach channel? (should be at least twice the depth above the crest and never under one foot)	______
13.	Does nappe touch only the upstream edges of the crest and sides? Is nappe free? Is there free fall?	☐
14.	Does zero head reading match with crest elevation?	☐
15.	Is head reading taken upstream a distance of at least 3 times the maximum head on the crest?	☐
16.	Is the cross-sectional area of the approach channel at least 8 times that of the nappe?	☐
17.	Does this condition extend upstream at least 15 times the depth above the crest?	☐
18.	If weir pool is smaller than defined above, measure velocity of approach with current meter.	______
19.	If appreciable velocity of approach is measured are head readings being corrected?	☐

weir box can be installed and used satisfactorily. Where the receiving stream level is above the invert but below the crown, a pipe extension and Palmer-Bowlus flume (or a Parshall flume in some instances) can possibly be used. The real problem occurs where the outfall is completely submerged, and the expense of a permanent device such as an electromagnetic flow meter (otherwise, an excellent choice for such a site since it can measure flow in either direction) cannot be tolerated. The best advice is to find another site. If that cannot be done, the only recourse is to use a current meter to obtain a velocity, adjust this to an average value, and multiply by the pipe area to obtain flow. Where there is insufficient debris in the flow to cause problems in operation, an oceanographic type recording current meter or some other recording point velocity sensor can be used. For very trashy flows, the only solution may be to measure velocities manually, cleaning up the current meter between observations. This approach may be acceptable for some intermittent discharges if a man can get to the site on time, but continuous records are impracticable.

D.4 Sampling Considerations, Equipment, and Procedures

The objective of any sampling effort is to remove, from a defined universe, a small portion that is in some way representative of the whole. Ideally, a representative sample will accurately reflect the physical and chemical characteristics of the bulk source in every respect as they were during the sampling period. In water quality, such representativeness is seldom if ever achieved and, fortunately, seldom required. As used herein, a representative sample is one that, when examined for a particular parameter, will yield a value from which that bulk source characteristic can be determined. The proper sampling methodology, i.e., that which will produce a representative sample, is dependent upon the type of bulk source to be sampled, e.g., surface water in natural channels (rivers, streams, lakes), municipal wastewater, ground water, urban runoff, industrial wastewater, treatment lagoon, and so on. Nonetheless, there are some more or less universal sampling considerations, and they will now be addressed.

D.4.1 Sample Types

The selection of the type of sample to be collected depends on a number of factors, such as the rates of change of flow and the character of the water or wastewater, the accuracy required, and the availability of funds for conducting the sampling program. All samples collected, either manually or with automatic equipment, are included in the following types, which terminology has been recommended for standard usage by Shelley and Kirkpatrick (14).

Discrete Sample

A discrete sample (sometimes called a grab sample) is one that is collected at a selected point in time and retained separately for analysis. A sequential discrete sample is a series of such samples, usually taken at constant time intervals (e.g., one each hour over a 24-hour period), but sometimes at constant discharge increments (e.g., one for each 100,000 gallons of flow) when paced by a flow totalizer.

Simple Composite Sample

A simple composite sample is one that is made up of a series of aliquots (smaller samples) of constant volume (Vc) collected at regular time intervals (Tc) and combined in a single container. Such a sample could be denoted by TcVc, meaning time interval between successive aliquots constant and volume of each aliquot constant.

Flow Proportional Composite Sample

A flow proportional composite sample is one collected in relation to the flow volume during the period of compositing, thus indicating the "average" condition during the period. One of the two ways of accomplishing this is to collect aliquots of equal volume (Vc), but at variable time intervals (Tv), that are inversely proportional to the volume of the flow. That is, the time interval between aliquots is reduced as the volume of flow increases. Alternatively, flow proportioning can be achieved by increasing the volume of each aliquot in proportion to the flow (Vv), but keeping the time interval between aliquots constant (Tc).

Sequential Composite Sample

A sequential composite sample is composed of a series of short-period composites, each of which is held in an individual container. For example, each of several samples collected during a 1-hour period may be composited for the hour. The 24-hour sequential composite is made up from the individual 1-hour composites.

Continuous Sample

A continuous sample is one collected by extracting a small, continuously flowing stream from the bulk source and directing it into the sample container. The sample flow rate may be constant (Qc), in which case the sample is analogous to the simple composite, or it may be varied in proportion to the bulk source flow rate (Qv), in which case the sample is analogous to the flow proportional composite.

For initial characterization of wastewater flows, sequential discrete sampling is generally desired. It is mandatory for accurate stormwater characterization, since it allows characterization of the wastewater over a time history and provides information about its variations with time. If the samples are sufficiently large, manual compositing can also be performed, based on flow records or some other suitable weighting scheme, and a preferred composite type determined. Some form of automatic compositing will usually be desired for continued wastewater discharge characterization.

A brief look at the different types of composite samples is in order. Any scheme for collecting a composite sample is, in effect, a method for mechanically integrating to obtain average flow characteristics. The simple composite is the crudest attempt at such averaging and will be representative of the waste flow during the period only if the flow properties are relatively constant.

For variable flows, some type of proportioning must be used. This is equivalent to saying that the simple composite is a very poor scheme for numerical integration, and a higher-order method is desirable. There are two fundamental approaches to obtaining better numerical integration, given a fixed number of steps. One is to increase the order of the integration scheme to be used, as in going from the trapezoidal rule to Simpson's rule. The other is to vary the step size in such a way as to lengthen the steps when slopes are changing very slowly and shorten them when slopes change rapidly. Typical of the first approach are the constant time interval, variable volume (TcVv) proportional composites. There are two straightforward ways of accomplishing this. One is to let the aliquot volume be proportional to the instantaneous flow rate, and the other is to make the aliquot volume proportional to the quantity of flow that has passed since extraction of the last aliquot. Typical of the second approach is the variable time interval, constant volume (TvVc) proportional composite. Here a fixed volume aliquot is taken each time an arbitrary quantity of flow has passed.

It is instructive to compare these four composite sample schemes. For the purposes of this example, four flow functions and five concentration functions are examined. The selections are completely arbitrary (except for simplicity in exact integration) and, in practice, site specific data should be used. For each flow/concentration combination, the exact average concentration of the flow was computed (as though the entire flow stream were diverted into a large tank for the duration of the event and then its concentration measured). The ratio of the composite sample concentration to the actual concentration so computed is presented in matrix form in Figure D-4 (taken from Shelly and Kirkpatrick, 15). The four rows in each cell represent the four types of composite samples discussed as indicated in the legend. The best overall composite for the cases examined is the TcVv, with the volume proportional to the instantaneous flow rate q. The TcVv where the volume is proportional to the flow since the last sample, and the TvVc gave very similar results with a slight edge to the former. However, the differences are not large for any case. This brief look at compositing merely scratches the surface. Flow records and a knowledge of the temporal

CONC k / q FLOW	$1-t$	$1\frac{t}{2}$	$\cos\frac{\pi t}{2}$	e^{-t}	$\sin \pi t$
c	0.90 0.90 0.90 0.90	0.97 0.97 0.97 0.97	0.92 0.92 0.92 0.92	0.95 0.95 0.95 0.95	0.99 0.99 0.99 0.99
t	1.35 0.90 0.86 0.87	1.09 0.97 0.96 0.96	1.26 0.90 0.87 0.89	1.14 0.97 0.95 0.95	0.99 0.90 0.89 0.97
1-t	0.68 0.95 0.92 0.92	0.87 0.98 0.97 0.97	0.72 0.98 0.95 0.93	0.82 0.96 0.95 0.95	0.99 1.12 1.09 0.97
$\sin \pi t$	0.90 1.01 0.90 0.90	0.97 1.00 0.97 0.97	0.88 1.00 0.92 0.92	0.97 1.00 0.95 0.95	0.80 1.01 0.98 0.97

The rows within each flow/concentration cell refer to the following sample types:

Row 1. TcVc - Simple composite
Row 2. TcVv - Volume proportional to flow rate (q)
Row 3. TcVv - Volume proportional to flow (Q) since last sample
Row 4. TvVc - Time varied to give constant ΔQ

FIGURE D-4
RATIO OF COMPOSITE SAMPLE CONCENTRATION TO ACTUAL CONCENTRATION

fluctuation of pollutants, as can be obtained from discrete samples, are required in order to choose a "best" compositing scheme for a given installation.

Continuous samples are also composite in nature but do not fit in the foregoing discussion since the discrete step integration analogy is not applicable. Had we included the Qv continuous sample in the foregoing example, its ratio would have been unity for all combinations in Figure D-4. Other considerations severely limit the instances where a continuous sample is the composite of choice. For wastewater sampling, it is generally agreed that the minimum line inside diameter is 0.6 cm (1/4 in.) and that the sample flow velocity should be at least 0.76 m/s (2.5 fps). A simple calculation shows that the minimum volume of a 24-hour continuous sample would be 2085 liters (551 gal), hardly a practicable size. For this reason, continuous samples are useful only for very pristine flows (e.g., drinking water), where the very low flow rates necessary to keep sample volumes reasonable may still allow a representative sample to be obtained.

D.4.2 Automatic Sampling Equipment

In the following, a systems breakdown of automatic sampling equipment is given in generic terms to allow the reader to better appreciate their functional purposes and requirements. A survey of commercially available automatic sampling equipment and costs is given, and a review of field experience with these devices is provided.

D.4.2.1 Elements of an Automatic Sampler System

In a system breakdown by functional attributes, an automatic liquid sampler may be divided into five basic elements or subsytems. Each of these will be discussed in turn.

D.4.2.1.1 Sample Intake Subsystem

The operational function of the sample intake is to reliably allow the gathering of a representative sample from the flow stream in question. Its reliability is measured in terms of freedom from plugging or clogging, to the degree that sampler operation is affected, and invulnerability to physical damage due to large objects in the flow. It is also desirable, from the viewpoint of sewer operation, that the sample intake offer a minimum obstruction to the flow in order to reduce the possibility of blockage of the entire pipe by lodged debris, etc.

The sample intake of many commercially available automatic liquid samplers is often only the end of a plastic suction tube, and the user is left to his own ingenuity and devices if he desires to do anything other than simply dangle the tube in the stream to be sampled. Some manufacturers provide a weighted, perforated plastic cylinder that screens the hose inlet from the unwanted material that might cause choking or blockage elsewhere within the sampler. Typical hole sizes are around 1/3 cm (1/8 in.) in diameter and, if there are sufficient holes to ensure free flow, results have been satisfactory in some applications. Samplers that employ pneumatic ejection have their own intake chambers that must be used in order for the equipment to function properly.

D.4.2.1.2 Sample-Gathering Subsystem

Three basic sample-gathering methods or categories can be identified: mechanical, forced flow, and suction lift. The sample lift requirements of the particular site often play a determining role in the gathering method to be employed.

Mechanical Methods. There are many examples of mechanical gathering methods used in both commercially available and one-of-a-kind samplers. One of the more common designs is the cup on a chain driven by a sprocket drive arrangement. In another design, a cup is lowered within a guide pipe, via a small automatic winch and cable. Other examples include a self-closing pipe-like device that extracts a vertical "core" from the flow stream, a specially contoured box assembly with end closures that extracts a short length (plug) of the entire flow cross section, and a revolving or oscillating scoop that traverses the entire flow depth.

Some of the latter units employ scoops that are characterized for use with a particular primary flow measurement device, such as a weir or Parshall flume, and extract an aliquot volume that is proportional to the flow rate. Another design for mechanically gathering flow-proportional samples involves the use of a sort of Dethridge wheel with a sample cup mounted on its periphery. Since the wheel rotation is proportional to flow, the effect is that a fixed volume aliquot is taken each time a certain discharge quantity has passed, and total discharge can be estimated from the size of the resultant composite sample.

The foregoing designs have primarily arisen from one of two basic considerations: (1) site conditions that require very high lifts, or (2) the desire to gather samples that are integrated across the flow depth. One of the penalties that must be traded off in selecting a mechanical gathering unit is the necessity for some obstruction to the flow, at least while the sample is being taken. 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.

Forced Flow Methods. All forced flow gathering methods require some obstruction to the flow, but usually it is less than with mechanical gathering methods. It may be only a small inlet chamber with a check valve assembly of some sort, or it may be an entire submersible pump. The main advantage of submersible pumps is that their high discharge pressures allow sampling at greater depths, thereby increasing the flexibility of the unit somewhat, insofar as site depth is concerned. Pump malfunction and clogging, especially in the pump sizes often used for samplers, is always a distinct possibility; because of the pump's location in the flow stream itself, maintenance is much more difficult and costly to perform than on above-ground or more easily accessible units. Submersible pumps also necessarily present an obstruction to the flow and are thus in a vulnerable position as regards damage by debris.

Pneumatic ejection is a forced flow gathering method used by a number of commercial samplers. The gas source required by these units varies from bottled refrigerant to motor-driven air compressors. The units that use bottled refrigerant must be of a fairly small scale to avoid an enormous appetite for the gas and, hence, a relatively short operating life before the gas supply is exhausted. Furthermore, concern has recently been expressed about the quantities of freon that are being discharged into the atmosphere. The ability of such units to backflush or purge themselves is also limited. The advantages of few moving parts, inherent explosion-proof construction, and high lift capabilities must be weighed against low or variable line velocities, low or variable sample intake velocities, and relatively small sample capacities in some designs. Another disadvantage of many pneumatic ejection units is that the sample chamber fills immediately upon discharge of the previous sample. Thus, it may not be representative of flow conditions at the time of the next triggering and, if paced by a flow meter, correlation of results may be quite difficult.

Suction Lift Methods. Suction lift units must be designed to operate in the environment near the flow to be sampled or else their use is limited to a little over 9m (30 ft) due to atmospheric pressure. Several samplers that take their suction lift directly from an evacuated sample bottle are available today. Vacuum leaks, the variability of sample size with lift, the requirement for heavy glass sample bottles to withstand the vacuum, the difficulty of cleaning due to the requirement for a separate line for each sample bottle, the necessity of placing the sample bottles near the flow stream (and hence in a vulnerable position), and the varying velocities as the sample is being withdrawn, are among the many disadvantages of this technique.

Other units are available that use a vacuum pump and some sort of metering chamber to measure the quantity of sample being extracted. These units, in some designs, offer the advantages of fairly high sample intake and transport velocities. The fluid itself never comes in contact with the pump, and the pump output can easily be reversed to purge the sampling line and intake to help prevent cross-contamination and clogging.

A variety of positive displacement pumps have been used in the design of suction lift samplers, including flexible impeller, progressive cavity rotary screw, roller or vane, and peristaltic types. Generally these pumps are self-priming (as opposed to many centrifugal pumps), but some designs should not be operated dry because of internal wearing of rubbing parts. The desirability of a low-cost pump that is relatively free from clogging has led many designers to use peristaltic pumps. A number of types have been employed including finger, nutating, and two- and three-roller designs using either molded inserts or regular tubing. Most of these operate at such low flow rates, however, that the representativeness of suspended solids is questionable. Newer high-capacity peristaltic pumps are now available and are finding application in larger automatic samplers. The ability of some of these pumps to operate equally well in either direction affords the capability to blow down lines and help remove blockages. Also, they offer no obstruction to the flow since the transport tubing need not be interrupted by the pump, and strings, rags, cigarette filters, and the like are passed with ease.

All in all, the suction-lift gathering method appears to offer more advantages and flexibility than either of the others for many applications. The limitation on sample lift can be overcome by designing the pumping portion of the unit so that it can be separated from the rest of the sampler and thus positioned within 6m (20 ft) or so of the flow to be sampled. For many sites, however, even this will not be necessary.

D.4.2.1.3 Sample Transport Subsystem

The majority of the commercially available automatic samplers have fairly small line sizes in the sample train. Such tubes, especially at 1/3 cm (1/8 in.) inside diameter and smaller, are very vulnerable to plugging, clogging due to the buildup of fats, etc. For many applications, a better minimum line size would be 1 to 1.3 cm (3/8 to 1/2 in.) inside diameter.

For flows that are high in suspended solids, it is imperative that adequate sample flow rate be maintained throughout the sampling train in order to effectively transport them. In horizontal runs, the velocity must exceed the scour velocity while, in vertical runs, the settling or fall velocity must be exceeded several times to ensure adequate transport of solids in the flow. Sharp bends and twists or kinks in the sampling lines should be avoided if there is a possibility of trash or debris in the lines that could become lodged and restrict or choke the flow. The same is true of some valve designs. In summary, the sampling train must be sized so that the smallest opening is large enough to give assurance that plugging or clogging is unlikely in view of the material being sampled. However, it is not sufficient to simply make all lines large, which also reduces friction losses, without paying careful attention to the velocity of flow. For many applications, minimum velocities of 0.6 to 1 m/s (2 to 3 fps) would appear warranted, and even higher velocities are required for some applications.

D.4.2.1.4 Sample Storage Subsystem

The sample container itself should either be easy to clean or disposable. Although some of today's better plastics are much lighter than glass and can be autoclaved, they are not so easy to clean or inspect for cleanliness. Also, the plastics will tend to scratch more easily than glass and, consequently, cleaning a well-used container can become quite a chore.

The requirements for sample preservation are discussed elsewhere, but it should be noted here that refrigeration is stated as the best single preservation method and will, in all likelihood, be required unless the sampling cycle is brief and samples are retrieved shortly after being taken. Light can also affect samples, and either a dark storage area or opaque containers would seem desirable. If opaque containers are used, however, they should be disposable, since it would be difficult to inspect an opaque container for cleanliness.

D.4.2.1.5 Controls and Power Subsystem

The control aspects of some commercial automatic samplers have come under particular criticism. It is no simple matter, to provide great flexibility in operation of a unit while at the same time avoiding all complexities in its control system. The problem is not only one of component selection but of packaging as well. For instance, even though the possibility of immersion may be extremely remote in a particular installation, the corrosive, highly humid atmosphere, which will, in all likelihood, be present, makes sealing of control elements and electronics desirable in most instances.

The controls determine the flexibility of operation of the sampler, e.g., its ability to be paced by various types of flow-measuring devices. Built-in timers should be repeatable, and time periods should not be affected by voltage variations. The ability to repeatedly gather the required aliquot volume independent of flow depth or lift is very important if composite samples are to be collected. Provisions for manual operation and testing are desirable, as is a clearly laid out control panel. Some means of determining the time when discrete samples were taken is necessary if synchronization with flow records is contemplated. An event marker is desirable for a sampler that is to be paced by an external flow recorder. Reliability of the control system can dominate the total system reliability. At the same time, this element will, in all likelihood, be the most difficult to repair and calibrate. Furthermore, environmental effects will be the most pronounced in the control system.

The required tasks can be best executed, in the light of the current electronics state-of-the-art, by a solid-state controller element. Such designs offer higher inherent reliability and are becoming more and more common in commercially available samplers. In addition, the unit should be of modular construction for ease of modification, performance monitoring, fault location, and replacement/repair. Such an approach also lends itself to encapsulation, which will minimize environmental effects. Solid-state switching eliminates the possibility of burned or welded contacts, either of which will cause complete sampler breakdown.

Some automatic samplers available today require a 110V AC power supply, but many battery-operated units are also available. The latter are, of necessity, smaller in size and sample transport velocity but still have a wide range of application. Other portable units utilize compressed gas or spring motors as the only required power source.

D.4.2.2 Considerations in Automatic Sampler Selection

Presently available automatic liquid samplers have a great variety of characteristics with respect to size of sample collected, lift capability, type of sample collected (discrete or composite), materials of construction, and numerous other both good and poor features. A number of considerations in selection of a sampler are:

- Rate of change of wastewater conditions
- Frequency of change of wastewater conditions
- Range of wastewater conditions
- Periodicity or randomness of change
- Availability of recorded flow data
- Need for determining instantaneous conditions, average conditions, or both
- Volume of sample required
- Need for preservation of sample
- Estimated size of suspended matter
- Need for automatic controls for starting and stopping
- Need for mobility or for a permanent installation
- Operating head requirements

In addition to the foregoing attributes of automatic sampling equipment, there are also certain desirable features that will enhance the utility and value of the equipment. For example, the design should be such that maintenance and troubleshooting are relatively simple tasks. Spare parts should be readily available and reasonably priced. The equipment design should be such that the unit has maximum inherent reliability. As a general rule, complexity in design should be avoided even at the sacrifice of a certain degree of flexibility of operation. A reliable unit that gathers a reasonably representative sample most of the time is much more desirable than an extremely sophisticated, complex unit that gathers a very representative sample 10 percent of the time, the other 90 percent of the time being spent undergoing some form of repair due to a malfunction associated with its complexity.

It is also desirable that the cost of the equipment be as low as practical both in terms of acquisition as well as operational and maintenance costs. For example, a piece of equipment that requires 100 man-hours to clean after every 24 hours of operation is very undesirable. It is also desirable that the unit be capable of unattended operation and remaining in a standby condition for extended periods of time.

The sampler should be of sturdy construction with a minimum of parts exposed to the sewage or to the highly humid, corrosive atmosphere associated directly with the sewer. It should not be subject to corrosion or the possibility of sample contamination due to its materials of construction. The sample containers should be capable of being easily removed and cleaned; preferably they should be disp[illegible]

For portable automatic wastewater samplers, the list of desirable features is even longer. Harris and Keffer (16) give a number of features of an "ideal" portable sampler, which are based upon sampler comparison studies and over 90,000 hours of field experience.

D.4.2.3 Survey of Commercially Available Equipment

Some types of automatic liquid sampling equipment have been available commercially for quite a while. In the last few years, however, there has been a proliferation of commercial sampling equipment designed for various applications. New companies are being formed and existing companies are adding automatic sampling equipment to their product lines. In addition to their standard product lines, most manufacturers of automatic sampling equipment provide special adaptations of their equipment or custom designs to meet unique requirements of certain customers. Some designs that began in this way have become standard products, and this can be expected to continue.

The products themselves are also rapidly changing. Not only are improvements being made as field experience is gathered with new designs, but attention is also being paid to certain areas that have heretofore been largely ignored. For example, one company is introducing sampling probes that allow the gathering of oil or various other liquids from the flow surface; solid-state electronics are being used more and more in sampler control subsystems; new types of batteries are offering extended life between charges and less weight; and so on. Table D-17 lists the names and addresses of some 38 manufacturers who are known to offer standard lines of automatic wastewater sampling equipment.

An overall matrix, which summarizes the equipment characteristics to facilitate comparisons, is presented in Table D-18. There are several column headings for each sampler model (or class of models). "Gathering Method" identifies the actual method used (mechanical, forced flow, suction lift) and type (peristaltic, vacuum, centrifugal pump, etc.). Depending upon the gathering method employed, the sample flow rate may vary while a sample is being taken, vary with parameters such as lift, etc. Therefore, the "Flow Rate" column typically lists the upper end of the range for a particular piece of equipment, and values significantly lower may be encountered in a field application. "Lift" indicates the maximum vertical distance that is allowed between the sampler intake and the remainder of the unit (or at least its pump, in the case of suction lift devices).

"Line Size" indicates the minimum line diameter of the sampling train. "Sample Type" indicates which type or types of sample the unit (or series) is capable of gathering. Not all types can necessarily be taken by all units in a given model class; e.g., an optional controller may be required to enable taking a TvVc type sample, etc. The "Installation" column is used to indicate if the manufacturer considers the unit to be portable or if it is primarily intended for a fixed installation. "Cost Range" indicates either the approximate cost for a typical unit or the lowest price for a basic model and a higher price reflecting the addition of options (solid-state controller, battery, refrigerator, etc.) that might enhance the utility of the

TABLE D-17
AUTOMATIC WASTEWATER SAMPLER MANUFACTURERS

A & H Enterprises
1711 South 133 Avenue
Omaha, Nebraska 68144

Advanced Instrumentation, Inc.
Box 2216
Santa Cruz, California 95063

T. A. Baldwin Company, Inc.
16760 Schoenborn Street
Sepulveda, California 91343

Bestel-Dean Limited
92 Worsley Road North,
Worsley
Manchester, England M28 5QW

BIF Sanitrol
P.O. Box 4
Largo, Florida 33546

Brailsford and Company, Inc.
Milton Road
Rye, New York 10580

Brandywine Valley Sales Co.
20 East Main Street
Honey Brook, Pennsylvania 19344

Chandler Development Company
1031 East Duane Avenue
Sunnyville, California 94086

Chicago Pump Division
FMC Corporation
1800 FMC Drive
Itasca, Illinois 60143

Collins Products Co.
P.O. Box 382
Livingston, Texas 77351

Environmental Marketing
Associates
3331 Northwest Elmwood Dr.
Corvallis, Oregon 97330

ETS Products
12161 Lackland Road
St. Louis, Missouri 63141

Fluid Kinetics, Inc.
3120 Production Drive
Fairfield, Ohio 45014

Horizon Ecology Company
7435 North Oak Park Drive
Chicago, Illinois 60648

Hydro-Numatic Sales Co.
65 Hudson Street
Hackensack, New Jersey 07602

Hydraguard Automatic Samplers
850 Kees Street
Lebanon, Oregon 97355

Instrumentation Specialties Co.
Environmental Division
P.O. Box 5347
Lincoln, Nebraska 68505

Kent Cambridge Instrument Co.
73 Spring Street
Ossining, New York 10562

Lakeside Equipment Corp.
1022 East Devon Avenue
Bartlett, Illinois 60103

Manning Environmental Corp.
120 DuBois Street
P.O. Box 1356
Santa Cruz, California 98061

Markland Specialty Eng. Ltd.
Box 145
Etobicoke, Ontario (Canada)

Nalco Chemical Company
180 N. Michigan Avenue
Chicago, Illinois 60601

Nappe Corporation
Croton Falls Industrial Complex
Route 22
Croton Falls, New York 10519

N-Con Systems Company
308 Main Street
New Rochelle, New York 10801

Paul Noascono Company
805 Illinois Avenue
Collinsville, Illinois 62234

NP Industries, Inc.
P.O. Box 746
Niagara Falls, New York 14302

Peri Pump Company, Ltd.
180 Clark Drive
Kenmore, New York 14223

Phipps and Bird, Inc.
303 South 6th Street
Richmond, Virginia 23205

Protech, Inc.
Roberts Lane
Malvern, Pennsylvania 19355

Quality Control Equipment Co.
P.O. Box 2706
Des Moines, Iowa 50315

Sigmamotor, Inc.
14 Elizabeth Street
Middleport, New York 14105

Sirco Controls Company
8815 Selkirk Street
Vancouver, B.C.

Sonford Products Corporation
400 East Broadway, Box B
St. Paul Park, Minnesota 55071

Testing Machines, Inc.
400 Bayview Avenue
Amityville, New York 11701

Tetradyne Corporation
1681 South Broadway
Carrollton, Texas 75006

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

Williams Instrument Co., Inc.
P.O. Box 4365, North Annex
San Fernando, California 91342

Universal Engineered Systems, Inc.
7071 Commerce Circle
Pleasanton, California 94566

TABLE D-18
SAMPLER CHARACTERISTIC SUMMARY MATRIX

Sampler	Gathering Method	Flow Rate (ml/min)	Lift (m)	Line Size (mm)	Sample Type	Installation	Cost Range ($)	Power
Bestel-Dean Mk II	S-Watson-Marlow	690	6.1	6.4	D, TcVc, TvVc	Portable	Unk	AC/DC
Bestel-Dean Crude	S-screw type	Unk	6.1	19.1	D, TcVc, TvVc	Portable	Unk	AC
BIF 41	M-cup on chain	NA	4.9	25.4	TcVc, TvVc	Fixed	~1,000	AC
Brailsford DC-F & EP	S-piston type	10	<2	4.8	Continuous	Portable	296-373	DC
Brailsford EVS	S-vacuum pump	5	3.7	4.8	TcVc, TvVc	Portable	520-672	AC/DC
Brailsford DV-2	S-piston type	10	<2	4.8	TcVc, TvVc	Portable	373	DC
BVS PP-100	F-pneumatic	*	85	3.2	TcVc, TvVc	Portable	853-1,525	AC/DC
BVS PE-400	F-submersible pump	7,600	9.8	12.7	TcVc, TvVc	Portable	1,500-2,510	AC/DC
BVS SE-800	F-submersible pump	7,600	9.8	12.7	D, TcVc, TvVc	Fixed	5,650	AC
BVS PPE-400	F-pneumatic	*	85	3.2	TcVc, TvVc	P or F	1,450-3,350	AC/DC
Chicago Pump	user supplied	~133,000	NA	25.4	TcVc, TvVc	Fixed	2,600-3,200	AC
Collins 42	user supplied	>3,785	NA	2.4	TcVc, TvVc	P or F	985-2,478	AC
Collins 40	user supplied	~5,000	NA	2.4	TcVc, TvVc	P or F	835-2,328	AC
EMA 200	F-piston type	Unk	<1	9.5	TcVc, TvVc	Portable	199-456	AC/DC
ETS FS-4	S-peristaltic	~20	8.8	6.4	Continuous	Portable	1,095-up	AC
Horizon S7570	S-peristaltic	100	9.1	0.8	Grab	Portable	~410	AC/DC
Horizon S7576	S-peristaltic	100	9.1	0.8	TcVc	Portable	~220	AC
Horizon S7578	S-peristaltic	100	9.1	0.8	Continuous, TcVc	Portable	595	DC
Hydraguard HP	F-pneumatic	*	>9	6.4	TcVc	Portable	246-541	Air
Hydraguard A	F-pneumatic	*	>9	6.4	TcVc	Portable	285-668	Air & AC
Hydra-Numatic	S-centrifugal	5,700	4.6	6.4	TcVc, TvVc	Portable	1,800	AC
ISCO 1392	S-peristaltic	1,500	7.9	6.4	D, TcVc, TvVc, S	Portable	1,095-1,498	AC/DC
ISCO 1480	S-peristaltic	NA	7.9	6.4	TcVc, TvVc	Portable	645-1,020	AC/DC
ISCO 1580	S-peristaltic	1,400	7.9	6.4	TcVc, TvVc	Portable	750-1,130	AC/DC
Kent SSA	S-peristaltic	150	4.9	6.4	Discrete	Portable	1,240	AC/DC
Kent SSB	S-peristaltic	200	4.0	6.4	D, TcVc, TvVc, S	Fixed	2,354	AC
Kent SSC	S-screw type	33,000	5.0	25.4	D, TcVc, TvVc, S	Fixed	2,354	AC
Lakeside T-2	M-scoop	NA	0	12.7	TcVv	Fixed	~700-up	AC
Manning S-4000	S-vacuum pump	3,800	6.7	9.5	D, S	Portable	1,290	DC
Markland 1301	F-pneumatic	*	18.3	6.4	TcVc, TvVc	Portable	1,095-1,350	Air & DC
Markland 101 & 102	F-pneumatic	*	18.3	6.4	D, TcVc	Fixed	594-2,189	Air & DC
Markland 104T	F-pneumatic	*	18.3	6.4	D, TcVc, TvVc	Fixed	1,091-2,644	Air & AC
Midlab ML 1000 & 2000	S-peristaltic	1,680	9.1	6.4	TcVc, TvVc	Portable	1,500-2,500	AC
Midlab ML 3000	S-peristaltic	1,680	9.1	6.4	TcVc, TcVv	Portable	3,000-3,500	AC
Nalco S-100	F-submersible pump	28,400	7.6	12.7	TcVc, TvVc	Portable	Unk	AC
Nappe Porta-Positor	S-flexible impeller	11,400	1.8	6.4	TcVc	Portable	225-285	AC/DC
Nappe Series 46	S-flexible impeller	13,200	4.6	9.5	TcVc, TvVc	Fixed	1,100-1,800	AC
Noascono Shift	S-peristaltic	8	9.1	4.8	Continuous	Portable	Unk	AC
N-Con Surveyor II	S-flexible impeller	20,000	1.8	6.4	TcVc, TvVc	Portable	290-590	AC
N-Con Scout II	S-peristaltic	150	5.5	6.4	TcVc, TvVc	Portable	575-935	AC/DC
N-Con Sentry 500	S-peristaltic	150	5.5	6.4	Sequential	Portable	1,125-1,205	AC/DC

TABLE D-18
SAMPLER CHARACTERISTIC SUMMARY MATRIX (Continued)

Sampler	Gathering Method	Flow Rate (ml/min)	Lift (m)	Line Size (mm)	Sample Type	Installation	Cost Range ($)	Power
N-Con Trebler	M-scoop	NA	0	12.7	TcVv	Fixed	1,050-1,350	AC
N-Con Sentinel	user supplied	63,000	NA	25.4	TcVc, TvVc	Fixed	~2,600	AC
Perl 704	S-peristaltic	160	7.6	6.4	TcVc	Portable	Unk	DC
Phipps and Bird	M-cup on chain	NA	18.3	NA	TcVc, TvVc	Fixed	1,000-up	AC
ProTech CG-110	F-pneumatic	1,000	9.1	3.2	TcVc	Portable	485	- -
ProTech CG-125	F-pneumatic	1,000	9.1	3.2	TcVc	Portable	695-1,205	-/AC
ProTech CG-125FP	F-pneumatic	1,000	9.1	3.2	TcVc, TvVc	Portable	925-1,610	AC/DC
ProTech CEG-200	F-pneumatic	1,000	16.8	3.2	TcVc, TvVc	P or F	1,354-2,445	Air/AC
ProTech CEL-300	F-submersible pump	6,000	9.1	12.7	TcVc, TvVc	P or F	1,495-2,750	AC
ProTech DEL-400S	F-submersible pump	6,000	9.1	12.7	Discrete	Fixed	3,995-4,765	AC
QCEC CVE	S-vacuum pump	3,000	6.1	6.4	TcVc, TvVc	Portable	570-1,030	AC/DC
QCEC CVE II	S-vacuum pump	3,000	6.1	6.4	TcVc, TvVc	Portable	~1,000-up	AC/DC
QCEC E	M-cup on chain	NA	18.3	NA	TcVc, TvVc	Fixed	~1,000-up	AC
Rice Barton	S-vacuum pump	Unk	3.7	25.4	TcVc	Fixed	Unk	AC
SERCO NW-3	S-evacuated jars	Varies	~3	6.4	Discrete	Portable	~1,000	-
SERCO TC-2	user supplied	42,000	NA	~19	TcVc, TvVc	Fixed	~2,500	Air & AC
Sigmamotor WA-1	S-peristaltic	60	6.7	3.2	TcVc	Portable	430-730	AC/DC
Sigmamotor WAP-2	S-peristaltic	60	6.7	3.2	TcVc, TvVc	Portable	650-870	AC/DC
Sigmamotor NM-3-24	S-peristaltic	60	6.7	3.2	Discrete	Portable	975-1,525	AC/DC
Sigmamotor WA-5	S-peristaltic	80	5.5	6.4	TcVc	Portable	750-990	AC/DC
Sigmamotor WAP-5	S-peristaltic	80	5.5	6.4	TcVc, TvVc	Portable	850-1,215	AC/DC
Sigmamotor NM-5-24	S-peristaltic	80	5.5	6.4	Discrete	Portable	1,225-1,775	AC/DC
Sirco B/ST-VS	S-vacuum pump	12,000	6.7	9.5	TcVc, TvVc	P or F	1,900-3,000	AC/DC
Sirco B/IE-VS	M-cup on cable	NA	61	9.5	TcVc, TvVc	Fixed	1,500-3,000	AC
Sirco B/DP-VS	user supplied		NA	9.5	TcVc, TvVc	P or F	1,600-3,000	AC/DC
Sirco MK-VS	S-vacuum pump	6,000	6.7	9.5	D, TcVc, TvVc, S	Portable	~1,300-up	AC/DC
Sonford HG-4	M-dipper	NA	0.5	19.0	TcVc, TvVc	Portable	325-495	AC/DC
Streamgard DA-2451	user supplied	NA	NA	6.4	Discrete	Portable	775	-
TMI Fluid Stream	F-pneumatic	*	7.6	12.7	TcVc	Fixed	~800	Air & AC
TMI MA 38 (Hants)	S-evacuated jars	Varies	~3	3.2	Discrete	Portable	~700-up	-
Tri-Aid	S-peristaltic	500	7.5	9.5	TcVc, TvVc	P or F	650-985	AC
Williams Oscillamatic	S-diaphragm type	60	3.6	6.4	TcVc	P or F	438	-

Legend:
M - Mechanical
F - Forced Flow
S - Suction Lift
* - Depends on pressure and lift
NA - Not Applicable
Unk - Unknown at time of writing

device. Finally, the "Power" column is used to indicate whether line current (AC), battery (DC), or other forms of power (e.g., air pressure) are required for the unit to operate.

D.4.2.4 Review of Recent Field Experience

In order to assess the efficacy of both commercially available samplers and custom engineered units in actual field usage, a survey of recent USEPA projects, many of which were in the storm and combined sewer pollution control area, was conducted. None of these projects was undertaken solely to compare or evaluate samplers, but all required determination of water quality. In the following paragraphs, difficulties encountered with various elements of the liquid samplers are described.

The small diameter, low intake velocity probes found in several commercial units were felt to be unable to gather as representative a sample of the flow as could be obtained manually. There were many instances of inlet tube openings being blocked by rags, paper, disposable diapers, and other such debris. Although less a fault of the equipment than an installation practice, there were several instances of intake tubes being flushed over emergency overflow weirs, up onto manhole steps, etc., during periods of high flow and left high and dry and unable to gather any samples when the flow subsided.

There were numerous instances of pre-evacuated bottle samplers losing their vacuum in 24 to 48 hours, resulting in little or no data. Furthermore, personnel find these units with their 24 individual intake tubes virtually impossible to clean in the field. The low suction lifts on many commercial units render some sites inacessible. In one project, three sites required manual sampling because none of the samplers on hand could meet the 5- to 6-meter lifts required at these sites. There were several instances of sample quantity varying with sewage level as well as with the lift required at the particular site. On at least two occasions, submersible pumps were damaged or completely swept away by heavy debris in the flow.

Within the sampling train itself, line freezing during winter operation was a problem in several projects with instances of up to 60-percent data loss reported. In one project, the intake line was too large, which allowed solids to settle out in it until it ultimately became clogged. There were numerous instances of smaller suction tubes becoming plugged with stringy and large-sized material. A very frequent complaint, applied especially to discrete samplers, was that they gathered inadequate sample volumes for the laboratory analyses required.

On one project, although not directly the fault of the sampling equipment itself, data were lost for 14 storms due to improper sterilization of non-disposable sample bottles.

The control subsystems of commercial units probably came in for more criticism than any other. Comments on automatic starters ranged from poor to unreliable to absolutely inadequate. There were instances where dampness deteriorated electrical contacts and solenoids causing failure of apparently well-insulated parts. The complexity of some electrical systems made them difficult to maintain and repair by field personnel. Inadequate fuses and failures of microswitches, relays, and reed switches were commonly encountered. The minimum time between collection of samples for some commercial units was too long to adequately characterize some rapidly changing flows.

Collected USEPA experience in one region reported by Harris and Keffer (16) involved over 90,000 hours use of some 50 commercial automatic liquid samplers of 15 makes and models. They found that the mean sampler failure rate was approximately 16 percent with a range of 4 to 40 percent among types. They also found that the ability of an experienced team to gather a complete 24-hour composite sample is approximately 80 percent. When one factors in the possibility of mistakes in installation, variations in personnel expertise, excessive changes in lift, surcharging, and winter operation, it is small wonder that projects on which more than 50 to 60 percent of the desired data were successfully gathered using automatic samplers were, until recently, in the minority.

In fairness to present day equipment, it must be pointed out that some of the above cited complaints stem from equipment designs of up to 10 years ago, and many commercial manufacturers, properly benefitting from field experience, have modified or otherwise improved their products' performance. The would-be purchaser of commercial automatic samplers today, however, should keep in mind the design deficiencies that led to the foregoing complaints when selecting a particular unit for his application.

D.4.3 Manual Versus Automatic Sampling

The decision whether to sample manually or use automatic samplers is far from straightforward, and involves many considerations in addition to equipment costs. Experience has indicated that operator training is necessary if manual sampling is to produce reproducible results. Instances have been noted wherein two different operators were asked to obtain a sample at a particular site with no other guidance given. Analyses of samples taken at almost the same instants in time have shown differences exceeding 50 percent. Other work conducted solely to compare manual sampling methods has indicated such discrepancies in results that suspicion must be cast upon manual methods that involve dipping of samples out of raw waste sources and has raised questions regarding the suitability of such manual grab sampling as a yardstick against which to measure other techniques.

The decision to use automatic sampling equipment does not represent the universal answer to water and wastewater characterization, however. For initial characterization studies, proper manual sampling may represent the most economical method of gathering the desired data. It is also prudent from time to time to verify the results of an automatic sampler with manual samples.

In general, manual sampling is indicated when infrequent samples are required from a site, when biological or sediment samples or both are also required from a site, when investigating special incidents (e.g., fish kills, hazardous material spills), where sites simply will not allow the use of automatic devices, for most bacteriological sampling, etc. Manual sampling will often be the method of choice in conducting stream surveys, especially those of relatively short duration where only a single daily grab sample is required from each site. For large rivers, lakes, and estuaries, manual sampling will almost always be required.

Automatic samplers are indicated where frequent sampling is required at a given site, where long-term compositing is desired, where simultaneous sampling at many sites is necessary, etc. Automatic sampling will often be the method of choice for storm-generated discharge studies, for longer period outfall monitoring, for treatment plant efficiency studies, where 24-hour composite samples are required, and so on.

Typically, the wide spectrum of 208 agency monitoring activities will require a capability for both manual and automatic sampling, and so the question is not which capability to obtain but when to use each. The answer should be determined in the design of each survey, using the above information as guidance.

D.4.4 Sampling Field Procedures

D.4.4.1 Manual Sampling Procedures

The preferred method of gathering manual samples from a raw waste stream is to use a pump to actually extract the fluid and tubing of appropriate size to transport it to the sample container. Pump and tubing sizes should be such that effective collection and transport of all suspended solids of interest is ensured. Both small, flexible impeller centrifugal pumps and progressive cavity screw pumps have been successfully used with good repeatability of results. It should be noted, however, that the collection of flow proportional or sequential composite samples can become quite tedious if performed manually at the sampling site. Locate the intake at approximately the three-quarters depth point (i.e., one-fourth of the way up from the bottom) and point it upstream into the flow. Adjust the pump speed until intake velocity approximately equals the mean flow velocity (obtained from a flow-measuring device or current meter) and, after about 60 seconds, direct the stream into the sample container. Avoid using an intake screen unless absolutely necessary.

When manually sampling natural streams, use a depth-integrating sampler at the center of the stream if the flow is laterally homogeneous. Check the site for this by occasionally taking samples from the quarter points and comparing results. If significant differences are found, either choose another site or take a number (5 to 20 depending upon stream width) of depth integrated samples along a transect perpendicular to the flow. Based on the results, choose the minimum number of transverse stations that will yield acceptable results.

Depth integrating samplers for use in more swiftly running streams are relatively heavy, and so some type of hoist or winch is normally used to facilitate handling. These can be mounted on boats for river and estuary cruises, on trucks or trollies for bridge sampling, etc. Contact the nearest USGS field office for more information on availability and use of different depth integrating samplers.

Samples may be manually gathered at a given depth in the water column by using a Juday bottle or one of its modifications (e.g., Kemmerer, Van Dorn). This type is essentially a cylinder with stoppers that leave the ends open while the sampler is being lowered to allow free passage of water through the cylinder. When the desired depth is reached (as determined by markings on the line, for instance) a messenger is sent down the line and causes the stoppers to close the cylinder, which is then raised and the sample transferred to its container. These devices can be used to approximate depth integration through the water column, to investigate stratification in lakes, or wherever a sample from a particular depth is desired. When using such devices from bridges, take precautions so that the messenger, when dropped from the height of the bridge, does not batter and ruin the triggers that release the stoppers. One simple way to avoid this is to support the messenger a few feet above the sampler with a string and release it when the desired depth is reached.

If vertical concentration gradients are not severe, a single grab sample will suffice. It is recommended that a container smaller in volume than the desired total sample volume be used, and that the required sample volume be obtained by repeated dippings at one minute intervals. Rinse the container two or three times in the water to be sampled prior to taking the first aliquot. Comparison of the results between depth integrated and simple grab samples will indicate when the latter technique will suffice.

For reproducibility of manual sampling results, operator training is absolutely essential; 208 agencies can ill afford to entrust this task to well-intentioned but untrained staff or volunteers. Also, it is time that we forget about using a beer can nailed to a stick as a sample gathering device. All in all, the manual pumping sampler described earlier in this section will produce the most reproducible results, and its use is recommended whenever feasible. One subject that should also be touched on briefly is manual compositing according to flow records. Given a series of discrete samples of equal volume taken at regular time intervals and a flow record, the question is what size aliquot should be taken from each discrete sample container to form the flow proportional composite sample? Recall from Section D.4.1 that this can be done in one of two ways: either extract an aliquot volume that is proportional to the instantaneous flow rate at the time the discrete sample was taken, or extract an aliquot volume that is proportional to the total discharge that has occurred since the last discrete sample was taken. The formula used for this can be written as:

$$a_i = f_i \, V_c / \Sigma f_i$$

where: a_i = aliquot volume to be extracted from the i-th discrete sample, i.e., the one taken at time t_i

i = index indicating the order in which the discrete samples were taken, $1 \leq i \leq n$

f_i = flow variable; either the flow rate when the i-th discrete sample was taken (q_i) or the total discharge that has occurred since the (i-1)-th sample was taken ($\Delta Q_i = Q_i - Q_{i-1}$)

V_c = composite sample volume desired

n = number of discrete samples taken

The desired composite sample volume is determined based on the requirements for the analyses to be conducted. The subtle problem is that one does not have complete freedom in selecting V_c because of the fixed discrete sample volume (V_d), and the entire sequential discrete series may be wasted if this is not recognized, because there might not be enough sample in one bottle to fulfill its aliquot requirements. This is best illustrated by an example (see Table D-19). Note that if steps 3 and 4 had not been carried out, when the operator came to bottle number 5 he would not have been able to continue, since he would be 250 mℓ short. This has happened. Also, it is incorrect to use leftover liquid from the adjacent discrete samples to make up the deficit (which has also occurred).

In actuality, one can compute the maximum composite sample volume that can be formed from a series of discrete samples. The formula is

$$(V_c)_{max} = V_d \, \Sigma f_i / (f_i)_{max}$$

If this quantity is greater than the amount desired, the formula given earlier for determining aliquot volume can be used. If not, the aliquot size should be computed from

$$a_i = f_i \, V_d / (f_i)_{max}$$

This will be illustrated by a second example, shown in Table D-20. Since the available composite sample is nearly half a liter less than was desired, a new decision on how to allocate the available volume must be made.

Example III (Table D-21) is included to indicate how to manually prepare a time-constant, volume-proportional-to-discharge-since-last-sample-was-taken composite when a record of flow rate rather than discharge is available. The results of Examples II and III agree because the same flow function (q=5,000 sin πt/8) was used in each case and the trapezoidal integration scheme worked well.

The details for manually preparing a time-constant, volume-proportional-to-instantaneous-flow-rate composite sample using the flow rate record given in Example III will not be presented (a_i=191, 354, 462, 500, 462, 354, 191, 0; Σa_i=2,514 mℓ), but it is of interest to contrast the measured concentration of a constituent of interest obtained by this method as opposed to the method of Example II. For this purpose, assume that the constituent behavior is a

TABLE D-19
MANUAL COMPOSITE SAMPLE EXAMPLE I

Example: Manually preparing a time-constant, volume-proportional-to-instantaneous-flow-rate composite sample.

Given: A 500 mℓ discrete sample was taken at the end of each hour over an 8-hour shift. A 2-liter composite is desired. A recording of flow rate is available.

Sample No. (i)	q_i	a_i	a_ix500/750
1	300	47	31
2	600	94	63
3	1,200	188	125
4	2,400	375	250
5	4,800	750	500
6	2,000	312	208
7	1,000	156	104
8	500	78	52
Σq_i =	12,800	2,000	1,333

Steps:

1. Enter q_i from record and sum.
2. Calculate $a_i = q_i V_c / \Sigma q_i = 2000 q_i / 12{,}800$.
3. Check to see if maximum a_i exceeds discrete sample volume.
4. Compute new aliquot volume = a_ix500/750.

TABLE D-20
MANUAL COMPOSITE SAMPLE EXAMPLE II

Example: Manually preparing a time-constant, volume-proportional-to-discharge-since-last-sample-was-taken composite.

Given: A 500-mℓ discrete sample was taken at the end of each hour over an 8-hour shift. A 3-liter composite is desired. A recording of totalized flow is available.

Sample No. (i)	Q_i	ΔQ_i	a_i
0	0	-	-
1	969	969	99
2	3,729	2,760	284
3	7,860	4,130	424
4	12,732	4,873	500
5	17,605	4,873	500
6	21,736	4,130	424
7	24,496	2,760	284
8	25,465	969	99
	$\Sigma\Delta Q_i$ =	25,464	2,614

Steps:

1. Enter Q_i from record and calculate $\Delta Q_i = Q_i - Q_{i-1}$.
2. Calculate $(V_c)_{max}$ = (500) (25,464)/4,873 = 2,614 mℓ.
3. Since $(V_c)_{max}$ is less than desired, calculate aliquot size from $a_i = 500\ \Delta Q_i/4{,}873$.

TABLE D-21
MANUAL COMPOSITE SAMPLE EXAMPLE III

Example: Manually preparing a time-constant, volume-proportional-to-discharge-since-last-sample-was-taken composite.

Given: A 500-mℓ discrete sample was taken at the end of each hour over an 8-hour shift. A 3-liter composite is desired. A recording of flow rate is available.

Sample No. (i)	q_i	ΔQ_i	a_i
0	0	-	-
1	1,913	957	99
2	3,536	2,725	283
3	4,619	4,078	424
4	5,000	4,810	500
5	4,619	4,810	500
6	3,536	4,078	424
7	1,913	2,725	283
8	0	957	99
	$\Sigma\Delta Q_i$ =	25,140	2,612

Steps:

1. Enter q_i from record and use trapezoidal rule to calculate $\Delta Q_i = (q_i + q_{i-1})/2$ (another integration scheme could be used if warranted).
2. Calculate $(V_c)_{max}$ = (500) (25,140)/4,810 = 2,613
3. Calculate $a_i = 500\ \Delta Q_i/4,810$

simple linear decay (i.e., conc.=9-t). The true concentration in the flow rate proportional sample would be 5.0 (assuming the discrete samples from which the composite was formed were 100 percent representative). The corresponding true concentration of the discharge proportional composite (Example II) would be 4.5, a difference of around 10 percent due solely to the method of compositing.

The possible importance of sediment oxygen demand (SOD) measurements to 208 agency plans is well illustrated by Butts (17) who noted, as a result of an extensive SOD study, that "... it is doubtful that the aquatic ecology of the (Illinois) waterway can be measurably enhanced solely by achieving current water quality standards." The subject of SOD measurement remains somewhat controversial, but it is recommended that determinations be made in situ rather than in the laboratory. Ascertaining the relationship between SOD rates and DO content of the overlying waters is better accomplished by performing in situ measurements. This can be done, for example, by setting a bell-shaped shallow cover over the spot on the bottom where the measurement is to be made, circulating the water within this "sampler" with a small pump, and measuring the change in DO with time.

The design of an in-situ SOD measuring device developed by the Illinois State Water Survey is described by Butts (17), who also reports favorably on its use. The cover was made from a 14-inch-diameter by 24-inch-long steel pipe split longitudinally in half. End plates were welded on, and angle iron was welded around the lower edge to act as cutting edges and seating flanges. Fittings for raising and lowering the device, two hose attachments to allow connection of a pump for water circulation, and a split collar to hold the DO/temperature probe were also welded in place. The "sampler" covered a flat bottom area of about 0.2 square meter (336 sq in.), and the total volume of water within the system was around 31 liters. The device is handled with a USGS bridge winch adapted for use on a boat.

D.4.4.2 Automatic Sampling Procedures

When using automatic samplers, the greatest problem comes in mounting the intake. Screened intakes should be used in waters containing large solids, trash, or debris to prevent clogging. Screen openings should be slightly smaller than the smallest opening in the sampling train. More and more commercial devices are now provided with intake screens by their manufacturers. When using these, the end of the intake hose should be approximately at the center of the screen. If intake screens are not provided with the samples, they can be fabricated quite simply by drilling a large number of appropriately sized holes in a piece of plastic pipe, cementing on end covers, and drilling out one end to accept the sample tube and fastening it with a hose clamp and fitting. Clear plastic is recommended to facilitate inspection. A typical size for an intake screen to accommodate a 3/8 inch ID tube is approximately 1.5 to 2 inches in diameter by 6 to 10 inches long. Hole diameters could be 1/4 inch if the rest of the sampling train is larger.

The flexible plastic intake tubing commonly used in most commercial automatic samplers will require some protection in many installations, or wear from particles in the flow and damage from debris will necessitate frequent replacement. Flexible electrical conduit and reinforced garden hose have been successfully used in this regard. Even with such protection, it is recommended that sample intake lines be trenched in where they run over earthen surfaces.

One of the most challenging sample intake mounting problems is in a natural, wet weather stream. If the intake is allowed to rest on the bottom where it could obtain samples at very low flows and, hence, more readily determine first flush effects, there is a possibility that flow fields around the intake may induce scour and cause artificially high solids readings. Mounting the intake well above the bottom obviates this problem but prevents acquiring samples of very low flow. The best compromise seems to be to mount the intake horizontally, at right angles to the flow, in the middle of the stream and with its lowest surface around 2 inches above the bottom (higher if significant bedload depths are anticipated). The stream bottom at this point should be reasonably flat and free of stones or other flow-altering obstructions upstream of the intake. For cobble-strewn bottoms, follow the above procedure but measure from a sheet of plywood resting on the stones.

To anchor the sample intake to the bottom, use screw augers or metal rods driven well into the soil. Simple hose clamps can be used to affix the intake screen to these supports.

For continuously flowing natural streams, similar considerations pertain. The main difference will be in the vertical location of the intake. In the absence of other factors, mount the intake near the low flow mid-depth. If stream depth allows, the intake should be mounted with its center line vertical, and suction taken from the bottom. In this configuration, a single mounting rod can be used. It should be located to one side of the intake (never in front of it).

The foregoing has been written with smaller streams, typical of those that would be encountered in an urban runoff study, in mind. As indicated earlier in this section, it is not expected that automatic samplers will find wide use in river monitoring.

In man-made channels and conduits, there is no longer a concern for bottom scour. For those carrying intermittent flows, the intake screen can be allowed to rest on the bottom unless significant bedload depths are anticipated. Where large debris is likely to be encountered, a spring-loaded intake screen mounting should be considered to help prevent destruction. It is a fairly common practice to simply let the intake screen trail downstream by its tubing. In very low or no-flow periods it will rest on the invert and, during higher flows, hydrodynamic forces will tend to lift it up. The chief objection to this practice is that probes facing downstream do not gather representative solids due to momentum effects. Data on the degree of under-representation caused by this practice are virtually nonexistent, however. Use this practice as a last resort.

Where the flow is continuous (but variable), position the intake screen near the low flow mid-depth. As opposed to natural streams, however, in many man-made conduits it will be more convenient to dangle the intake from above with the suction tube pointing down. Although the vertically up orientation is preferable, this practice is also acceptable. The chief disadvantage of "dangling" approaches to intake mounting is that you never really know where the intake is. Be certain that there is no possibility of full flow positioning the intake where it could be left "high and dry" as the flow recedes. Manhole benches, steps, weirs, and the like have taken their toll in careless intake installations.

For the (rare) case where relatively steady flow is anticipated in either natural or man-made channels, position the intake at about the three-quarter depth point. If two automatic sampling devices are used for redundancy at a critical site, position one intake at the eight-tenths depth point and one at the four-tenths depth point. Shelley (18) discusses the rationale for sample intake location in some detail and presents designs for maintaining intakes at a constant percentage of depth in variable flows, noninvasive intakes, etc.

All of the foregoing has been written primarily with suction lift intakes in mind, but similar considerations apply if forced-flow devices are used. For samplers employing mechanical gathering methods, follow the manufacturer's directions.

Mounting the main body of the automatic sampler is rather straightforward; follow the manufacturer's directions. Keep the lift as short as possible commensurate with the likelihood of submergence. If excess sample tubing exists, cut it off. Do not simply coil it out of the way, thinking that the extra length might be useful at the next installation.

After setting up the controls and power subsystem according to the operator's manual for the particular sampler being used, manually cycle it a few times and measure the quantity of sample actually being taken. This is especially important where fixed aliquot volume composite samples are to be collected. Verify sample volume gathered on each site visit. Partial plugging, intake blockage, or other occurrences that might not be immediately obvious can affect the sample quantity in most designs. Also, use a stopwatch to record the time that it takes to gather the sample and verify this on subsequent visits. For battery-operated units, frequent voltage checks are in order until service life can be established for the installation. Manufacturers are not noted to be conservative in estimating battery life, and it will be affected by a number of factors such as sample lift, temperature, etc. Always inspect the sample intake at each visit.

For operation in very cold weather, a heated enclosure for the sampler body will be required. Sample lines should be wrapped with heater tape and insulated -- large plastic trash bags work well for this. Check for possible ice buildup at each visit. Should frozen (or partially frozen) samples be encountered, do not discard them, but immediately enter the facts in the field log and also report the condition to the analytical laboratory when the samples are delivered.

Maintenance and troubleshooting of automatic samplers are so design-dependent that little general guidance can be given other than to follow manufacturer's instructions and recognize the importance of these activities in contributing to project success. However, one word of caution pertaining to suction lift samplers using peristaltic pumps must be made. Some of these pump designs require that the tubing be lubricated. This must be done or tube life will be considerably shortened; failures after less than 2 hours of operation have been reported for some designs when inadequate lubrication was applied. With care and consideration, most automatic samplers can be made to work reasonably well; with carelessness and disregard, almost none will.

D.4.5 Sample Quantity, Preservation, and Handling

Since the required sample volume is dependent upon the type and number of parameters to be analyzed for and the instrumentation and methods to be employed in the analysis at the laboratory, the laboratory analyst is the best person to specify the quantity needed. A preliminary estimate of sample volume can be obtained as follows. Determine the parameters to be analyzed for and, from the Parameter Handbook, obtain the sample volume required for each analysis. Sum these to obtain the minimum volume, and increase this amount as necessary to allow for spillage, mistakes, sample splitting, and for analytical laboratory quality control purposes. In the absence of better information, doubling the minimum volume should be adequate.

Having collected a representative sample of the fluid mixture in question, there remains the problem of sample preservation and analysis. It is a practical impossibility either to perform instant analyses of the sample on the spot or to completely and unequivocally preserve it for subsequent examination. Preservation methods are intended to retard biological action, retard hydrolysis of chemical compounds and complexes, and reduce volatility of constituents. They are generally limited to pH control, chemical addition, refrigeration, and freezing. The USEPA (19) has compiled a list of recommendations for preservation of samples according to the measurement analysis to be performed. In order to provide an overview for some common parameters, this list has been reproduced here as Table D-22. For other parameters and program design, reference should be made to the Parameter Handbook.

Proper sample handling is also essential to obtaining successful results from any monitoring program. A few general guidelines are given below.

1. Each sample container must have a designation, normally a number, that uniquely distinguishes it from all other samples in the survey.

TABLE D-22

RECOMMENDATIONS FOR PRESERVATION OF SAMPLES ACCORDING TO MEASUREMENT[1]

Measurement	Vol Req (ml)	Container	Preservative	Holding Time[6]
Acidity	100	P,G[2]	Cool, 4°C	24 Hrs
Alkalinity	100	P,G	Cool, 4°C	24 Hrs
Arsenic	100	P,G	HNO_3 to pH <2	6 Mos
BOD	1000	P,G	Cool, 4 C	6 Hrs[3]
Bromide	100	P,G	Cool, 4 C	24 Hrs
COD	50	P,G	H_2SO_4 to pH <2	7 Days
Chloride	50	P,G	None Req	7 Days
Chlorine Req	50	P,G	Cool, 4°C	24 Hrs
Color	50	P,G	Cool, 4°C	24 Hrs
Cyanides	500	P,G	Cool, 4°C NaOH to pH 12	24 Hrs
Dissolved Oxygen				
Probe	300	G only	Det on site	No Holding
Winkler	300	G only	Fix on site	No Holding
Fluoride	300	P,G	Cool, 4°C	7 Days
Hardness	100	P,G	Cool, 4°C	7 Days
Iodide	100	P,G	Cool, 4°C	24 Hrs
MBAS	250	P,G	Cool, 4°C	24 Hrs
Metals				
Dissolved	200	P,G	Filter on site HNO_3 to pH <2	6 Mos
Suspended			Filter on site	6 Mos
Total	100		HNO_3 to pH <2	6 Mos
Mercury				
Dissolved	100	P,G	Filter HNO_3 to pH <2	38 Days (Glass) 13 Days (Hard Plastic)
Nitrogen				
Ammonia	400	P,G	Cool, 4°C H_2SO_4 to pH <2	24 Hrs[4]
Kjeldahl	500	P,G	Cool, 4°C H_2SO_4 to pH <2	24 Hrs[4]
Nitrate	100	P,G	Cool, 4°C H_2SO_4 to pH <2	24 Hrs[4]
Nitrate	50	P,G	Cool, 4°C	24 Hrs[4]
NTA	50	P,G	Cool, 4°C	24 Hrs
Oil and Grease	1000	G only	Cool, 4°C H_2SO_4 to pH <2	24 Hrs
Organic Carbon	25	P,G	Cool, 4°C H_2SO_4 to pH <2	24 Hrs
pH	25	P,G	Cool, 4°C Det on site	6 Hrs[3]
Phenolics	500	G only	Cool, 4°C H_3PO_4 to pH <4 1.0g $CuSO_4$/l	24 Hrs
Phosphorous				
Orthophosphate, Dissolved	50	P,G	Filter on site Cool, 4°C	24 Hrs[4]
Hydrolyzable	50	P,G	Cool, 4°C H_2SO_4 to pH <2	24 Hrs[4]
Total	50	P,G	Cool, 4°C	24 Hrs[4]
Total, Dissolved	50	P,G	Filter on site Cool, 4°C	24 Hrs[4]
Residue				
Filterable	100	P,G	Cool, 4°C	7 Days
Nonfilterable	100	P,G	Cool, 4°C	7 Days
Total	100	P,G	Cool, 4°C	7 Days
Volatile	100	P,G	Cool, 4°C	7 Days
Settleable Matter	1000	P,G	None Req	24 Hrs
Selenium	50	P,G	HNO_3 to pH <2	6 Mos
Silica	50	P only	Cool, 4°C	7 Days
Specific Conductance	100	P,G	Cool, 4°C	24 Hrs[5]
Sulfate	50	P,G	Cool, 4°C	7 Days
Sulfide	50	P,G	2 ml zinc acetate	24 Hrs
Sulfite	50	P,G	Cool, 4°C	24 Hrs
Temperature	1000	P,G	Det on site	No Holding
Threshold Odor	200	G only	Cool, 4°C	24 Hrs
Turbidity	100	P,G	Cool, 4°C	7 Days

NOTES:

1. Taken from (9).
2. Plastic or Glass.
3. If samples cannot be returned to the laboratory in less than 6 hours and holding time exceeds this limit, the final reported data should indicate the actual holding time.
4. Mercuric chloride may be used as an alternate preservative at a concentration of 40 mg/l, especially if a longer holding time is required. However, the use of mercuric chloride is discouraged whenever possible.
5. If the sample is stabilized by cooling, it should be warmed to 25°C for reading, or temperature correction made and results reported at 25°C.
6. It has been shows that samples properly preserved may be held for extended periods beyond the recommended holding time.

2. When frequent sampling over a long time period is involved, consideration should be given to incorporating a temporal indication as a part of the sample identification number; e.g., the number of the week in a year, the last two digits of the year, etc. The temptation to code too much information about the sample into its identification number must be resisted, however, or else the risk of mixups due to unauthorized abbreviations becomes too great.

3. Consideration should be given to the use of preprinted, sticky-back labels in many instances. Be certain, however, that they are waterproof. Rubberband and tie-on tags have also been used successfully.

4. The use of color-coded labels has been successful where sample splitting or different preservation techniques are employed. In the latter case, for example, a green label could indicate that nitric acid had been added and that, therefore, an analyst could obtain aliquots from this sample for metal analyses, etc.

5. Where possible, the type of sample, date, and any preservatives added should be written on the sample label prior to collecting the sample in the field. The time of day should be added when the sample is collected. Additional information should be noted in the field notebook and on supplemental forms where used.

6. The foregoing should be observed in addition to any chain-of-custody procedures that are involved. See (20) for USEPA recommendations for a chain-of-custody program.

The proper cleaning of all equipment used in the sampling of wastewater is essential to ensuring valid results from laboratory analyses. Cleaning protocols should be developed for all sampling equipment early in the design of the monitoring program. Here, also, the laboratory analyst should be consulted, both to ensure that the procedures and techniques are adequate as well as to avoid including practices that are not warranted in view of the analyses to be performed. The possibility of the container affecting the sample analyses should be checked periodically. Distilled or demineralized water should be placed in a typical container for a period of time similar to that of a normal sample. Then the particular constituent of interest should be measured in the water from this blank. Also, checks for sample adsorption on the container should be made by placing a known amount of a particular constituent in a typical container. After a specified holding time, analyses should be made to determine if any of the material was adsorbed into the container or changed in any other manner. These checks should be done after sample bottles have been used for a series of samples. In this way the cleaning techniques used can be tested for thoroughness.

The use of blanks and spikes just mentioned brings up the subject of quality control in general. Although outside the scope of this Appendix, each 208 agency must have a viable quality assurance program. The USEPA (21, 22) has published minimal requirements for a water quality assurance program and a handbook for analytical quality control in the laboratory. The recommendations in these two references should be followed by all 208 agencies.

D.4.6 Sampling Accumulated Roadway Material

Accumulated roadway material may represent a significant source of pollution during storm-generated discharges in urban areas. In order to quantify this source, provide inputs for models, determine if better urban housekeeping practices would produce commensurate water quality improvements, etc., sampling of accumulated roadway material will be required. The following discussion is abstracted from Wullschleger et al. (7).

Samples of materials deposited on roadways are collected using a combination of sweeping, vacuuming, and water flushing techniques. Each sample will consist of three fractions: litter, dust and dirt, and water flush. The particulate materials collected by sweeping and vacuuming are separated on the basis of particle size into a litter fraction and dust and dirt fraction. The litter fraction consists of that portion of the particulates retained by a U.S.A. No. 6 sieve (i.e., greater than 3.35 mm in diameter). This fraction is usually composed of stones, gravels, wood fragments, and other larger sized materials in addition to bottles, cans, paper production, etc., which are normally thought of as litter. The dust and dirt fraction will contain particulates smaller than 3.35 mm in diameter. The water flush fraction contains those components of the dust and dirt fraction which were not picked up at high efficiencies by the sweeping and vacuuming techniques. The flush plus the dust and dirt constitute a total dust and dirt fraction which is the major source of water pollutants found in runoff from urban roadways.

If a physical and chemical description of the street surface contaminants is needed, the sample should be collected by hand sweeping, followed by flushing. All of the dry solid material collected from the test area should be placed in clean containers and shipped back to the laboratory. There it should be air dried thoroughly and sealed for storage until analyzed. All of the flushed material should be measured for volume, but only a portion of it need be retained for analysis. The liquid sample should be stored in clean containers (glass, if pesticide analyses are to be made) and cooled to <4°C if possible. The analyses of the liquid fraction should be made as soon as possible after collection. To reduce the number of chemical analyses required, the dry and liquid samples can be combined on an equal sample area basis before the analyses are performed.

If only physical loading information (such as kg (lb) of solids per curb km (mile)) is needed, hand sweeping is probably sufficient. In most cases, the additional quantity of material that can be obtained by subsequent vacuuming and/or flushing is insignificant. If information regarding particle size distribution is required, then the sample should be collected using a combination of hand sweeping and dry vacuuming. The vacuum is more efficient in removing the fine particles which are needed for size distribution analyses. If size distribution of the solids in the wet phase is needed, then flushing will also be required.

The basic procedures for the collection of samples are:

Hand sweeping - Hand sweeping for dry solids collection should utilize a standard stiff-bristled push broom. The sweeping pattern should be from the center of street or from one edge of the test area towards the gutter or opposite side of the test area. After concentrating the material along this edge, the sample should be collected, using a whisk broom and dustpan.

Vacuuming - Vacuuming the test area usually removes more smaller-sized particles than is possible by only using sweeping techniques. The vacuuming pattern should approximate the pattern described for hand sweeping. An industrial wet/dry "shop" vacuum cleaner with a 5-7.6 cm (2 in. to 3 in.) diameter hose is recommended. Other types of units, ranging from small household vacuums to large motorized vacuum sweepers, may also be satisfactory, depending on the size of the test area.

Flushing - The test area can be flushed with water after hand sweeping to remove soluble films and other nonsweepable material. The materials removed with this method more closely resemble those which are removed by a runoff event. The test area is first slightly wetted to soften and facilitate removal of soluble materials. It is then flushed with a stream of water from a garden hose and spray nozzle connected to a fire hydrant or other water supply. Begin at the road crown and flush toward the edge. The downslope gutter is dammed with sandbags to create a collection area. A small vacuum collector is used before an industrial wet/dry vacuum cleaner to remove the sample water from the collection area. All water and contaminants are collected using this vacuum-operated collector trap. This is an air-tight box or drum with a capacity of several gallons to several hundreds of gallons (depending upon specific test procedures), outfitted to function as a "trap" in a vacuum line. The inlet hose of the collector trap has a pickup nozzle on the open end. The outlet hose of the collector trap is connected to an industrial shop vacuum.

The vacuum cleaner used for collection of roadway particulates consists of a pick-up head attached to a 38ℓ (10 gal) canister on the top of which is mounted an exhaust motor. Exhaust ports from the canister leading to the motor are covered by a filter bag to retain solids picked up during the vacuuming operations. Since the finer particles found on roadways are relatively more heavily laden with water pollutants, experiments have been performed to determine the retention of smaller-sized particles by the filter bag. Recoveries of 99, 93, and 94 percent were obtained using a new filter bag with each sampling run. These tests indicate satisfactory retention of fine particulates by the filter bags as well as quantitative removal and recovery of vacuumed particles from the canister walls and bags.

The water flush procedure has also been tested in the field. It was found that a roadway area of 92 sq m (1000 sq ft) could be thoroughly flushed with about 95ℓ (25 gal) of water. In most cases, over 50 percent of the applied flush was recovered by vacuuming of the impounded water along the curb.

A specific stepwise sampling procedure for the collection of street surface contaminants is given below.

1. Select a roadway sampling site 30.48 continuous curb meters (100 ft) or more. The street surface and curbing should be in relatively good condition. Mark the limits of the sampling length selected.

2. Rake and/or brush along the curb for 3.0 or 4.6m (10 or 15 ft) from the limit markings <u>away</u> from the section to be sampled.

3. Knock the brush clean. Rake and/or brush from the higher elevation limit. Shovel bulk litter plus swept dust and dirt into a clean galvanized garbage can.

4. Vacuum along the entire curb length of the roadway sampling site out to a distance of four to five feet from the curb. Three vacuumings of the site should be carried out to collect the dust and dirt sample fractions. Two vacuum cleaners are

used simultaneously to speed up the operation with particular attention at the litter pickup point.

5. Position several sand bags at the curb of the lower limit of the sampling area to impound the flush water.

6. Place the nozzle of a dual motor shop vacuum at a low point in front of the sand bags so as to suck water into a 208ℓ (55-gal) drum.

7. Place the intake hose from a rotary screw pump into a 208ℓ (55-gal) drum filled with water and begin flushing the roadway using the garden hose.

8. Flush the entire roadway surface area toward the curb and finish by flushing the gutter toward the sand bags.

9. Approximately 57 to 95ℓ (15 to 25 gal) of water are required to flush 56-93 sq m (600-1000 sq ft) of roadway. Generally greater than 50 percent of the flush water applied is recovered by the vacuum.

10. Take out the filter bags and shake well into garbage can with bulk material. Save the bags.

11. Empty vacuum canisters into garbage can. Brush canisters well.

12. Take combined litter and dust and dirt in garbage can and the flush fraction to the laboratory. Other equipment may proceed to next sampling site.

Sampling sites should be chosen to represent the range of conditions that occur in the area. Important variables may include land use, average daily traffic, type of adjacent landscaping, and street surface material. It is recommended that at least a single complete analysis be made for each land use area, with total solids analyses being made on samples representing other identified variables. If several sampling sites are established in each land use area, a portion of each sample could be combined for complete composite chemical analysis representing that land use.

For one 12-month field study, seven area roadways were chosen based primarily upon the range of average daily traffic levels and road use categories encompassed. Other factors considered in the roadway selections were speed limit and roadway surface material. Satisfactory condition of the street surface and a sufficient length of curb against which the sample could be deposited and collected were important factors in selection of the specific sampling sites on the area roadways chosen.

In general, the following information should be collected for a sampling site: sampling location; date; local land use; parking restrictions; traffic characteristics; composition, type and condition of the street, gutter, and curb; the size of the test area; and a description of the adjoining area. Photographs of the area are often valuable. Data concerning the cleaning frequency, the date of the last recorded cleaning, and the recent rainfall history should also be obtained for each test area.

If the selected study area is subject to vehicular traffic, it will be necessary to establish some type of traffic control for the protection of the field workers. Flagmen and traffic cones are probably a minimum precaution which should be used in all areas.

The type of study area (street surface, parking lots, or other large surfaces) and sampling objectives will determine the size of sampling area. A typical secondary street can usually be sampled using a single test area of about 93 sq m, 7.6m x 12.2m (1000 sq ft, 25 x 40 ft). Large paved surfaces may be better sampled using several smaller test areas (0.9 sq m (10 sq ft)) and averaging the results. Experimental design procedures should be incorporated to determine the necessary types of study areas to sample to satisfy specific study objectives.

As with the selection of the study area, the frequency of sampling will depend on the objectives of the sampling program. For one 12-month field study, a schedule was set up early in the program such that the roadways were sampled during several seasons of the year in order that seasonal effects on pollutant deposition rates might be studied. However, during the winter season, freezing conditions prevented the collection of some of the flush fractions.

Sampling periods were scheduled to begin on a Monday and end one week later on the following Monday. Sample collections were planned to be carried out in the following manner:

1. An initial sample was obtained by cleaning the roadway surface and quantitative collection of materials initially found on the site. No measurements of traffic were taken to correspond with the initial sample; however, records of precipitation and dates of the most recent antecedent cleaning of the roadway surfaces were maintained throughout the 12-month field study.

2. The site was sampled a second time after an accumulation period of approximately 24 hours during which time a measured volume of traffic passed the roadway site. As many as four samples having a one-day accumulation period were taken during the remainder of the week. Traffic counts were taken with each one-day sample.

3. The final sample of the period was gathered following the weekend. Ideally then, a sampling period consisted of an initial sample, four one-day samples, and a weekend sample with traffic data for all samples except the initial one.

4. Precipitation frequently interrupted the planned pattern of the sampling periods. Samples were gathered after rainstorms in a few cases; however, it was felt that such samples would be atypical; and, therefore, collections after runoff events were

abandoned early in the program. The roadway site was cleaned as soon as convenient after precipitation had ceased and a new sample accumulation period begun. Sampling periods were extended in some instances in order to make up for loss of samples due to precipitation.

Experimental design procedures should be incorporated to determine the required sampling frequency and sample numbers to satisfy specific study objectives. The published results of previous sampling programs may be useful in this design process.

D.5 Cost Estimation

It is difficult to provide precise program cost information, since costs are dependent upon so many program and locality related factors, e.g., institutional setting and accounting procedures, area complexities and program size, opportunity free labor, etc. This section presents a methodology for cost estimation for any given program, some "ball park" rules of thumb for preliminary rough cut costing, and some specific examples. The costing methodology is divided into six steps:

1. Estimate Instrumentation Costs
2. Estimate Related Equipment Costs
3. Estimate Manpower Costs
4. Estimate Field Operations Costs
5. Estimate Laboratory Analysis Costs
6. Estimate Data Analysis and Reporting Costs

These will be discussed in turn. Note that modeling costs are not included.

D.5.1 Instrumentation Costs

Instrumentation costs were discussed in Section D.3 and will only be summarized here. These costs represent capital acquisition costs for the most part, and amortization schedules will be a matter of local accounting procedures and discretion. Resist the temptation to lower apparent program costs by using long amortization periods, especially for equipment used in storm-generated discharge studies. Such hostile flows take a great instrumentation toll, and one or two years life is much more typical than ten or twenty.

For flow measurement, the types and numbers of primary and secondary devices must be determined. These are multiplied by the cost of each to arrive at the total dollars required. Make an allowance for spare parts for secondary devices (say 10% in the absence of more specific information). Consider the purchase of at least one complete extra unit to allow for quick field fixes. Instrument breakdown is most likely to occur during important data collection periods, and record interruptions should be as brief as possible.

Langbein and Harbeck (23) reported that a sample of four USGS districts yielded the following costs (in 1972 dollars) for flow-gaging stations: $5K to $10K for installation of an indefinite-term full-record station; $2.5K to $4K for installation of a short-term full-record station; station operating costs of $0.8K to $1.3K per year; office costs for processing the record of $0.5K to $1.3K per year. For partial-record stations, costs as a percentage of full-record stations were stated as: 5 percent for low flow only; 15 to 20 percent for crest stage record; and up to 50 percent for a flood hydrogram. They also noted that there could be extremely large variations outside of these nominal ranges.

In the absence of better information, it is suggested that $10K be budgeted for each urban flow measurement site for the acquisition and installation of a primary flow measurement device. Allow $2K each for the secondary device. The former number takes into account that some sites will allow relatively inexpensive portable devices to be used, while others may require considerable modification, e.g., installation of a below ground metering vault. The desirability of using existing USGS gaging sites where feasible is obvious.

Where possible, try to use existing meteorological instrumentation operated by others. One notable exception will be raingages. They typically cost less than $400 each; recorders may add another $500-$1,000 each. Give serious consideration to the use of leased telephone lines to provide rainfall indication back to a central location. The cost is nominal, and the information is invaluable in crew dispatching and operations. At least one raingage per catchment will be required.

For automatic samplers, the number and types must be determined. For storm-generated discharge sampling, the bulk of the commercially available devices will not be suitable without some modification. Most manufacturers will do this, but it adds cost. Between $2K and $4K should be allowed for each unit. Allow 10 percent for spares and purchase at least one complete extra unit. Also give consideration to installing two separate automatic samplers at critical sites for redundancy. If both function flawlessly, the extra sample quantity won't hurt, and the likelihood of missing a critical storm event is considerably diminished. Manual sampling equipment must be provided to each field crew. Allow two sets for each crew and plan on $100 for each set.

D.5.2 Related Equipment Costs

Shelters will be required for monitoring instrumentation at most sites. Costs can range from under $300 for a metal garden shed to well over $2K if concrete slabs and heavy fencing are required. Consideration should be given to ease of moving instrumentation from site to site; transportable (i.e., trailer) shelters have been used successfully in this regard. For some installations, e.g., one with a large mechanically refrigerated sampler, AC power will be required, and the expense of running electrical lines should be included as part of the overall station cost. Such costs may not be insignificant; $6.4K was spent just to get power to one 208 stormwater monitoring site in Illinois. Site preparation costs should not be capitalized.

Other related equipment that will be required includes small tools, personnel safety and protective gear (e.g., waders, hard hats, respirators, harnesses, etc.), and miscellaneous field hardware. These may or may not be already available. As a very rough estimate, allow 2 percent to 5 percent of the total instrumentation acquisition cost for this purpose. Do not capitalize them.

Other related equipment includes vehicles (automobiles, vans, trucks, etc.), boats, motors, generators, pumps, and the like. These are capital equipment items but, because of their multiplicity of uses, they should probably not be fully charged to a 208 program alone. In the event that the local 208 agency does not have such equipment at its disposal, consideration should be given to leasing rather than purchase. Lease rates vary with locality, but for longer term rentals, i.e., months, not days, rates can be quite reasonable. For mobility of field crews, consideration should be given to leasing extra vehicles during periods of intense activity. Of course all leasing costs should be directly charged to the monitoring program.

D.5.3 Manpower Costs

The manpower costs associated with a 208 monitoring program will vary tremendously from agency to agency, depending upon the size of the program (and hence the number and skill mix of personnel required) as well as local wage scales (including fringe benefits) and accounting practices (application rates for overhead and general and administrative expenses). Therefore, skill levels here will be indicated by estimating equivalent federal government service ratings. Salaries can be adjusted up or down to suit local conditions, and burdens can be applied according to local accounting practices. Table D-23 indicates the types of talent that a 208 program may require.

As an example of the use of Table D-23 to estimate manpower requirements, consider the following. It is desired to conduct one intensive survey per month for a one-year period. The objective of these intensive surveys is to provide information for waste load allocation studies. The basic unit manpower for the estimates made here consist of a field party chief, three qualified technicians, a chemist, a microbiologist, and a biologist. It is assumed that the minimum sampling period would be 5 consecutive days. The

TABLE D-23
TALENT REQUIREMENTS

Skill Area	Federal GS Rating	Annual Pay Rate
Environmental Engineer (1)	GS 13-14	$23K to $35K
Sanitary Engineer	GS 11-12	$16K to $25K
Hydrologist	GS 9-11	$13K to $21K
Chemical Engineer	GS 9-11	$13K to $21K
Chemist	GS 11-13	$16K to $30K
Oceanographer (2)	GS 11-12	$16K to $25K
Biologist	GS 9-12	$13K to $25K
Limnologist (3)	GS 9-11	$13K to $21K
Field Technicians	GS 3-6	$7K to $13K
Lab Technicians	GS 5-7	$9K to $14K
Clerical	GS 2-4	$6K to $10K

NOTES:

1. Assumed to be responsible for overall monitoring program.
2. Required for estuarine or near coastal studies.
3. Required for lake surveys.

basic intensive survey unit manpower estimates are shown in Table D-24. Using the salary figures from Table D-23 as a guide, the direct labor costs for one intensive survey are as follows: Field Party Chief, $26K x 3.75 MW = $1.9K; Chemist, $18K x 16 MW = $5.5K; Biologist, $16K x 5 MW = $1.5K; Field Technicians, $9K x 5 MW = $0.9K; Lab Technicians, $11K x 3.25 MW = $0.7K; Typist $7K x 1 MW = $0.1K. Thus, the total salary requirements for one intensive survey would be approximately $10.6K.

Of course it must be kept in mind that not all personnel time can be utilized at 100 percent efficiency due to a number of reasons (e.g., in runoff studies the field crews have to be paid whether it rains or not), and so a better procedure for budget estimation is to calculate annual salary costs for all required personnel rather than on a work unit basis. One last comment on manpower costs deals with the actual hours worked while in the field. Twelve hour (or longer) days are the rule rather than the exception, and extra compensation for this overtime must be allowed for in arriving at total manpower costs. Non-professional (i.e., non-exempt) personnel must be paid in accordance with applicable wage/hour laws (e.g., time and one-half for over 8 hours per day or sixth straight day in a week, etc.). Professional (exempt) personnel will be paid straight time for hours worked, given compensatory time off, or some such consideration depending upon local policy, but this also represents cost to the program and must be accounted for.

D.5.4 Field Operations Costs

This is a miscellaneous category that covers costs incurred incidental to field operations and that do not logically fit in any of the foregoing discussions. Included are such items as personnel travel costs and per diem as appropriate, miscellaneous supplies (as opposed to equipment, e.g., ice for samples if required, chemical preservatives, sample containers, gasoline, etc.), performance bonds for site restoration if required, charges for utilities (electricity, telephone lines, etc.), and so on.

TABLE D-24
ESTIMATED MANPOWER REQUIREMENTS FOR INTENSIVE SURVEYS

Activity	Personnel	Time (man-weeks)	Remarks
Initial planning	Field party chief* and lab personnel	2 MW	Assemble maps and post data
Reconnaissance (if needed)	Field party chief* and biologist	1 MW	Select sampling sites and synoptic biological screening
Mobilize field equipment and crew	Field party chief* technicians and lab crew	1 MW	Get all equipment together and ensure it is in working order
Field sampling	Field party chief* 2 laboratory crew 3 technicians 1 biologist	1 MW 3 MW 4 MW 1 MW	Field sample collection and field lab analyses
Fixed lab analyses chemistry and biology	Chemist Biologist	15 MW 3 MW	Assume 20 samples per day for 15 parameters, chemistry and plankton, and invertebrate identification and enumeration
Data analyses and report preparation	Field party chief* chemist and microbiologist, typist	3 MW	Analyze data, write and type report

* In the case of estuarine or near coastal studies this would be an oceanographer.

Taken individually, these items do not represent major sums of money but, collectively, they form a sum that may not be insignificant for many 208 monitoring programs and, therefore, must be considered in total cost estimation. They are so project and locality specific that no specific guidance can be given for cost estimation. Lacking anything else, add 2 to 5 percent of the total survey cost to cover this category and adjust as appropriate during detailed survey design.

D.5.5 Laboratory Analysis Costs

Use costs for analyses of the selected parameters quoted by the chosen laboratory where possible. Use costs given in the Parameter Handbook for preliminary estimating if local cost data are not available. Add 10 percent to 20 percent to the total for quality control costs.

As an example, Table D-25 contains average analysis costs for the minimum recommended parameter list for characterizing urban runoff. Summing the costs for the individual analyses results in a total estimated analysis cost of $163 per sample. If a sequential discrete sample series of 24 bottles was collected to characterize a storm event, the total lab fee would be $163 x 24 = $3,912. Adding 15 percent for quality control, the final estimated laboratory analysis cost would be approximately $4.5K per storm event. Thus, laboratory analysis costs are one of the major operating costs and may amount to 30 percent to 50 percent of the total cost for this portion of the program budget.

D.5.6 Data Analysis and Reporting

Costs in this category will depend upon the complexity of the survey, the degree of data interpretation required, computer charges for statistical analyses where necessary, and the type of report being generated, e.g., event summary, annual project, etc. Ball park estimates of 20 percent to 50 percent of the estimated professional manpower costs for field work will be adequate in most instances. Use more refined, project specific cost information as it becomes available.

TABLE D-25
AVERAGE ANALYSIS COSTS FOR URBAN RUNOFF PARAMETERS

Parameter	Cost
BOD_5	$ 10
TOD	30
Suspended Solids (NFS)	8
Volatile Suspended Solids	7
Fecal Coliform (MF)	10
Fecal Streptococcus (MF)	10
Nitrate-Nitrite Nitrogen	15
Kjeldahl Nitrogen	15
Total Phosphorous	15
Lead	10
Zinc	10
Copper	10
Chromium	10
pH	3

D.5.7 Example USEPA Costs

Harris and Keffer (16) have provided some information on the costs of a USEPA Surveillance and Analysis Field Investigations Section engaged in effluent monitoring for compliance verification purposes and technical assistance to 208 agencies, e.g., stream monitoring. Major field equipment with approximate initial costs is listed in Table D-26. The Field Investigations Section professional staff includes two sanitary engineers (GS-13 and 11), one chemical engineer (GS-11), and one hydrologist (GS-9). The subprofessional staff consists of four engineering technicians in grades ranging from GS-3 to 6. The regional laboratory, with a staff of eight professional chemists (GS-7 to 13) and three microbiologists (GS-7, 9, and 12), is responsible for operating the mobile laboratories of the section during field surveys.

TABLE D-26
MAJOR FIELD EQUIPMENT AVAILABLE TO USEPA REGION VII
SAD FIELD INVESTIGATIONS SECTION

Quantity	Equipment	Approximate Initial Cost
1	Mobile Laboratory	$15,000
1	Mobile Laboratory (on loan)	-
7	GSA Vehicles	-
5	Boats and Motors	5,000
50	Automatic Samplers	28,000
-	Flow-Measuring Devices	6,600
-	Field Analysis Devices	6,100
-	Portable Detector	1,200
1	Metal Detector	300

In areas outside the range in which analytical support can be provided by the regional laboratory, field sampling teams normally operate within a 161-km (100-mile) radius of a mobile laboratory, which is generally set up at a wastewater treatment facility in a community within the area of interest. Because of logistics problems in some of the more sparsely populated areas of the region, it is frequently necessary to work field teams outside of this 161-km (100-mile) radius. Ten to twenty-five percent of the total field activity may be conducted at distances up to 322 km (200 miles) from the laboratory base. Operating at these greater distances reduces capability by an estimated 50 percent and greatly increases the unit cost of sample collection.

Prior to mounting a survey, every effort is made to ascertain and consolidate the various data needs of the Agency and of the State in order to avoid duplication of effort and to minimize the number of laboratory setups. It requires a minimum of 1 week to 10 days to prepare and stock a mobile laboratory; get it on site; have electricity, water, and phone installed; and then torn down and returned to the base station following completion of a survey. If possible, field activities in areas requiring mobile laboratory support are restricted to surveys of 30 days duration or longer.

Under favorable conditions, a mobile laboratory field operation works best with a crew of seven people including: two engineers, two engineering technicians, one chemist, one microbiologist, and one laboratory technician. Working entirely within a 161-km (100-mile) radius of the mobile laboratory, this staff (which is rotated at 2-week intervals) would be able to install samplers and collect approximately 100 samples per week for field and laboratory analyses. Total time and costs for a 30-day field survey are estimated as follows:

Engineers

- 1 man-month office preparation
- 2 man-months field work
- 2 man-months data analyses and report writing

Engineering Technicians

- 2 man-months mobile laboratory and equipment repair and preparation
- 4 man-months field work

Laboratory Personnel

- 6 man-months mobile laboratory work
- 6 man-months regional laboratory analytical work

Clerical

- 2 man-months planning and report preparation

Costs

Salaries	$23,500
Per Diem	7,300
Travel of Personnel	400
Government Bill of Ladings	400
Vehicles	1,000
Miscellaneous Equipment (Ice, batteries, containers, utilities, chemicals, etc.)	1,500
	$34,100

When reviewing the foregoing costs, it should be kept in mind that they do not reflect any burdens (e.g., office space, heating, employee fringe benefits), that equipment costs have increased considerably, and that this team is proficient, well trained, and one of the most efficient in the country.

D.6 Waste Load Allocation Study Procedures

This section contains procedures for conducting a waste load allocation study and some recommendations and guidelines for implementation of the field surveys that will be necessary to carry it out. Most waste load allocation studies will require, as a minimum, one reconnaissance survey and two intensive surveys, one to gather model calibration data and the other to gather verification data. The procedural steps to be followed in conducting a waste load allocation study are outlined in Table D-27.

The first step is to obtain all relevant existing data. This will include all available water quality and flow data for surface water and known sources of wastes. Locations of water use (and a list of legitimate uses) should be determined. Obtain maps and either mark or prepare overlays showing land uses, outfall locations; existing stream gaging and monitoring site locations; stream slopes, cross sections, and flows; locations of rapids, dams, pools, etc.

Analyze the existing data; estimate stream velocities, relative loads from each point source and nonpoint source area, water quality coming into and leaving the planning area, travel times downstream from discharge locations, etc. Use the results to determine first approximations of station locations and parameters to be covered. Plan the reconnaissance survey accordingly. It is recommended that the reconnaissance survey include a toxics scan of all major discharges and others of concern to the 208 agency in order to identify toxic parameters that should be included in the intensive survey.

The next step is the conduct of the reconnaissance survey. The information gathered at this time will form the basis for the intensive survey implementation plan. In conducting the reconnaissance survey, the field survey

TABLE D-27

PROCEDURAL STEPS FOR CONDUCTING A WASTE LOAD ALLOCATION STUDY

(1)	Obtain all relevant existing data.
(2)	Analyze existing data and perform preliminary calculations.
(3)	Based on (1) and (2), plan reconnaissance survey.
(4)	Conduct reconnaissance survey.
(5)	Analyze results of reconnaissance survey and make preliminary model runs.
(6)	Based on (3) and (5), plan calibration survey.
(7)	Conduct intensive survey for model calibration.
(8)	Reduce data from calibration survey and analyze results.
(9)	Fit model using results from (8) and run.
(10)	Review results of model runs.
(11)	Based on (8) and (10), plan verification survey.
(12)	Conduct intensive survey for model verification.
(13)	Compare results of verification survey with model predictions.
(14)	If results of (13) are favorable, use the model for planning. If not, make adjustments to the model as warranted in view of (13), using the verification data gathered in (12) as additional calibration data. New verification data will now be required, so repeat steps (11) through (13).

manager should be accompanied by persons who supplement his own skills, e.g., if he is a sanitary engineer, he may have with him a biologist and a chemist. The biologist is an especially important member of the reconnaissance team. An experienced aquatic biologist in a very short time can collect and examine bottom organisms that will reveal both the severity of pollution in a general way, and the length of stream affected. His findings can, for example, reveal whether the effects of the wastes have extended farther downstream in the past then they do at the time of the reconnaissance and will have an important influence on the final planning of the study, especially with regard to the number and locations of biological sampling sites.

A quick tour of the area and the streams at readily accessible points may be taken to get the general "lay of the land" and the relationships among water uses, waste sources, and the stream. After this, the individuals of the team may go about their separate duties. The field survey manager needs to cover much of the ground that each of the others does, though in less detail. He must have the entire situation in mind to develop the final study plan, supervise the subsequent field operation, and prepare the report.

The field survey manager should become thoroughly familiar with characteristics of the streams. A trip throughout each reach by boat, if the stream is deep enough, provides the best opportunity for observation. Access to the stream may be limited to bridges and roads that parallel the stream if a boat cannot be used. An overall view of the stream may be obtained from a plane or helicopter, but observation of detail from the height involved is limited. Walking often is difficult because of undergrowth or rough terrain, and can be extremely time consuming unless the stream reach is very short.

Detailed notes of observations should be made promptly; don't depend on memory. Notes should include general impressions of depths, currents, velocities, bends, widths, types of bottom, water uses, waste discharges and mixing of wastes, availability of access, and sensory evidences of pollution, such as excessive plankton or attached growth, floating materials, oil, color, suspended matter, sludge deposits, gas bubbles, and odor. Special attention should be paid to tentative sampling stations selected in the preliminary planning. Accessibility of stations, as well as suitability for sampling, must be considered. Stations should be marked or otherwise identified to ensure sample collection at the proper points. For example, the stream miles may be painted on bridges, with arrows indicating the sampling points.

A dry run of the sampling route or routes should be made and timed. This information will be needed in estimating the final number of sample collectors that will be necessary and the maximum time samples will be held. The routes should be marked on a map, and notes made of any check points that will assist in following the routes. Stream samples for preliminary analysis should be collected at this time to assist in parameter selection for the intensive survey and to familiarize the laboratory personnel with what to anticipate when the study starts, e.g., determination of coliform and BOD will assist in selection of proper dilutions, possible interferences can be identified, etc. Simple field determinations, such as those of temperature, DO, and pH, may be made at the same time.

Potential locations for a mobile laboratory, if one is to be used, should be investigated. Frequently the site is a local water or sewage treatment plant. Accessibility and suitability of an area where the unit may be parked must be considered. Availability of necessary water and electrical connections must be checked. Arrangements for metering water or electricity should be made, if necessary. An area, sewer, or drain to which wastes can be discharged from the laboratory without nuisance is needed. Arrangements for access at any time, day or night, must be made if the area is fenced or otherwise protected. A nearby storage room or space for supplies and materials that are not in immediate use in the laboratory is useful. Convenient telephone service is a must, especially if the laboratory is to serve as headquarters for the field crew.

Facilities may be established in a local laboratory of a water or sewage treatment plant, high school, university, or industrial plant as a substitute for a mobile laboratory. The chemist in the reconnaissance survey crew should review such local facilities to determine their adequacy and what additional equipment and supplies will be needed.

If stormwater runoff is a survey concern, try to include a rainy-day visit as part of the reconnaissance effort. Much valuable information can be obtained, as well as a better appreciation of the conditions the field crew will be working under. For urban areas, sewer maps should be verified as to discharge locations, and the possibility of unrecorded outfalls investigated. Obtain information on traffic density by driving during rush hours and use these travel times for urban field crew logistics planning.

After completion of the reconnaissance survey, analyze the results and make preliminary model runs using the reconnaissance data to get the model segmented properly and to better locate stations. With the results of the reconnaissance survey and model runs as a guide, a workable intensive survey plan may be generated. Start by a careful review of the objectives; can they all be accomplished? Now is the time for any additions or deletions, not halfway through the field activity. Put the detailed plan down in writing and have it reviewed by all involved prior to finalizing. Don't discount helpful comments and suggestions from the field technicians. Include samples of all field data sheets, equipment checklists, etc.

Pay especial attention to all logistics aspects during preparation of the intensive survey plan. For example, if ice is used to cool samples and the survey calls for round-the-clock activity, locate sources where ice can be obtained at odd hours, e.g., automatic machines at service stations, all-night convenience stores, etc., and write them down so all will know. The 25-cent do-it-yourself car wash facilities at some service stations represent sources of high-pressure hot water (and soap, if detergent analyses are not performed) that can be used for cleaning automatic sampling and other field equipment, and their locations should be indicated.

The parameters to be measured must be listed, taking into account the problem assessment of parameters determined from the toxics scan, along with any special handling precautions to be observed, preservatives to be used, sample volumes required, etc. Lists of special supplies and equipment and personnel requirements should be prepared at this time. The funds allocated for the survey and the anticipated cost of the field operations should be reviewed here also.

For around-the-clock survey efforts (with two crews working 12-hour shifts, for example), allow for communication of significant information at shift change by having each shift leader report at least 30 minutes early. If such surveys are for extended periods of time, plan on changing crews every 2 weeks to avoid excessive fatigue. In any event, a system of communication that allows any crew member to be contacted within a reasonable period of time (say 3 hours) is highly recommended. Radios on vehicles are also useful communication aids.

Prepare complete equipment inventories that show locations, status, and maintenance and calibration schedules. Be certain that maintenance responsibilities are clearly defined. In addition to the more obvious equipment, instrumentation, and spares discussed earlier in this Appendix, there are a number of other miscellaneous items that will prove useful in the field, and a few examples will be mentioned. A fairly strong magnet on a line is useful for retrieving metal objects dropped in water. A metal detector is also a handy device at times. A set of basic surveying gear (transit, distance tape or chain, stadia poles, optical rangefinder, etc.) will be useful in some instances. A pick, shovel, ax, and saw will find several applications, such as improving rural stream access for sampling. Some of the basic carpenter's tools on hand will be needed at times. A Danaides (orifice) bucket is useful for estimating moderate pipe discharges into open air. A number of uses will arise for rope, string, wire, and reinforced sticky tape. A walkie-talkie set greatly facilitates communications in the field.

Obviously, not every contingency can be allowed for, and experience in conducting field surveys will facilitate future planning. However, the field survey manager should feel very uncomfortable in reviewing the intensive survey implementation plan if he:

- Does not clearly understand the survey objectives,
- Has strong preconceived notions about the results,
- Has not personally visited each measurement site,
- Has not consulted with laboratory personnel,
- Has not clearly assigned responsibilities,
- Has trusted to luck or favorable opportunities.

Conduct the intensive survey in accordance with the implementation plan insofar as practicable. Be certain that there are compelling reasons for any changes or deviations and document them. The importance of recording all information that might aid in the interpretation and analysis of other data that are being collected has been stressed throughout this Appendix. Even seemingly insignificant bits of information may be very useful in fitting the entire puzzle together. However, if they are not recorded in a clear and intelligible way, they are likely to be lost completely. Never trust to memory.

Field logbooks should be provided to each leader of a survey team and others as appropriate. Standard procedures for field data taking should be observed, e.g., logbooks should be bound with pages numbered serially, entries should be made with ballpoint pen, erasures should never be permitted (use strike-outs), all entries should be signed and dated, etc. Field logbooks should be clearly titled on the cover (to prevent the aquatic biologist from accidentally picking up the equipment crew's log, for example) and should have an assigned location when not in use. The field survey managers should frequently review all field logbooks and initial and date them when this is done.

The field logbooks are the main source of data annotation information. Be sure to record information so that it will be useful to future surveys as well as the present one. For example, entries may range from snake sightings to traffic jams that delayed getting samples to the laboratory. Knowledge of the former can reduce possible future danger to personnel, while information about the latter may suggest the desirability of route alteration. It would be improper to assume the snake would never pose a problem (even if it were killed, others may be around) or that anyone could tell that there had been a delay in getting the samples to the laboratory by comparing the time they were removed from the sampler with the time they were logged in at the laboratory.

The importance of time synchronization of data has been stressed earlier. This is equally important with data annotations. Write down the time of day (use watch time) whenever an entry is made in a field logbook. This will assist in subsequent interpretation. Finally, make full use of field logs and other annotation records in report preparation. The perfect survey has yet to be performed, and mistakes and errors will happen. Sweeping these under the table is much more censorable than admitting that they occurred, especially where a significant impact on data quality or interpretation is likely to result. The worst sin is data fudging (or outright falsification) in an attempt to cover up mistakes. This abhorrent practice should be subject to the most severe reprimand possible. Do not confuse this with data adjustment based on the best available information and professional judgment, e.g., adjustment to a flow record time base to account for a uniformly slow-running clock drive, accounting for a zero offset, etc. Data adjustment is an acceptable practice if it is clearly annotated and explained.

After completing the intensive survey for model calibration, reduce and analyze the data and prepare it for model input. Fit the model using the calibration data and make several runs. After reviewing the results of the calibration survey and the model runs, plan the intensive survey to collect verification data. Unless confidence in the model results is very high, it will be prudent to plan and conduct the verification survey with the same degree of coverage as the calibration survey. Conduct the intensive survey for verification data following the above guidance for the calibration survey and taking advantage of lessons learned from it.

Finally, compare the results of model runs with the data gathered during the verification survey. If the comparison is favorable, the model may be considered verified and can be used for waste load allocation planning. If differences are significant, make adjustments to the model as warranted from a review of the discrepancies between the model predictions and the results of the verification survey, using the verification data now as additional calibration data. Once this latter step is done, there is no longer any information about the verification of the model. The importance of this point must not be overlooked. To verify the model it will be necessary to plan and conduct another intensive survey solely for this purpose. In many instances, however, it will not need to be as extensive as the earlier intensive surveys, since the level of confidence in model results should be considerably higher than before.

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