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METHODOLOGY FOR THE STUDY OF URBAN STORM GENERATED POLLUTION AND CONTROL

Municipal Environmental Research Laboratory
Office of Research and Development
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METHODOLOGY FOR THE STUDY OF URBAN STORM GENERATED POLLUTION AND CONTROL

by

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community. It contains recommended standard procedures to be used in studies of urban storm generated pollution and control. Although the study was sponsored by the Storm and Combined Sewer Section and recommendations are made with such an application in mind, this report is much more general. It is hoped that it will be of interest and helpful to anyone active in the water pollution control field.

Francis T. Mayo
Director
Municipal Environmental Research Laboratory

ABSTRACT

This report contains recommendations for standard procedures to be followed in the conduct of projects dealing with pollution assessment and abatement of storm generated discharges. The purpose of this project was to develop standard procedures needed to insure that all discharges and treatment processes could be evaluated by the same means. The procedures chosen were those found to be the most applicable and optimum for the field of storm and combined sewer overflow pollution control.

The project efforts were devoted to the major areas listed below.

1. Recommended methods for sampling and sample preservation.

2. Appropriate monitoring instrumentation available.

3. The choice of quality parameters to be utilized.

4. The analytical procedures to be followed.

5. The methods for evaluating storm generated discharge pollution.

6. The standard procedures for evaluating treatment processes treating storm generated flows.

Choice of the recommended procedures was based upon the U.S. EPA research and demonstration project reports in this and associated fields, other published literature, ongoing U.S. EPA funded projects, and the contractor's experience in the field of stormwater pollution control.

This report was submitted in fulfillment of Contract No. 68-03-0335 under the sponsorship of the Environmental Protection Agency. The project was performed by the Environmental Sciences Division of Envirex Inc. Work was completed as of December 1974.

CONTENTS

TABLES

TABLES (continued)

TABLES (continued)

LIST OF FIGURES

FIGURES (continued)

FIGURES (continued)

FIGURES (continued)

Figures (continued)

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SECTION I - SUMMARY

SAMPLING PROCEDURES AND CONSIDERATIONS

1. The importance of proper sampling is paramount since the decisions which will be based upon the samples can be no more accurate than the sample itself.

2. Great variance in flow patterns and quality characteristic patterns, together with the spatial differences in storm generated discharges makes obtaining of truly representative samples almost impossible.

3. When locating samplers for storm generated discharge sampling, certain trade offs have to be made between ideal samples and intake location and accessibility.

4. A single grab or random sample is not sufficient for characterizing the average quality of a storm generated discharge.

5. There are four common methods of compositing storm generated discharges. They are:

    a. Constant time - constant volume: samples of equal volume are taken at equal increments of time and composited to make an average sample.

    b. Constant time - volume proportional to flow increment: samples are taken at equal increments of time and are composited proportional to the volume of flow since the last sample was taken.

    c. Constant time - volume proportional to flow rate: samples are taken at equal increments of time and are composited proportional to the flow rate at the time each sample was taken.

d. Constant volume - time proportional to flow increment: samples of equal volume are taken at equal increment of flow and composited.

Although this study has shown the method described by c. is the best, both b. and d. are considered acceptable.

6. At least 2000 ml of sample are required to perform the recommended analyses contained in this report.

7. Although there are many automatic samplers on the market, the ideal sampler for sampling storm generated discharges still does not exist.

8. Theoretically, at least four separate sample bottles would be needed per sample so that the various preservatives required for certain constituents could be added to the sample bottle at the time of sampling.

9. The following steps must be taken when locating a sampler for storm generated discharge sampling:

   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 and/or submergence by surface water should be avoided if possible. Avoid locations which may tend to invite vandalism.

   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 sampling 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 sewer.

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

   5. Locate at a point of maximum turbulence, as found in sewer sections of greater roughness and of probably 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.

10. Plastic sample containers should be used in all sample collection except where grease and oil or pesticides are to be analyzed.

11. All samples should be kept in a refrigerator or ice cooled container during and after sampling.

12. Bacterial analyses run on composite samples can only be used for system control and not for "reportable" values because of the cross contamination which will occur. If a quantitative test is required by regulatory agencies, then the sampling and preservation techniques mandated by the agency should be followed.

MONITORING INSTRUMENTATION

1. The construction and performance features of ultrasonic level gaging equipment makes it suitable to the measurement and maintenance requirements of level gaging. With a cost in the $800-$1,200 range, and at least twelve domestic manufacturers now offering them, the ultrasonic level gage should find increasing use for tracing sewer levels during and after storm events, for infiltration studies, for determining discharge flows in overflow sewers, and for determining storage capacity, routing programs, and gate control in "in-line" storage systems.

2. There is presently no generally accepted sewer flow gaging technique which provides accurate measurement over the entire range of sewer flows from minimum dry weather flows to surcharge conditions. There are, however, several promising methods which must yet be fully demonstrated in actual installation.

3. In sewers not subject to surcharging, where hydraulics allow flumes to operate within acceptable submergence, these structures are suitable and flow head can be measured by ultrasonic level gages, floats, scows, capacitance gages, bubblers, lead cell gages and dippers.

4. _In situ_ monitoring equipment with instream sensing is available for measurement of turbidity, suspended solids and nitrates, and side stream analyzers are available for TOD, orthophosphate, nitrates and nitrites. Other _in situ_ monitors for parameters characteristic of particular storms are also available. _In situ_ monitoring, at this time, is not recommended to replace analytical laboratory measurements, however, _in situ_ monitors are recommended for flow control purposes, quick indicators of treatment efficiency, or for monitoring changes in sewage characteristics.

5. The most common errors arising in raingage measurement are (1) mistakes in reading the scale of the stick or chart, (2) evaporation of water in the gage, (3) improper placement of the gage and

(4) instrument error.

6. Optimum raingage location is simply on level ground with no trees or structures in a proximity such as to affect the capture of rainfall.

7. The use of raingages in storm generated discharge studies is dependent upon the purpose of the project as shown below.

RAINGAGE NETWORK NEEDS FOR DIFFERENT STUDY AREAS

	Need for Network
To define areal rainfall and its variations	yes
Mathematical Model verification	yes
Sewer, Treatment Plant, or System Design	varies
Operation of Storm Generated Discharge Systems (Treatment or Holding Basin)	no
Operation of In-line Storage or Selective Discharge Systems	yes

8. The density of raingages is not clearly formulated and is dependent upon project objectives. However, at least three raingages should always be used when precipitation monitoring is being performed, so that the Theissen method may be used.

QUALITY CHARACTERISTICS AND LABORATORY STUDIES

1. The peculiar characteristics of storm generated discharges preclude the direct usage of commonly used characteristics for municipal dry-weather flows without some changes or modifications. This fact applies not only to the characteristics themselves, but also to the analytical laboratory techniques used.

2. The many variables which can affect the quality of storm generated discharges such as time between occurrences, rainfall amount, intensity and duration and drainage area surface conditions make the use of the term "typical" to describe the quality of storm generated discharges a nuisance.

3. The following water quality parameters have been recommended for routine use in storm generated discharge projects: Total Oxygen Demand, Five Day Biochemical Oxygen Demand, Fecal Coliform, Total Oxidized Nitrogen, Total Reduced Nitrogen (Kjeldahl), Total

Phosphorus and pH. In addition to the recommended procedures, periodic analyses for certain metals, pesticides and oils and greases should be performed.

4. In a review of past studies the most commonly used parameters for describing storm generated discharges were BOD and SS, followed by total coliform, COD, Kjeldahl nitrogen, total phosphorus and fecal coliform. In studies evaluating treatment processes, the BOD analysis was used considerably more than the COD analysis, but for studies on the receiving water quality, the BOD and COD tests were used about the same.

5. Because of the high percentage of potential oxygen demanding materials that are in the particulate form and the possible presence of oils and toxic materials together with the possible presence of materials such as silt, dirt, and wood that may not exert an immediate oxygen demand but will have an ultimate demand, the conventional oxygen demand tests can be seriously affected.

6. When determining the effectiveness of an oxygen demand indicator, it must be considered that the material may be in the aquatic environment for a long period, thus an oxygen demand test of limited time is not appropriate.

7. Although the conventional BOD_5 test is considered to have many disadvantages, it has been recommended for use because of the existing historical data available, regulatory requirements, and the wide knowledge and utilization of the test.

8. The range of particulate concentration can vary greatly in storm generated discharges, depending upon the characteristics of the drainage area, the intensity and duration of the rainfall, and the time between rainfall events.

9. In most applications, the removal of the entire suspended residue fraction from combined sewer overflows and storm runoff would be considered an ideal achievement or goal. Anything less than this total would be a partial success which can be effectively evaluated by making the appropriate suspended residue analyses.

10. It is recommended that the settleable residue be determined for those applications where gravity separation is involved, or where an assessment must be made of bottom deposit buildup directly below or surrounding an outfall.

11. The 4.7 cm glass fiber filter is recommended for the suspended residue analysis because of its lower cost (when compared to cellulose acetate filters), ease of use, and resistance to quick blinding. The major disadvantage is that the filter must be prewashed to remove fines prior to use. The likelihood of an

appreciable amount of sand and grit in storm generated discharge samples precludes the use of pipettes in aliquot transfer.

12. Although volatile suspended residue is not recommended for every analysis, it can be used in certain situations for additional information and if so, it should be insured that a large enough sample is used so that enough weight loss can be measured and that a high degree of accuracy is achieved in the gravimetric analysis.

13. Because of a blinding problem, the "weight" method as found in Standard Methods should be used instead of the Imhoff Cone method for settleable residue determination.

14. It has been demonstrated historically that the only practical way of making an overall health assessment in water supply and pollution control is through the use of an indicator organism rather than analyzing for the actual pathogens themselves.

15. The most commonly used indicators of pathogenic pollution are the total coliform, fecal coliform, and fecal streptococci. All of the above analyses have disadvantages, the most common is the lack of positive correlation with the presence of specific pathogens themselves.

16. Until a better indicator system becomes available, the assumption can be made that if fecal coliforms are absent so are the pathogens of all waterborne diseases, including viruses. Likewise, if fecal coliforms are present, the likelihood of some microbial pathogens being present is high, particularly bacteria of the salmonella group.

17. The use of the fecal coliform analysis is sufficient for characterizing the effectiveness of pathogen destruction of any treatment process applied to either combined sewer overflows or stormwater runoff.

18. In the case of storm generated discharges, gross bacterial counts indicating relative differences are usually more important than the absolute numbers. Thus, it is more important that the procedure employed be convenient to run, economical, and one in which results are obtained as quickly as possible, rather than one where accuracy is the main criterion. Of course, this is not true in studies in the areas of research or public health where precision is required.

19. Optimum sampling for bacteriological analysis is to collect a discrete or grab sample in a sterile bottle and return to the laboratory for immediate analysis. Whenever automatic samplers are used, the sampler head and sample lines should be disinfected.

20. Samples for fecal coliform analysis should be chilled at 10^{o} C or below during sample collection, storage and transit to the laboratory, and refrigerated at the laboratory for less than two hours before processing. Freezing of the samples shall be avoided, since this will cause a destruction of the microorganisms.

21. When utilizing 24 hour composite samples, it is obvious that the first sample will have been stored 24 hours before transport to the laboratory begins. Die-off of microorganisms can be kept to a minimum by proper cooling of the sample during the entire time the composite is stored in the sampler. Relative gross counts will be unaffected as long as all samples are handled in a similar fashion.

22. The membrane filter technique for fecal coliform and fecal streptococcus analyses has many advantages over the MPN technique, even for the case of chlorinated samples.

23. From available evidence at the present time, it appears that either nitrogen and/or phosphorus are the limiting nutrients, and as such both should be used as a measure of eutrophication potential.

24. Analysis of both the oxidized form of nitrogen (NO_2^- and NO_3^-), by the superior nitrite analytical method, and the reduced form of nitrogen (ammonia and organic) by the Kjeldahl procedure are recommended.

25. Because of the many forms in which the phosphorus fraction can occur (up to fourteen), the total phosphorus analysis is recommended utilizing the persulfate digestion method.

26. When sampling for heavy metals, the bottles must be absolutely clean and inert to the metal being determined, all glassware must be scrupulously clean, extreme care must be taken in analytical preparation, and the digestion procedures must be followed carefully to insure no loss of metal. These steps are critical due to the fact that the metals may be found in the µg/l (ppb) range, and slight analytical errors can greatly affect the concentration determinations.

27. It is recommended that composite samples of storm generated discharges be analyzed for lead, zinc, copper, chromium, mercury, cadmium, arsenic, nickel, and tin four times per year (seasonally). Based upon these tests, decisions can be made on the need for routine analysis.

28. Analyses of samples for heavy metals should always include the total amount of the metal present and the samples digested prior to analysis. Samples for metal analysis can be preserved with nitric acid to pH2 and refrigerated for up to 6 months.

29. For various reasons, no pesticides are recommended for routine analysis. However, it is recommended that when evaluating the quality of a storm generated discharge, a study of the drainage areas should be made to determine the possibility and type of pesticide use.

30. Other parameters which may be of interest in storm generated discharge studies for various reasons include asbestos, asphalt and road materials, color,debris and bulk solids, density, specific gravity, solids settling velocity distribution, oils and grease, odor, particle size distribution, pH, rubber, specific conductance, sulfates, temperatures and trace organics. Of the above, only pH is recommended for routine analysis.

31. The sludges produced from treatment of storm generated discharges should be measured for total residue if concentrated and suspended residue if dilute. Various other analyses may be required depending upon the method of sludge treatment and disposal.

DESCRIBING STORM GENERATED DISCHARGES

1. The following parameters are recommended for presentation and quantification when reporting background data on storm generated discharge projects: (1) drainage area, (2) land usage, (3) population density, (4) median residential incomes, (5) climate, (6) topography, (7) pervious and impervious areas, (8) street and curb miles, (9) average daily traffic, (10) methods and frequency of street cleaning, and (11) lengths, sizes and slopes of sewers.

2. Generally, storm generated discharges monitoring programs fall into one of the following categories:

   - Evaluation of the impact on receiving water quality
   - Facilities design studies
   - Process evaluation
   - Compliance with regulatory requirements

3. The evaluation of the impact on receiving water quality almost always requires the generation of new data since most of the existing data is gathered regardless of storm occurrence.

4. In facilities design programs, special characteristics must be monitored because of the difference in characteristics between storm generated discharges and dry weather domestic sewage.

5. It is anticipated that in the future, storm generated discharges will require some type of monitoring in which case automatic sampling equipment and composite samples should prove to be adequate.

METHODS FOR EVALUATION OF TREATMENT PROCESSES FOR STORM GENERATED DISCHARGES

1. Existing methods of storm generated flow treatment can be generally classified as follows:

    1. Storage

        a. In-line
        b. Off-line (with and without sedimentation)

    2. Physical and Physical/Chemical

        a. Coarse Screening
        b. Fine Screening
        c. Gravity Sedimentation
        d. Swirl Concentration
        e. Tube Settling
        f. Sedimentation-Filtration-Adsorption
        g. High Rate Filtration
        h. Adsorption-Coagulation-Tube Settling-Multi Media Filtration
        i. Coagulation-Tube Settling
        j. Series High Rate Filtration
        k. Screening/Dissolved-Air Flotation

    3. Biological

        a. Contact Stabilization
        b. Trickling Filter
        c. Biological Contactors
        d. Lagoons

    4. Disinfection

        a. Chlorination
        b. Sodium and Calcium Hypochlorite
        c. Chlorine Dioxide
        d. Ozonation

2. When evaluating a prototype treatment system, the entire pollutional load, including bypass must be considered. However, when evaluating a "pilot" type system, only the efficiency of the process units themselves should be considered.

3. When evaluating a treatment system, various types of efficiencies may be determined. These include volumetric efficiency (how much of the contaminant(s) is prevented from overflowing to the receiving stream?) and treatment efficiency (what portion of the contaminant(s) is removed in each unit process of the treatment scheme?). Both volumetric efficiency and overall efficiency must take into account

all flows bypassing the storage/treatment unit.

4. In order to determine the efficiency of a system, it is recommended that samples be taken at constant time intervals and when composited, they may be proportioned either according to the flow rate at the time the sample was taken or according to the volume of flow since the last time the sample was taken. Either of these methods will provide a sufficiently representative sample. A third method of sampling and compositing that is sufficient is to take samples of equal volume at equal intervals of flow volume. However, this type of sampling requires a more flexible sampler since the time interval for sampling will be variable. The ideal method of sampling would be to draw a sample continuously, with the flow of sample being proportional to the flow rate. However, an automatic sampler of this type with proven field reliability for storm generated discharge studies may not be practical to require at this time.

5. For almost all types of treatment systems, only two sampling and flow measurement locations are needed. These are at the discharge point itself and at the effluent. The bypass can be calculated as the difference of the two. To determine the total mass of a contaminant removed, a single composite of the influent and effluent is necessary. With this type of sample, the determination of overall efficiency is relatively simple.

6. Efficiencies of treatment plant performance should be calculated as an arithmetic average of percent removals achieved and as the weighted average based upon total mass treated and total mass removed during the period of study.

7. When evaluating the efficiency of a storm generated discharge treatment system, any deleterious effect on the dry-weather treatment plant or any pollutants removed at the discharge site that escape in the effluent of the dry-weather plant must be subtracted from the treatment efficiency.

8. So that all treatment processes evaluated may be compared on an equal basis, the following data should be reported following an evaluation study:

    1. Rainfall data
    2. Drainage area description
    3. Sewerage system data
    4. Physical description of the treatment system
    5. System operation
    6. System costs
    7. Sludge handling facilities
    8. Dry-weather treatment plant data
    9. Combined sewage data (for combined systems only)

The general information required is the same for all types of treatment systems.

SECTION II - RECOMMENDATIONS

It is recommended that:

1. The standardized procedures contained in this report be utilized in all future projects dealing with storm generated discharge.

2. An automatic sampler, suited specifically for sampling storm generated discharge, be developed.

3. The recommended sampling programs as found in this report be made more specific as to number of samples, sample frequency, duration of sampling program, etc., by means of a study based primarily upon a statistical approach.

4. Continued research and studies be undertaken on the development/ improvement of wide range flow measuring devices for sewer applications.

5. A standardized procedure for determining the number of raingages per area to be used in storm generated discharge projects be developed.

6. Further work on sample preservation methods be conducted, with emphasis on the maximum holding time for the BOD analysis and on the feasibility of freezing as a preservation means.

7. Further study be performed on the development of an oxygen demand potential analytical technique that fulfills the criteria for the ideal test.

8. The long term oxygen demand of a number of storm and combined sewer overflow discharges be determined in an effort to develop firm data on the ratio of the long term to BOD_5 values in storm generated discharges.

9. Analytical techniques be developed for easier and more definite detection of specific pathogenic organisms themselves or for pathogenic indicators having a more positive correlation with pathogens themselves.

10. Research, development, and demonstration of new more reliable, interference free instruments, especially for organic loading, suspended solids, total phosphorus, and pathogenic indication be conducted.

11. A study be conducted to determine the true expected life of facilities built for storm generated discharge applications. Because of periodic usage, the 20 or 25 year amortization periods may be too short and can result in extremely high unit operating costs.

12. Since the findings presented in this report are based on knowledge and experiences to date, future changes can be expected as additional research and experience occurs.

13. Immediate action be undertaken to determine how storm generated discharges will be monitored when they eventually fall under some type of regulatory restrictions.

SECTION III - INTRODUCTION

This study, EPA Contract No. 68-03-0335, having the exact title, "Standardize and Universalize Procedures for the Analysis/Evaluation of Stormwater and Combined Sewage Characteristics/Treatment" was begun in June 1973 and completed in December 1974. The purpose of the project was to develop standard procedures recommended for use when conducting projects associated with the evaluation and abatement of storm generated discharge pollution.

The results of this project, as presented in this report, will have an extremely significant impact on all ongoing and future projects dealing with storm generated discharges. Development of these recommended standard procedures was necessary because of the wide variation in methods being used to sample, analyze, and evaluate storm generated discharges and associated treatment processes. Not only were the standard procedures needed to insure that all discharges and treatment processes be evaluated by the same means, but also because these procedures were found to be the most applicable and optimum for use in this field.

The project efforts were devoted to the major areas listed below.

1. Recommended methods for sampling and sample preservation.
2. Appropriate monitoring instrumentation available.
3. The choice of quality parameters to be utilized.
4. The analytical procedures to be followed.
5. The methods for evaluating storm generated discharge pollution.
6. The standard procedures for evaluating treatment processes treating storm generated discharges.

The recommended method of sampling was necessary because of the many different methods presently being used, that is, grab, volume proportional to flow rate at equal time intervals, equal volume at constant flow increment, etc. The need for a uniform sampling program is pointed out and the rationale used in selecting sampling procedures is discussed.

An entire section was devoted to montirong instrumentation finding use in storm generated discharge projects. This included level and flow measurement instrumentation, _in situ_ parameter monitoring equipment and raingages.

The choice of quality parameters was divided into seven general areas. These were:

1. Oxygen demand potential indicator.
2. Particulate concentration.
3. Pathogenic indicator.
4. Eutrophication potential.
5. Heavy metals.
6. Pesticide and Polychlorinated Biphenyls.
7. Other characteristics.

The report also discusses the relative merits and disadvantages of the BOD_5, BOD_{20}, BOD_x, COD, TOC, and TOD tests, and explains why the TOD was chosen as best for use in dealing with storm and combined sewer discharges. The same is done for the other pollution parameters. For example, an extensive literature search was necessary to document the choice of fecal coliform as the best indicator of the presence of pathogens. This test was found to be more advantageous than the total coliform, fecal streptococcus or analysis for any specific pathogen. If uniform quality parameters are to be used, they only have meaning for comparison if the laboratory procedures used in analysis are the same. Therefore, for each quality parameter selected, the exact laboratory procedures are not only spelled out for common analyses such as suspended solids but also for the more exotic heavy metals and pesticide analyses.

The method of determining the impact or pollutional load of storm generated discharges concerns itself primarily with the units of description for a discharge. Various reports of storm generated discharge quality use units of mg/l, kg/min (lbs/min), kg/year (lbs/yr), and so forth. Also, some studies report pollutional loadings based on source loadings such as kg/curb m (lb/curb mile), kg/ha/day (lbs/acre/ day) and g/axle m (lb/axle mile). Not only does this make relative comparison difficult, but the periodic frequency of these discharges and their acute loading makes description such as mg/l and kg/year (lbs/year) useless for any purpose other than the specific design of a treatment process component once the basic process has been selected. Therefore, the description which provides a common base for comparison of all discharges and indicates the possible effect of a discharge on a receiving body of water is presented and explained.

Finally, since many municipalities and industries are beginning to plan for implementation of some type of treatment process to abate their storm generated discharges, it is imperative that process efficiency be determined by the same means. Although it is obvious that true efficiency is best measured by the difference of total mass into and out of a process, many other considerations must also be made. The report discusses these. For example, true efficiency must include the contaminants bypassed when the process is running at full capacity. If captured flow is bled back to a conventional treatment plant, then the effect of this extra flow on plant performance must be calculated. In essence, this discussion specifies the precautions that must be taken to insure that the true net process efficiency is actually determined and reported.

SECTION IV - SAMPLING PROCEDURES AND CONSIDERATIONS

SAMPLING STORM GENERATED DISCHARGES

Purpose of Water and Wastewater Sampling

Sampling can be defined as the act of obtaining a small volume of water that represents a much larger body or flow or water, e.g., a lake or wastewater treatment plant influent or effluent. The water quality of this small volume is then characterized in terms of BOD, TOD, suspended solids, etc., and is assumed to be the same as the larger body of water from which the sample was obtained. This water quality information is then used to accomplish one or more of the purposes listed below.

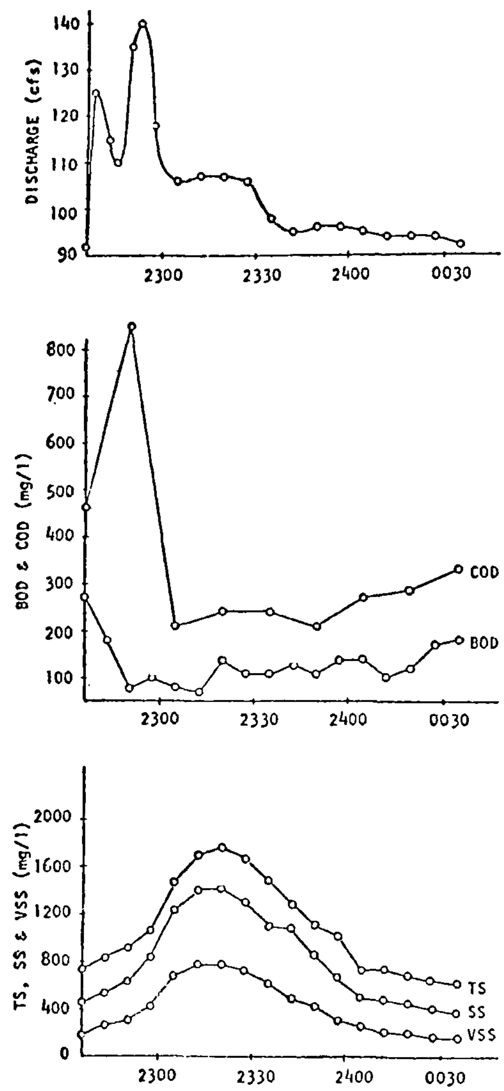
1. Problem identification.
2. Wastewater treatment plant evaluation and process control.
3. Treatment plant design - modification.
4. Receiving water quality determination.
5. Criteria to be used for enforcement of water quality and effluent standards.
6. Determination of waterborne health hazards.
7. Application to basic research.
8. Regulatory agency requirements.
9. Others.

The key to accomplishing these sampling objectives is to obtain a "representative" sample; one that reflects the true condition of the larger water volume from which the sample is taken. This is a difficult task and will be discussed in some detail in this section. Improper sampling can lead to very serious consequences, in that no reliable decisions regarding problem solving can be made if the samples do not reflect the quality of the larger volume of water. There are a variety of methods or guidelines available for accomplishing reliable sampling, dependent on the situation encountered. In order to obtain samples that will accurately describe the main body of water it is necessary to know something about the water characteristics being sampled. Is the water highly polluted with BOD, TOD and suspended solids or toxic substances? How do the wastewater or stream characteristics vary with time or location in the stream? How does the flow or volume vary? Are floating materials present? Are heavier materials slowly being carried along the bottom of the stream flow? There are many other qualitative characteristics that will be helpful in accurately sampling a stream of water or wastewater. Some of these important characteristics will be known from an understanding of the origin of the water flow. Municipal and industrial wastewaters have certain known characteristics and flow fluctuation trends that can be used to help obtain representative samples. In many cases it may be necessary to determine some of these water quality trends by means of a well scheduled series of grab samples before the sampling program is initiated. Storm generated discharge sampling is complicated because the source of pollutants that characterize the wastewater may contain both municipal and industrial wastes. The water quality may be affected by other factors such as street cleaning frequency. It will also depend on rainfall intensity and duration, antecedent rainfall, degree of urbanization, geologic and hydraulic characteristics of the area, the sewerage system and many other factors.

Characteristics of Storm Generated Discharges

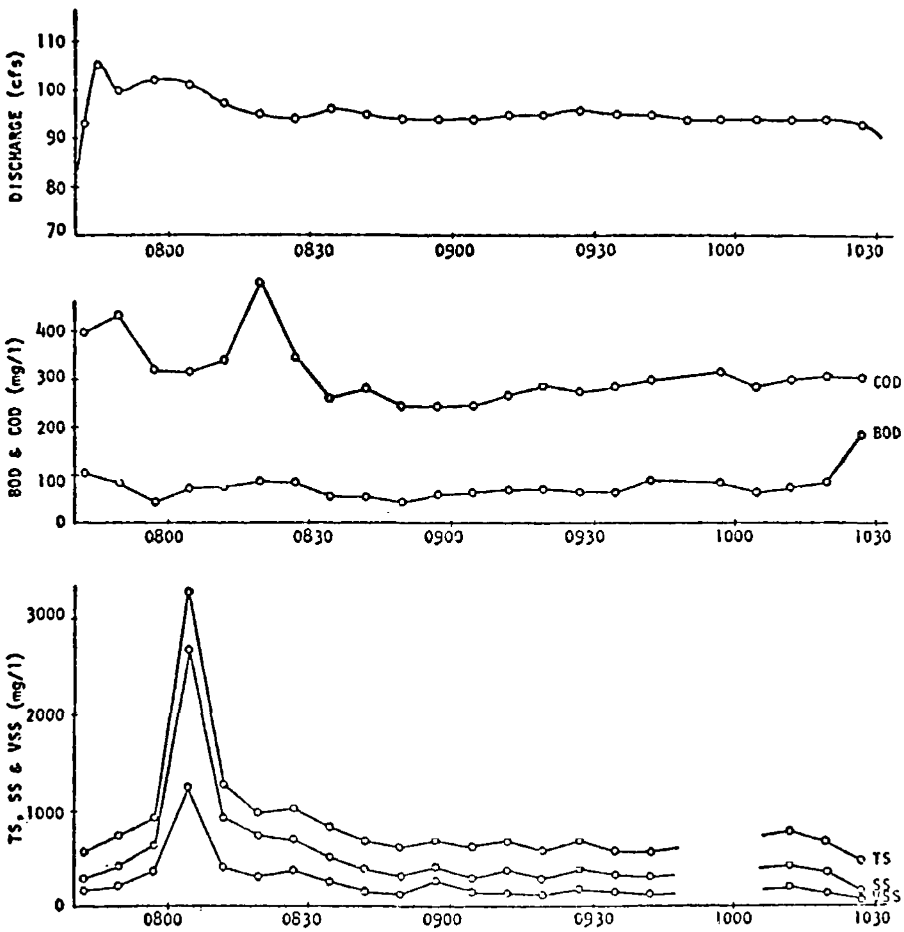
Variation of Wastewater Flow and Contaminant Concentration - It is well documented that the quality and flow rate of a storm generated discharge at a specific location vary significantly during a storm event (1)(2)(3). Figures IV-1 and IV-2 show typical variations in storm generated discharges. The greatest concentration of suspended solids and oxygen demanding material often occurs during the early period of the storm runoff as seen in these data. As the storm generated discharge causes increased flow in the sewers, accumulated dry weather solids are flushed from the sewers, and washed or eroded from the tributary land areas. These initial flows containing high concentrations of contaminants are often referred to as the "first flush". Contaminants may increase in concentration as continued flows tend to flush out the material that has settled out in the sewers since the last rainfall.

When rainfall events occur close together the runoff may keep the sewer lines and tributary areas clean enough so that first flush characteristics may not be observed (4). Figure IV-3 shows additional data from the U.S. EPA sponsored combined sewer overflow project in Racine, Wisconsin (5) that demonstrates the first flush phenomenon. It can be appreciated that taking one discrete grab sample during this storm event would tell nothing about the average sewage quality, and there is some question as to the meaning of the average of these data. Sampling techniques will be discussed later.



Time (clock hours)

Figure IV-1. Example of variance in runoff quality and quantity with time, taken from reference 2



Time (clock hours)

Figure IV-2. Example of variance in runoff quality and quantity with time, taken from reference 2

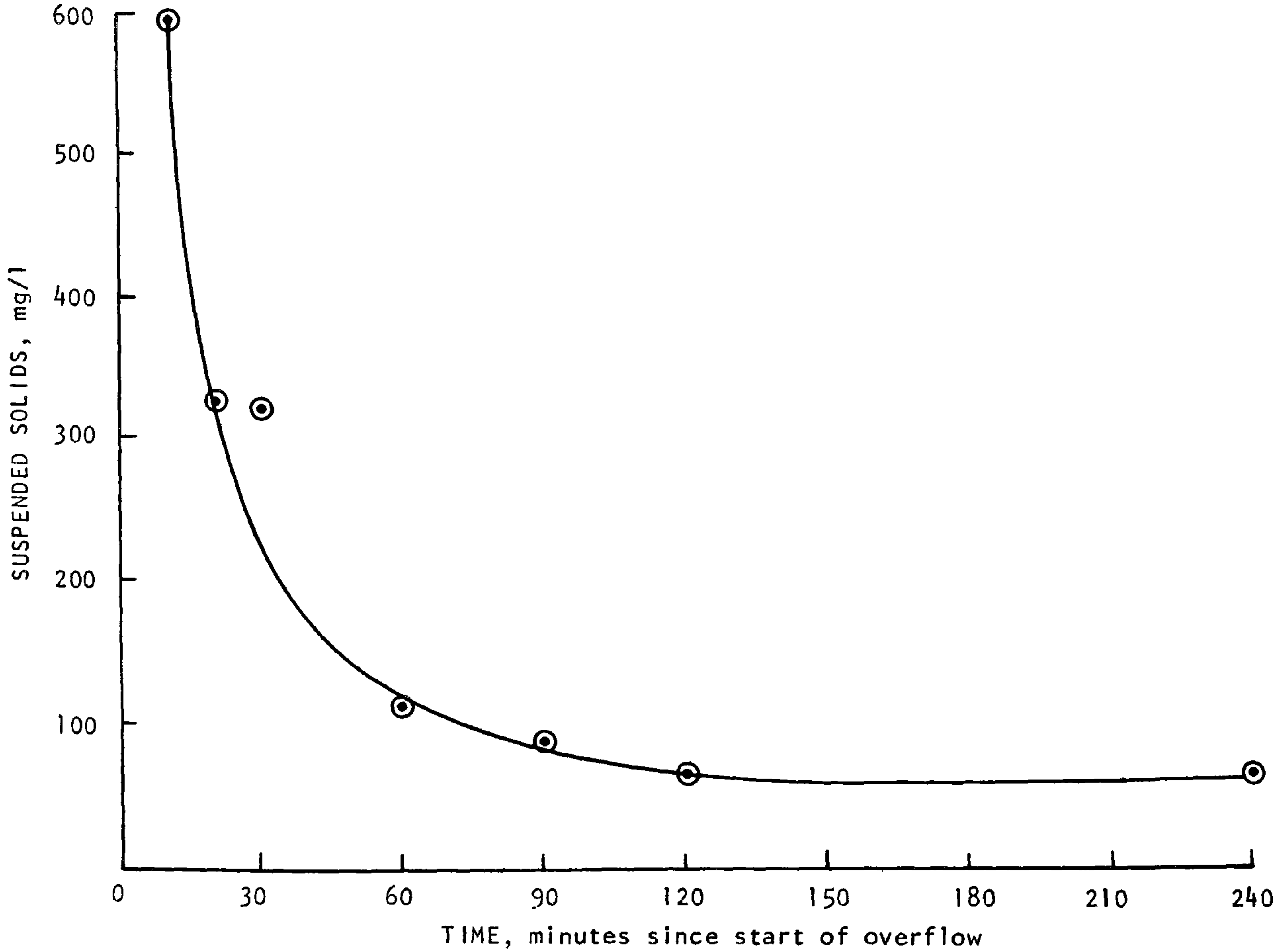


Figure IV-3. Suspended solids variation with time, Racine, Wisconsin (EPA Grant No. S800744)

The concentrations of pollutants may vary across the section of the sewer or stream. Factors influencing this concentration variability include the degree of turbulence in the wastewater stream and the fact that velocities naturally vary within the cross section due to friction losses and boundary effects, density currents, temperature differences, the settling velocity and structure of suspended solids particles, etc. All these factors tend to influence the concentration of pollutants across the sewer cross section. Understanding these factors helps to appreciate the difficulties in sampling storm generated discharges representatively.

Where two streams or sewers come together density currents may occur such that pollutant concentrations may vary significantly throughout the cross section of the sewer. Sampling should be done downstream from these points such that sufficient turbulence and time is allowed for thorough mixing of the two stream flows.

The more turbulence there is the better the mixing will be and hence the sooner sampling will give a representative sample characteristic of the sewage. The more thoroughly mixed the wastewater, the easier it is to obtain a representative sample of the cross section. It may be necessary to obtain a series of grab samples along the length of the sewer and at different points in each cross section in order to establish where permanent sampling stations should be located.

Irregular Event Occurrence - Storm generated discharges by definition occur when a sufficient amount of rainfall has fallen to cause runoff. As will be discussed later, rainfall can vary significantly from both a time and spatial standpoint. Therefore, the storm generated discharges to be sampled will also occur periodically. Because of the variable nature of these discharges, it is difficult to have personnel immediately available at preselected sampling sites to manually begin taking samples or to turn on automatic samplers. At times the duration of an overflow event may be so short that the designated sampling personnel may not reach the site until the discharge is completed, or at least well past the first flush occurrence. Conversely, long duration, low intensity storms may result in discharges lasting 24 hours or more. Consequently, it is desirable that automatic samplers be employed for storm generated discharge sampling. These samplers should be capable of starting their sampling cycle automatically when a rainfall producing runoff occurs. In this manner, all discharge events will be sampled from the beginning of discharge through the entire duration of the event. This assumes the samplers are reliable and the proper preventative maintenance has been performed. In some cases the storm may last sufficiently long so that all the sample containers are filled. The operating personnel should be aware of the approximate starting time of each storm so that sampler containers can be replaced when necessary, or relief or standby samplers put into operation for a long duration event.

<u>Floating Substances and Coarse Bottom Sediments</u> - Contaminants that have a specific gravity significantly different from water cause special problems in sampling. This has recently been discussed.

> "Suspended solids heavier than water have their lowest concentrations near the surface and the concentration increases with depth. Near the bottom of the sewer may occur a 'bed load' composed almost entirely of heavier solids. This may 'slide' along the bottom, or, with insufficient flow velocity, may rest on the bottom. As the velocity and turbulence increase, the 'bed load' may be picked up and suspended in the sewage.
>
> "At the beginning of storm runoff, as water picks up solids which have accumulated in the sewer upstream during periods of no rainfall, the flow may be composed largely of sewage solids, or 'bed load', which appears to be pushed ahead by the water.
>
> "Suspended materials lighter than water, such as oils and greases, float on the surface, as do leaves, limbs, boards, bottles, and cloth and paper materials. Other small, light particles are moved randomly within the flow by turbulence. These may be well distributed in the cross-section without significant effect of variable velocity within the section." (4)

Unless a sampler intake is located near the surface of the wastewater and/or the bottom of a storm or combined sewer flow having floating materials or coarse sediments, these sewage constituents will not be present in the samples taken. Consequently, important pollutants that can cause significant stream quality deterioration, or have major effects on the treatment plant may not be taken into account. Oils and grease, coarse floatables, and heavy solids may cause unpredicted overloaded conditions in the treatment plant (grit can present specific problems) and deposition or unsightly conditions in stream beds. Special methods can be adopted to specifically sample for these constituents so that their quantity and quality can be determined and it can be decided whether or not a problem with these materials exists. Grab samples may be used to determine the presence of these types of materials. If floating or especially heavy materials are frequently found in the storm generated discharges special samplers may have to be designed based on the type of pollutants that is most significant. Alternately, improved sampler inlet devices should be developed.

The relative amounts of these materials can be determined by placing a representative sample of storm generated discharge in a one liter graduated cylinder and allowing it to settle for a predetermined time interval. The volume of settled and floated solids can be measured. The settling time interval should be relatively short so that the condition in the graduated cylinder resembles the sewer rather than the sedimentation basin. However, as discussed in a later part of this report, this test is not quantitative, and is only intended to provide an estimation of floatable or settleable water quality.

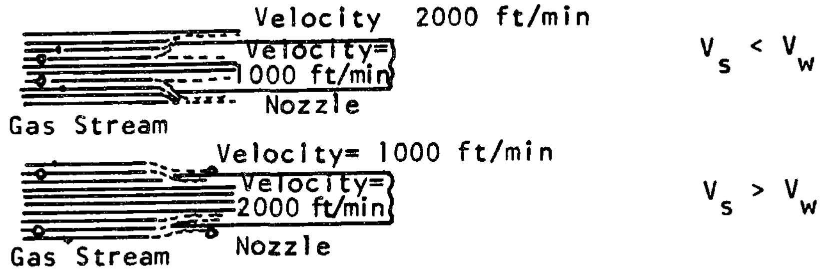
Excess grit from storm flow can be determined by measuring grit removed at the sewage treatment plant grit chambers during wet-weather flow periods.

Suspended Solid Particle Size and Sampling Velocity - The size and specific gravity of the suspended solid particulates in storm generated discharges influence the type of sampling equipment used and location of intake orifices; the sampling velocity (velocity through sampler orifice, tubing, and other critical points) and intake orifice dimensions directly influence the size of suspended solids that will be collected. When particle size and specific gravity is sufficiently large for suspended materials to settle out during an overflow discharge, bottom sludge may build up in the sewer or move slowly along the bottom of the sewer. If an increased rainfall intensity causes higher velocities in the sewer, a resuspension or scouring may occur. The sampling velocity must be sufficiently high to ensure that the most rapidly settling particle will not settle out in the sample tubing or in other sections of the sampler train. Otherwise, some of the suspended solids will not reach the sample container and a representative sample will not be obtained. If any particles are found settling out in the sample lines, the flow velocities must be increased or a more suitable sampler should be used.

It has been determined that the velocity of sewage flowing through the sampling orifice influences the concentration of suspended solids obtained in the sample (6). This has a greater effect in air sampling because of the large difference in densities between air and the particles. However, a similar phenomonen occurs in water samples. This is shown in Figure IV-4 and is a result of the larger, heavier particles continuing to flow in a straight line path while the smaller particles tend to follow changes in flow caused by the sampling orifice. To eliminate these interferences the sampling velocity should be the same as the velocity in the stream being sampled. This intake velocity is apparently more critical than the angle of the intake orifice with respect to the flow direction.

Sample Site Consideration

When establishing a sampling station for water quality monitoring or storm generated discharge sampling, it is important that the location can easily accommodate an automatic sampler and provide enough accessibility to maintain and operate the samplers. If the sampler is located in the sewer or low in the manhole chimney, then the sampler should be waterproof, as the sewer can be expected to flow completely or surcharge full during some storm events. Location in a sewer or manhole is advantageous from the standpoint that it is out of sight and will not attract vandals, though this sacrifices some advantages in ease of maintenance and accessibility. After each storm event, an automatic sampler must have clean bottles installed, be reprogrammed



1. When sampling velocity (V_s) is less than water velocity (V_w), then a disproportionate number of large particulates enter the sampling orifice, and a number of small particulates that should enter the orifice bypass it.

2. When $V_s > V_w$, a disproportionate number of small particulates enter the sampling orifice, and a number of large particulates that should enter the orifice bypass it.

Figure VI-4. Influence of sampling velocity on suspended solids (from Reference 6)

and readied for the next storm event. Also, if bacteriological tests are to be performed, cleaning and disinfection of the sampling lines is recommended. Consequently, if it is located in a hard to reach area, it will be difficult to perform these necessary functions, unless it is portable and can be removed from its sampling position.

The suitability of a storm generated discharge sampling site is largely determined by how representative the samples are; the samples should have the same characteristics as larger flow streams. Generally, it is recommended that in:

> ". . .sewers and in deep, narrow channels, samples should be taken from a point one-third the water depth from the bottom. The velocity of flow at the sample point should, at all times, be sufficient to prevent deposition of solids. When collecting samples, care should be taken to avoid creating excessive turbulence which may liberate dissolved gases and yield an unrepresentative sample. Additional considerations are as follows: (1) the site should provide maximum accessibility and safety; (2) it should be a sufficient distance downstream from the nearest tributary inlet to ensure complete mixing of the two flows; and (3) there should be a straight length of pipe at least 7 sewer diameters upstream of the site." (7)

If all the above conditions are met, then one can be reasonably certain that the flow is of relatively uniform quality across the sewer cross section, thus making it easier to obtain a "representative" sample. Although it is not always possible to meet the above conditions for selecting a sampling site, these requirements should be followed as closely as possible.

Samplers that are located in sewers will be exposed to very humid and corrosive conditions. Thus, the sampler should be constructed of non-corrodible material, such as fiberglass. If the sampler is capable of corroding, there is a good possibility that any samples obtained will be contaminated by the corrosion products, or samples may be lost completely. If the sampler is not located in a sewer or manhole, but instead is located at ground level, it is necessary that some type of housing be available to protect against both climate conditions and vandalism. Common types of housing which are sufficient include such things as large diameter concrete sewer tiles and commercially available metal "garden" sheds.

Just as important as the consideration of sampler housing is the method of protection of the sampler tubing leading from the sampler to the sampler intake. Sample tubing located in the sewer itself must be protected from objects such as wood, branches, gutters, etc. contained in the flow, together with the high velocities experienced. Also, this tubing must be buried or otherwise protected (such as enclosure in conduit), from the point of exit from the sampling house to the point of entrance in the sewer or manhole.

The sampler should also be able to withstand freezing conditions. In northern climates discharges caused by freezing rains or snow melt can occur while the sampler is under a freezing condition. Similarly, if the sampler is permanently installed, it must resist freezing conditions during inactive months. The location of the sampler should minimize the freezing of samples and be accessible to check for freezing conditions which require frequent maintenance.

TYPES OF SAMPLING PROGRAMS

There are a variety of types of water samples that can be obtained; however, each type belongs to one of two main categories. These categories can be classified as discrete or composite. Discrete samples characterize water quality for a particularly short period in time. Composite sampling is an attempt to synthesize a sample which will represent the average discharge characteristics over a period of time. The various types of samples that can be obtained are shown in Table IV-1 (4).

In the discrete sampling techniques described above, the random grab samples are the easiest and most economical, but the least reliable in

Table IV-1. DIFFERENT TYPES OF SAMPLES

Discrete samples

Random grab - one sample obtained at any time at any point by any available method (Figure IV-5).

Unit time - a series of samples taken during a discharge event at equal time intervals (Figure IV-6).

Unit volume - a series of samples taken during a discharge event at equal volume increments. A flow recorder and totalizer is required for this type of sampling. (See Figure IV-7.)

Composite samples

Constant time - constant volume: samples of equal volume are taken at equal increments of time and composited to make an average sample (similar to Figure IV-6).

Constant time - volume proportional to flow increment: samples are taken at equal increments of time and are composited proportional to the volume of flow since the last sample was taken. (See Figure IV-8.)

Constant time - volume proportional to flow rate: samples are taken at equal increments of time and are composited proportional to the flow rate at the time each sample was taken. (See Figure IV-9.)

Constant volume - time proportional to flow volume increment: samples of equal volume taken at equal increment of flow volume and composited. (See Figure IV-10.)

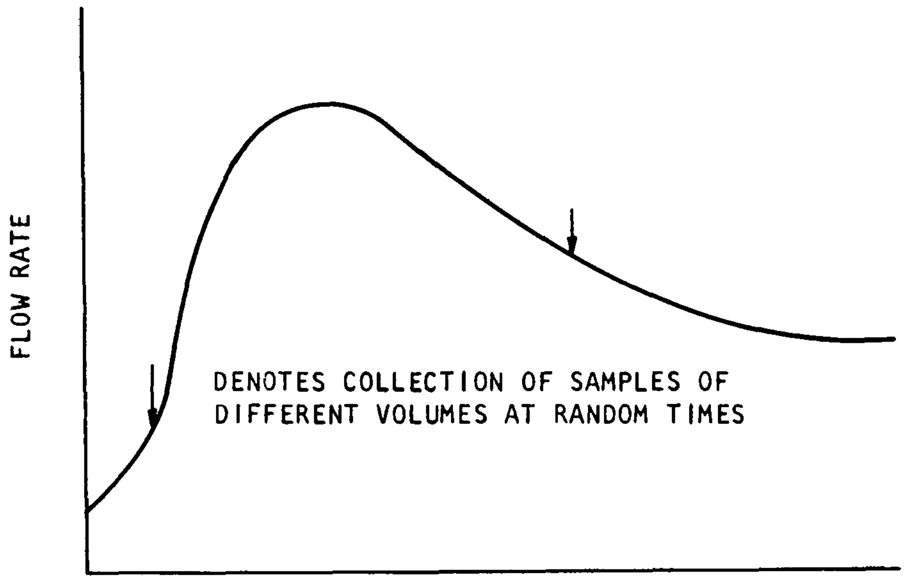


Figure IV-5. Random grab sample collection

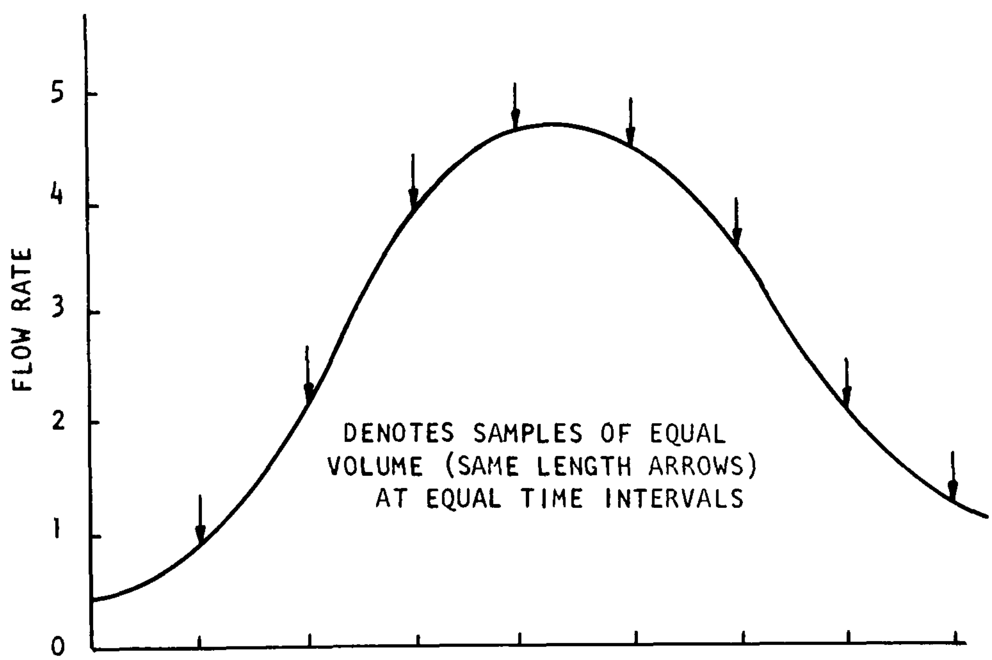


Figure IV-6. Method of compositing samples on a fixed volume-fixed time interval basis

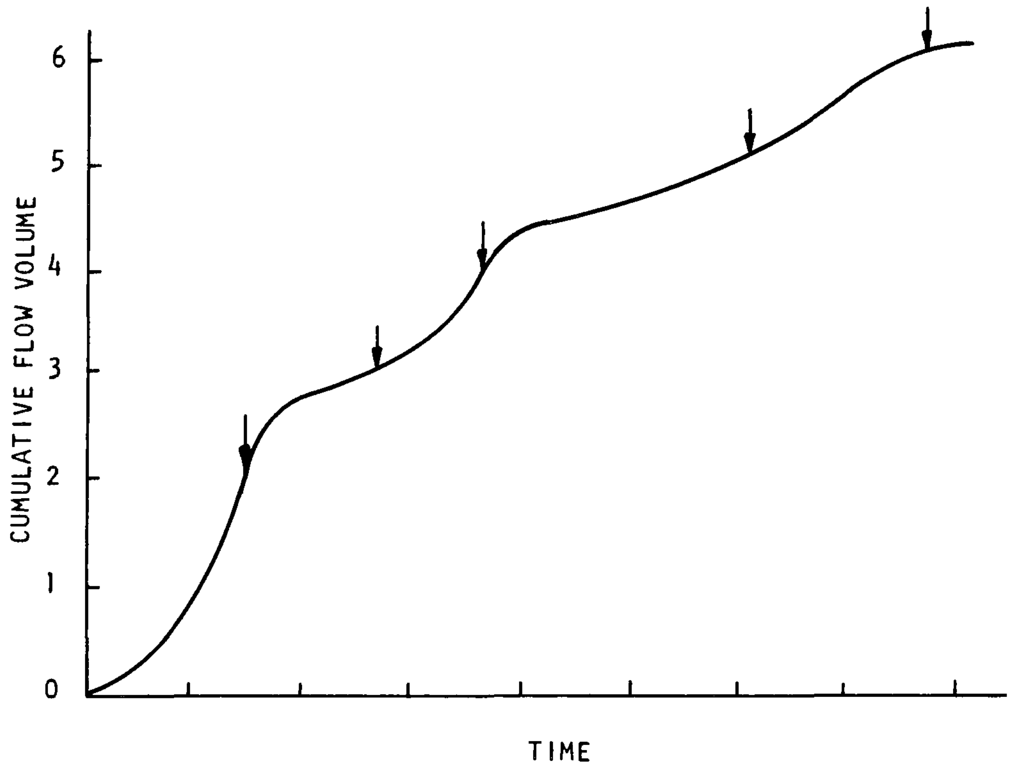


Figure IV-7. Method of taking discrete samples at constant flow volume increments

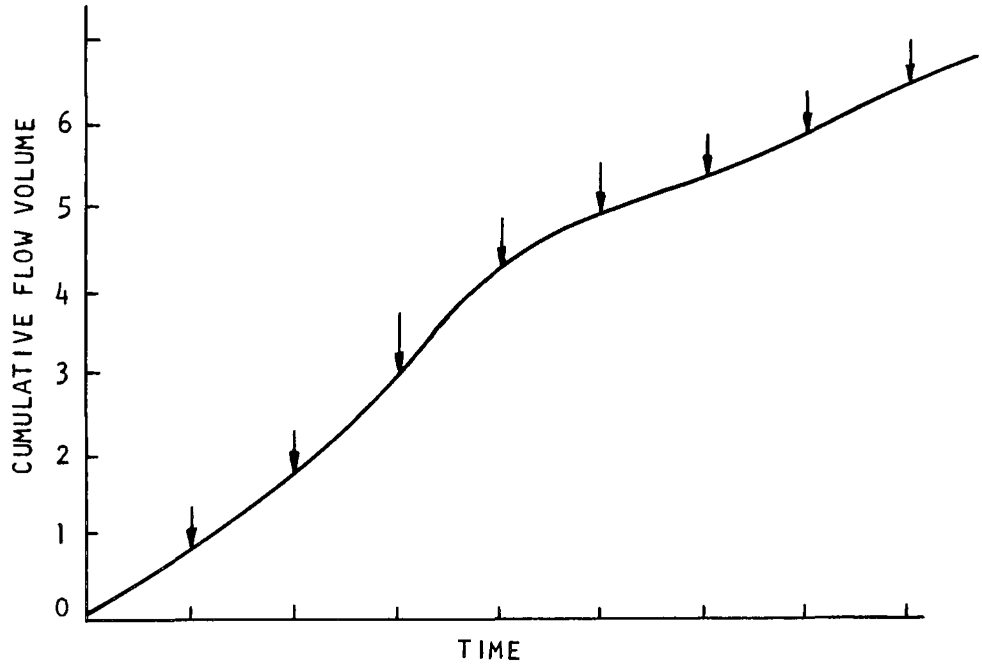


Figure IV-8. Method of compositing samples proportional to flow volume at constant time interval

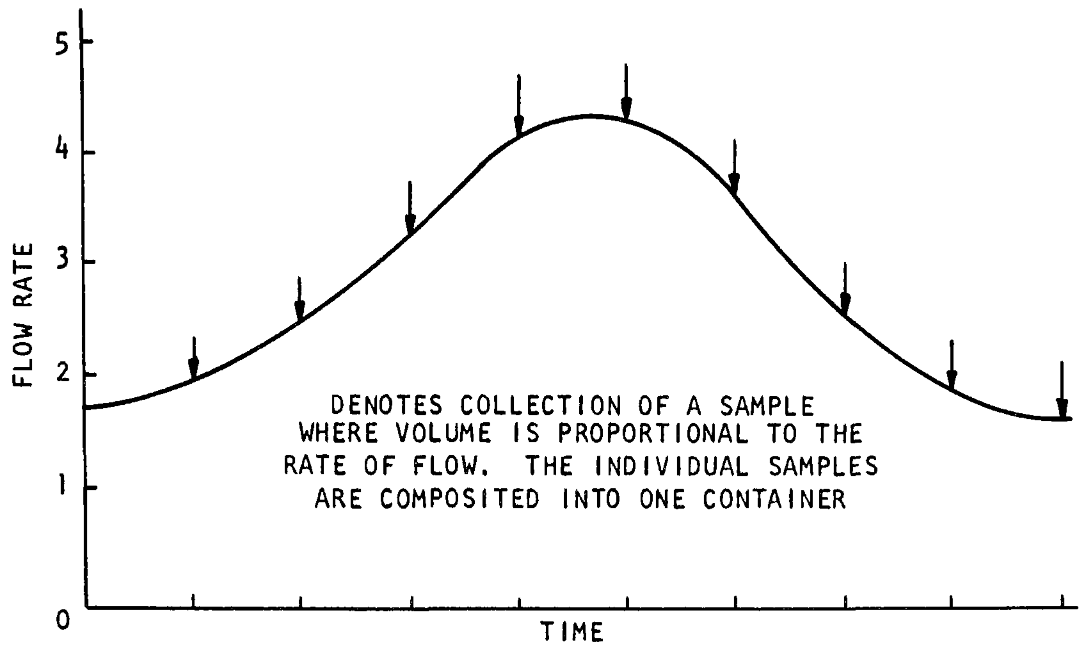


Figure IV-9. Method of compositing samples proportional to flow rate

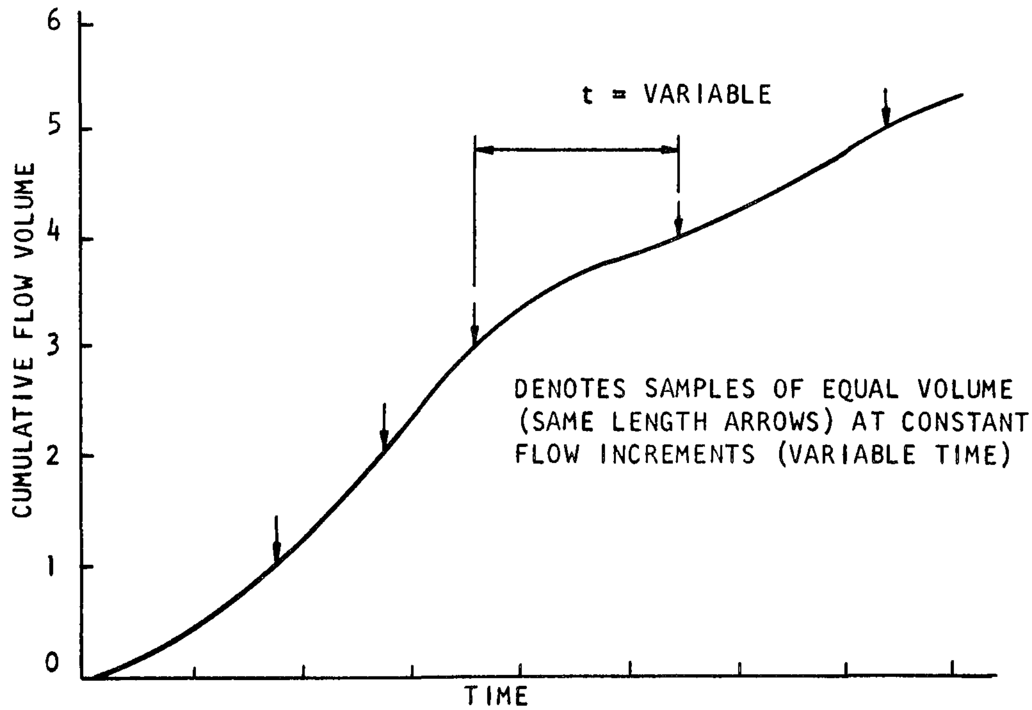


Figure IV-10. Method of compositing samples of equal volume at equal increments of flow terms of representing the wastewater flow characteristics. As previously discussed, storm discharges can be expected to vary in both flow and strength; obviously a random sampling procedure as shown in Figure IV-5 cannot possibly describe the wastewater characteristics. However, when series of discrete samples are taken in chronological order or for a fixed interval of waste flow as shown in Figure IV-6 and IV-7, it is possible to determine the waste characteristics. These two types of discrete samples can be taken either manually or with automatic samplers. In order to accurately describe a waste discharge using discrete samples, the time or flow interval must be sufficiently short to obtain the important wastewater characteristics. These two types of sample techniques are indispensable in describing the waste characteristics throughout any particular storm event. Peak or maximum wastewater characteristics associated with the first flush can be determined and frequently these characteristics are of major importance in storm generated discharge systems.

Composite sampling will provide information about the average storm generated discharge flow but not maximum or minimum values. The constant time-constant volume composite sample approach will provide information about average characteristics only if the waste flow is relatively constant. Where the waste flow is not approximately constant, one of the other types of compositing approaches must be used to determine average wastewater characteristics. A composite sampling procedure may consist of drawing discrete samples into individual containers which can be added together manually, or a series of discrete samples may be automatically mixed in a single container to make up the composited sample. The two main devices used to gather the wastewater samples are a dipping mechanism and a pumping system. The pumping type sample collection systems use either a vacuum arrangement or some type of centrifuge or positive displacement pump. Details of different automatic samplers have recently been discussed in reference 4.

In evaluation of a recent review of storm generated discharge wastes (4) it was found that discrete random grab samples were used in four different studies, automatic-discrete samplers were used in five studies, and automatic-composite samplers were used in six studies. In four of these projects, both automatic and manual sampling were used. This evaluation points out the importance of using discrete sequential samples to obtain time-series data. In one study, automatic-composite samples were used in the first phase (8), and in a later phase of the project automatic discrete samples were used (9) in order to obtain the detailed characteristics of the storm generated discharges.

In other studies grab samples were used to verify discrete samples taken with automatic samplers (3)(19)(11). Another obvious advantage of automatic samplers that obtain individual discrete samples (in some cases sample volumes may be automatically proportioned to flow rate or volume) is that each individual sample may be examined (12). In this manner it is often possible to visually determine if time series analyses should be made or if composite sample analyses to determine the average characteristics will be sufficient.

The various types of composite sampling techniques available have both advantages and disadvantages when dealing with storm generated discharges. The four types of sample compositing procedures have been evaluated using a mathematical approach for five different concentration variations. The constant time-volume proportional to flow rate at the time of sample drawing composite sampling approach was found to give a sample concentration most nearly the same as the true weighted average waste concentration. However, the difference found between the variable volume or time sampling techniques was quite small and in most cases any of these procedures approached the true value of the stream characterized.

The time constant-volume proportional to flow rate is a commonly used compositing method. This type most closely approximates continuous sampling proportional to flow rate which is considered ideal. This knowledge indicates that the smaller the time increment between samples, the more closely the sample will approximate the actual stream. Another advantage to this sample is that a sample need not be directly connected to the flow monitor if discrete samples are taken. The compositing technique of time constant-volume proportional to flow since last sample can also be obtained without direct connection to a flow meter. The accuracy of samples taken would be dependent upon the time interval and the variability of the discharge.

The volume constant-time proportional to volume since the last sample is more difficult to obtain due to the necessity of a flow monitor incorporated into the sampling mechanism. However, this may be a valuable technique for some storm generated discharge sampling. The phenomenon of first flush, as discussed previously, may be better characterized using this technique because there may be more samples taken when the flow rate is high. Therefore, the loading parameters, which may vary, will be approximated more closely. Then as the flow rate lessens the sample interval will widen and only a few samples will be taken of the tail end flow. This method has inherent difficulties due to the lack of manual monitoring. A major problem would be to determine the volume increment of flow needed to obtain a representative sample without overruning the bottle supply or not collecting a sufficient number of samples for analyses. This decision must be left to the discretion of the operator.

There is a need for the flow monitoring equipment to be reliable and accurate so that proper composites can be obtained. For some composite types (Figure IV-8 and IV-10) a totalizer or integrator will be needed. It will also be advantageous to take samples into discrete containers for manual compositing and for those cases when discrete analyses are performed. As discussed later, this discrete sampling may be necessitated with sampling storm generated discharges having first flushes of flows and for some physical or chemical treatment processes.

Very little information is available concerning the use or success of automatic switching devices to activate samplers at the beginning of an event. Two studies have reported successful use of rising water levels to actuate switching devices and start sampling operations (13)(14). A third study reported that their automatic starting devices did not work, and it was necessary to manually start each sampler at the beginning of each rainfall (10). Satisfactory results have been obtained using a float switch in a wet well at Racine to initiate sampling (15). The same switching system also starts the treatment process through a series of time delay devices. The advantages of automatic switching to start sampling equipment are obvious and should be used in every case where possible.

SAMPLE HANDLING AND PRESERVATION

Volume of Sample Required

ASTM D1496 specifies that at least 2 liters of sample should be collected for evaluation of industrial wastewater. It is also noted that 4 liters is preferable and 20 liters may be necessary (16). Tables have been published to give an estimate of the sample volume that is necessary for any given analytical testing (4)(16). Table IV-2 is reproduced for the convenience of the reader in determining sample volumes. Note that for total metals there is no preservative technique for hexavalent chromium. This analysis must be performed within 24 hours. Also, ferrous iron must be adjusted to pH <6 and filtered, followed by the addition of HNO_3 to the filtrate to pH <3. The actual volume needed depends on the characteristics of the water and the number and type of analyses that must be determined. Using Table IV-2 for estimated sample size for testing wastewaters for BOD, TOD (assuming same sample volume as required for organic carbon), fecal coliform, total phosphorus, nitrate, total Kjeldahl nitrogen, and suspended solids (see Section VI) would be 2700 ml. This number can be considered conservative (high) since 1000 ml each for the BOD and suspended solids tests are extremely high. It is the authors' opinion that all of these tests could easily be performed with 2000 ml of sample. However, in the case of most samplers when the discrete samples are composited, the composited volume will be many liters. It is good practice with storm generated discharges to bring approximately 4 liters (∿1 gal.) of sample to the laboratory under normal circumstances.

Sample Container Characteristics

Disposable containers may prove to be more easily used and economical than reusable containers that must be cleaned after each use. However, samplers that require special shaped containers will likely necessitate the use of reusable containers. Also, for such constituents as oils and grease, pesticides, TOC, etc., plastic containers cannot be used. A study of plastic and glass containers has shown that storage in Pyrex

Table IV-2. RECOMMENDED PRESERVATION METHODS

Parameter	Preservative	Maximum holding period	Approximate required sample size, ml
Acidity-alkalinity	Refrigeration at $4^{o}C$	24 hours	50-100
Biochemical Oxygen Demand (5-day)	Refrigeration at $4^{o}C$	6 hours	1000
Calcium	None required	Indefinite	50
Chemical Oxygen Demand	2 ml H_2SO_4 per liter	7 days	50
Chloride	None required	Indefinite	50
Bacteria - fecal coliform, total coliform, or fecal streptococcus	Maintain temperature as at source - usually requires refrigeration	8 hours	200
Color	Refrigeration at $4^{o}C$	24 hours	50
Cyanide	NaOH to pH 10	24 hours	500
Dissolved Oxygen	Determine on site	No holding	250-300
Fluoride	None required	7 days	200-300
Hardness	None required	7 days	25
Metals, total[a]	5 ml HNO_3 per liter	6 months	100
Metals, dissolved	Filtrate: 3 ml 1:1 HNO_3 per liter	6 months	100
Nitrogen, ammonia	40 mg $HgCl_2$ per liter at $4^{o}C$	7 days	100
Nitrogen, Kjeldahl	40 mg $HgCl_2$ per liter at $4^{o}C$	Unstable	100
Nitrogen, nitrate - nitrite	40 mg $HgCl_2$ per liter at $4^{o}C$	7 days	100
Oil and grease	2 ml H_2SO_4 per liter at $4^{o}C$	24 hours	1000
Organic carbon (total and dissolved)	2 ml H_2SO_4 per liter (pH 2)	7 days	100
pH	Determine on site	No holding	--
Phenolics	1.0 g $CuSO_{4/1}$ + H_3PO_4 to pH 4.0 - $4^{o}C$	24 hours	500
Phosphorus	40 mg $HgCl_2$ per liter at $4^{o}C$	7 days	200
Solids (total, dissolved, suspended, volatile)	None available	7 days	1000
Specific conductance	None required	7 days	--
Sulfate	Refrigeration at $4^{o}C$	7 days	100
Sulfide	2 ml Zn acetate per liter	7 days	1000
Threshold odor	Refrigeration at $4^{o}C$	24 hours	200
Turbidity	None available	7 days	1000

a. Sum of the concentrations of metals in both the dissolved and suspended fractions.

and polyethylene did not significantly change the silica, sodium, total alkalinity, chloride, boron, specific conductance, pH or hardness of water samples for a storage period of about 5 months (17). Soft glass containers did show an increase in silica after 2 to 3 weeks, and after longer periods increased sodium and hardness were found. All new containers should be thoroughly washed and allowed to soak for several days in order to remove as much water soluble material as possible. Old beverage or other similar type containers should not be utilized for wastewater sampling.

The proper method for cleaning sample containers will depend on the contaminants to be analyzed. A good soap washing will normally be used first. When samples are to be tested for phosphorus, heavy metals, pesticides, and grease and oil additional procedures should be used (18).

Sample Container Cleaning Procedures

1. After soap washing, use cleaning solution made by adding 1 liter of concentrated sulfuric acid to 32 ml of a saturated water solution of sodium dichromate.

2. Rinse out cleaning solution thoroughly using generous amounts of tap water followed by distilled or demineralized water.

3. For samples to be analyzed for heavy metals, an additional nitric acid rinse is needed. Rinse containers with a nitric acid solution made up of 1 part concentrated nitric acid and 4 parts water.

4. Complete container preparation by thoroughly rinsing with distilled or demineralized water followed by drying.

Containers to be used when testing for pesticides and bacteriological analyses may require additional special preparation as will the sample lines themselves (discussed later).

Sample Preservation

If possible, samples should be analyzed immediately after collection and no preservative is needed. However, from a practical standpoint both composite and a series of sequential discrete samples cannot be analyzed immediately. In some cases, for example, samples taken for bacteriological testing, it is necessary to take short term composite or grab samples in order to ensure reliable results [(14), page 81]. A number of preservation methods have been suggested (1)(3)(14)(15)(17)(18) for different constituents. Review of the methods of preservation (from the above references) shows that conflicts exist as to the type of preservation to use and the length of storage allowed before significant changes occur in the sample. For example, maximum recommended sample holding times for the BOD range from 6 hours (16) to 24 hours (19) when the sample has been stored at 4°C. If the maximum storage time is 24 hours, it is obvious that 24 hour composite samples cannot be used. Recommended preservatives and holding times shown in Table IV-2 can be used as guidelines for storm generated discharge analysis. Where several constituents that require different preservatives must be determined, multiple samples will have to be collected. The purpose of different preservatives are shown in Table IV-3 (20). As can be seen in Table IV-2, the most universal preservation method for a large number of tests is refrigeration. In all cases where storm generated discharge samples are not analyzed immediately, refrigeration or icing should be used to maintain samples at 4°C. Preservation techniques for the specific recommended quality characteristics, after the sample has arrived in the laboratory, are presented in Section VI.

Sample Identification

Samples should be carefully identified using tags or by printing directly on the container wall with a grease pencil to ensure that the date of collection and the location of sample is known. If plastic containers are used, masking tape should be applied with the marking put on the tape so it can be reused. Discrete samples should also be identified by the time of their collection. When preservatives are added prior to sample collection, containers should also be marked with the type of preservative used and analysis to be run. Code or abbreviations may be used in sample identification, but these should be standardized with a known format.

AUTOMATIC SAMPLING EQUIPMENT

Survey of Samplers

A published U.S. EPA report (4) has summarized the characteristics of 41 automatic samplers commercially available from 18 different companies, as well as 12 custom designed samplers. Tables IV-4 and IV-5 present a summary of the sampler characteristics outlined in that report. Table IV-4 lists the costs of the commercially available samplers and distinguishes what type of samples each sampler is capable of obtaining. An extra sample type has been added to those previously discussed -- a continuous sample -- whereby the waste discharge has a sample stream removed continuously and composited in a suitable sample container. Those samplers that could be modified to obtain a continuous flow type sample have been noted by the footnote letter "a". Table IV-5 presents the same sampler's capabilities with reference to sample preservation by refrigeration, applicability to hostile environments, and sample contamination plausibility.

Table IV-3. PURPOSE OF DIFFERENT PRESERVATIVES

Preservative	Action	Applicable to:
$HgCl_2$	Bacterial inhibitor	Nitrogen forms, Phosphorus forms
Acid (HNO_3)	Metals solvent, prevents precipitation	Metals
Acid (H_2SO_4)	Bacterial inhibitor	Organic samples (COD, oil & grease, organic carbon, etc.)
	Salt formation with organic bases	Ammonia, amines
Alkali (NaOH)	Salt formation with volatile compounds	Cyanides, organic acids
Refrigeration or freezing	Bacterial inhibitor	Acidity - alkalinity, organic materials, BOD, color, odor, organic P, organic N, carbon, etc., biological organisms (coliform, etc.)

Table IV-4. AUTOMATIC SAMPLER COSTS AND SAMPLE TYPES OBTAINABLE

Sampler	August 1972, Cost - $	Discrete/ time	Discrete/ volume	Comp./ Flowrate	Comp./ volume	Comp./ time	Continuous
BIF	595					x	
Brailsford DC-F	281						x
Brailsford EV-P	583					x	
BVS PP-100	1,000			x	x	x	
BVS SE-400	2,600			x	x	x	
BVS SE-600	2,800			x	x	x	a
Chicago "Tru-Test"	2,578			x	x	x	
Hydra-Numatic	1,800			x	x	x	a
Infilco	4,400			x	x	x	
ISCO 1391	1,095	x	x	x	x	x	
Lakeside T-2	1,577			x[b]		x	
Markland 1301[c]	1,210			x	x	x	
Markland 101[c]	980					x	
Markland 102[c]	1,265					x	
Markland 104T[c]	1,415			x	x	x	
N-Con Surveyor	275			x	x	x	
N-Con Scout	450					x	
N-Con Sentry	895						
N-Con Trebler	1,560			x[b]		x	
N-Con Sentinel	2,350			x	x	x	

a. Can be easily modified to sample continuously.
b. Flow must be proportional to depth as in a Parshall Flume.
c. Representativeness of sample questioned in Reference 1.

Table IV-4 (continued). AUTOMATIC SAMPLER COSTS AND SAMPLE TYPES OBTAINABLE

Sampler	August 1972 Cost - $	Discrete/ time	Discrete/ volume	Comp./ Flowrate	Comp./ volume	Comp./ time	Continuous
Phipps & Bird	1,145			x	x	x	
Protech CG-125[c]	723					x	
Protech CG-125FP[c]	1,038			x	x	x	
Protech CG-150[c]	895			x	x	x	
Protech CEL-300	1,450			x	x	x	a
Protech DEL-2405	5,606	x	x	x	x	x	a
QCEC CVU	940			x	x	x	
QCEC E	875			x	x	x	
SERCO NW-3[c]	920	x					
SERCO TC-2	2,495			x	x	x	
Sigmamotor WA-1[c]	700					x	
Sigmamotor WA-3[c]	700					x	
Sigmamotor WDPP-2[c]	680			x	x		
Sigmamotor WM-1-24[c]	1,525	x	x				
SIRCO B/ST-VS	2,950	x	x	x	x	x	
SIRCO B/IE-VS[c]	2,850	x	x	x	x	x	
SIRCO B/DR-VS	2,640	x	x	x	x	x	
SIRCO PII-A	1,387					x	
SONFORD HG-4[c]	495			x	x	x	
TMI	660					x	
TMI Mark 38	685	x					

a. Can be easily modified to sample continuously.
b. Flow must be proportional to depth as in a Parshall Flume.
c. Representativeness of sample questioned in Reference 1.

Table IV-4 (continued). AUTOMATIC SAMPLER COSTS AND SAMPLE TYPES OBTAINABLE

Sampler	August 1972, Costs - $	Discrete time	Discrete vol.	Comp. flowrate	Comp. volume	Comp. time	Continuous
AVCO[c]	d			x			
Springfield	d					x	
Milk River	d			x	x	x	
Envirosenics	d	x - 1 sample only					
Rohrer I	d	x		x	x		
Weston	d	x	x				
Pavia-Byrne	d	x					
Rexnord	d	x					
Colston	d	x					
Rohrer II	d	x				x	
Near	d			x[b]	x	x	
Freeman	d	x					

a. Can be easily modified to sample continuously.
b. Flow must be proportional to depth as in a Parshall Flume.
c. Representativeness of sample questioned in Reference 1.
d. Custom designed for sampling combined sewage.

Table IV-5. AUTOMATIC SAMPLER CAPABILITIES AND SAMPLING METHODS

Sampler	Method of sample transport	Refrigeration provided	Ability to withstand: Freezing	Ability to withstand: Immersion	Ability to sample: Floatables	Ability to sample: Coarse bottom sediments	Self-cleaning features
BIF	Dipper	yes	no	no	no	no	none
Brailsford DC-F	Positive displacement pump	no	no	no	no	no	continuous flow
Brailsford EV-F	Vacuum pump	no	no	no	no	no	backflush
BVS PP-100	Pneumatic ejection	yes	yes	no	yes	no	air purge
BVS SE-400	Submersible pump	yes	yes	no	no	no	continuous
BVS SE-600	None provided - solenoid valve diversion from sample line[c]	yes	yes	no	b	b	continuous flow
Chicago "Tru-Test"	Dipper from sample chamber provided by customer	yes	no	no	b	b	continuous
Hydro-Numatic	Centrifugal pump	no	yes	no	b	b	continuous flow
Infilco	Dipper from sample chamber provided by customer[c]	yes	no	no	b	b	continuous flow
ISCO 1391	Peristaltic pump	ice cavity	no	yes	yes	no	backflush
Lakeside T-2	Dipper	yes	no	no	some	some	none
Markland 1301[a]	Pneumatic ejection	no	yes	no	no	no	none
Markland 101[a]	Pneumatic ejection	yes	yes	no	no	no	none
Markland 102[a]	Pneumatic ejection	yes	yes	no	no	no	air purge
Markland 104T[a]	Pneumatic ejection	yes	yes	no	no	no	none
N-Con Surveyor	Centrifugal pump	no	no	no	b	b	gravity drain
N-Con Scout	Peristaltic pump	no	no	no	no	no	backflush
N-Con Sentry	Peristaltic pump	no	no	no	no	no	backflush
N-Con Trebler	Dipper	yes	no	no	some	some	none

a. Representativeness of sample questioned in Reference 1.
b. Depends on how user arranges sampler intake.
c. Continuous flow sample line provided by user.
c. Refrigeration provided only for stationary

Table IV-5 (continued). AUTOMATIC SAMPLER CAPABILITIES AND SAMPLING METHODS

Sampler	Method of sample transport	Refrigeration provided	Ability to Withstand: freezing	Ability to Withstand: immersion	Ability to sample: Floatables	Ability to sample: Coarse bottom sediments	Self-cleaning features
N-Con Sentinel	Dipper from sample chamber provided by customer[c]	yes	no	no	b	b	continuous flow
Phipps & Bird	Dipper	no	no	no	no	no	none
Protech CG-125[a]	Pneumatic ejection	yes	yes	no	no	no	backflush
Protech CG-125FP[a]	Pneumatic ejection	d	yes	no	no	no	backflush
Protech CG-150[a]	Pneumatic ejection	d	yes	no	no	no	backflush
Protech CEL-300	Submersible pump	d	yes	no	no	no	continuous flow
Protect DEL-2405	Submersible pump	yes	yes	no	no	no	continuous flow
QCEC CVE	Vacuum pump	yes	yes	no	no	no	air purge
QCEC E	Dipper	no	no	no	no	no	none
SERCO NW-3	Evacuated bottles	ice cavity	no	no	no	no	none
SERCO TC-2	Dipper from sample cahmber provided by customer[c]	yes	no	no	b	b	continuous flow
Sigmamotor WA-1[a]	Peristaltic pump	yes	no	no	no	no	backflush
Sigmamotor WA-3[a]	Peristaltic pump	no	no	no	no	no	none
Sigmamotor WDPP-2[a]	Peristaltic pump	no	no	no	no	no	none
Sigmamotor WM-1-24	Peristaltic pump	yes	no	no	no	no	backflush
SIRCO BST-VS	Vacuum pump	yes	yes	no	b	b	backflush
SIRCO B/IE-VS[a]	Dipper	yes	yes	no	no	no	none
SIRCO B/DP-VS	None provided - solenoid valve diversion from sample line	yes	yes	no	no	no	continuous flow
SIRCO PII-A	Vacuum pump	no	no	no	b	b	backflush

Table IV-5 (continued). AUTOMATIC SAMPLER CAPABILITIES AND SAMPLING METHODS

Sampler	Method of sample Transport	Refrigeration provided	Ability to withstand Freezing	Ability to withstand Immersion	Floatables	Coarse bottom sediments	Self-cleaning features
Sonford HG-4[a]	Sample tube which fills by gravity	ice gravity	no	no	no	no	none
TMI	Pneumatic ejection	no	yes	no	no	no	none
TMI Mark 38	Evacuated bottles	no	no	no	no	no	none
AVCO[a]	Peristaltic pump	no	no	no	some	no	none
Springfield	Dipper from sample chamber provided with continuous flow by screwrotor pump	yes	no	no	some	some	continuous flow
Milk River	Submerged pump	yes	--	--	--	--	--
Envirogenics	Mechanical - gravity	no	yes	yes	yes	yes	na
Rohrer I	Diaphragm pump	no	yes	no	b	b	continuous flow
Weston	Evacuated bottle from smaple cha ber provided with continuous flow	yes	no	no	b	b	continuous flow
Pavia-Byrne	Screw pump	yes	no	no	no	no	continuous flow
Rexnord	Positive displacement pump	no	no	no	b	b	backflush
Colston	Serco NW-3 samples from a flume provided with continuous flow	no	no	no	no	no	none for SERCO par
Rohrer II	Diaphragm pump	no	yes	no	b	b	continuous flow
Near	Piston in tube	no	no	no	yes	no	none
Freeman	None provided - solenoid valve diversion from sample line[c]	no	yes	no	b	b	continuous flow

a. Representativeness of sample questioned in Reference 1.
b. Depends on how user arranges sampler intake.
c. Continuous flow sample line provided by user.
c. Refrigeration provided only for stationary

Of the 41 commercially available samplers, only 9 are capable of obtaining a number of discrete samples and only 6 of these accept signals from flow monitoring equipment. Two of those six have the representativeness of the samples obtained questioned. Those models that are capable of doing this are generally the more expensive samplers. It may be noted that of those samplers developed specifically for sampling combined sewage, 7 of 12 were designed to obtain a quantity of discrete samples. It is evident from this that those persons with expertise in combined sewage sampling prefer this method of discharge characterization.

Table IV-5 shows that 21 of 41 commercially available samplers are refrigerated to provide sample preservation. This is strongly desirable for storm generated discharges in that they are routinely analyzed for biological and pathogenic bacterial indicators such as fecal coliforms. Four of 12 custom designed samplers were refrigerated. Of all the samplers, only two are capable of withstanding total immersion (which could occur in storm or combined sewers when samplers are placed in manholes) and 22 of 53 are capable of operating in freezing weather. Ability to operate in freezing weather is not a necessary prerequisite for sampling combined sewage due to the infrequent overflows during winter conditions. However, it can be a desirable feature.

The dipper type samplers do not have provisions for keeping the dipper clean, i.e., free of entanglement with rags or other debris. This is a serious drawback to these type of samplers, since storm generated discharges can contain large quantities of debris which could cause failure during overflow events. Other sampler types have backflush (sample flow reversal) or air purge systems to help unclog sample lines and prevent sample line blockage.

The samplers that use vacuum or peristaltic pumps to withdraw water samples usually obtain sample volumes inversely proportional to the lift height. To increase the sample volume for a greater lift it is necessary to sample for a longer period of time.

Very few of the samplers have provisions for sampling floatable or coarse bottom sediments. Quantification of these materials cannot be reliably done by automatic methods, and need to be accomplished using manual grab sampling techniques.

Desirable Characteristics of Ideal Sampler

There are a number of different types of samplers with a large number of different characteristics (Table IV-4 and IV-5). The ideal sampler for storm generated discharge studies still does not exist. Some sampler characteristics are mutually exclusive and compromises must be made. The following is a partial list of the most desirable sampler characteristics for storm generated discharge studies.

1. Ability to take a sequential timed (variable timer) series of discrete samples. It should be possible to use an external signal to allow sample volumes to be taken proportional to flow rate or increments of flow. Five minutes should be the minimum sampling interval and should be adjustable.

2. Four different sample containers should be filled at each sampling: (a) for solids and BOD testing to hold no preservatives, (b) for metals and TOD analysis acid added to preserve sample, (c) for nitrogen and phosphorus $HgCl_2$ added, and (d) sterilized containers for bacterial analysis. The fourth set of containers could also be used for grease and oil, pesticides or some other tests.

3. Capability of using 1 to 3 liter sample containers so that individual discrete sample analysis can be made.

4. Capability of programming the time interval at which samples are taken, so the sampling interval can be short during the early stages of the storm and longer intervals automatically used as the storm continues.

5. To hold 96 sample containers - this would allow sampling every five minutes for two hours, or ten minutes for four hours where longer duration discharges are expected.

6. Refrigeration capabilities to hold samples at 4^{o} C.

7. Capability of lifting sample 7.6 m (25 ft) or more without affecting sample size.

8. Have a self-contained power source.

9. Be automatically activated to sample at beginning of storm.

10. Inlet and inlet line to be sufficiently large to eliminate problems of plugging.

11. Inlet orifice velocity to be sufficiently high to keep heavy particles in suspension throughout their flow to the sample container.

12. Inlet device of such a configuration to allow obtaining a representative sample throughout the depth of the stream flow. Light floating material and heavy bottom sludge should be included in each sample.

13. Inlet device does not plug easily and is self-cleaning. Sample lines are self-purging with cleanser and/or disinfectant so that next sample is not included in any of the previously taken sample.

The aforementioned described ideal sampler does not currently exist; however, improved samplers are being developed (21). Operating personnel may have to modify or construct adequate samplers for their application. Continued development work is needed to provide new and improved sampling devices for storm generated discharge projects.

RECOMMENDED SAMPLING PROGRAMS

Types of Sampling Programs

The various types of sampling programs have been discussed earlier in this section. The application of these different types of sampling programs are presented in Section VII for evaluating storm generated discharges and in Section VIII for evaluating storm generated treatment processes. Regardless of what type of sampling is being done, automatic samplers are recommended and these samplers should have automatic start-up capabilities. Samplers taking discrete samples are recommended. Each sample bottle should be at least 500 ml in volume, preferably closer to 4 l, if possible.

Sampling Location

In order to ensure characteristic samples and optimum sampler accessibility, several considerations are recommended (4).

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 and/or submergence by surface water should be avoided if possible. Avoid locations which may tend to invite vandalism.

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 sampling 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 sewer.

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

5. Locate at a point of maximum turbulence, as found in sewer sections of greater roughness and of probable higher velocities. Locate just downstream from a drop or hydraulic jump, if possible. However, if sampler is tied into flow measuring equipment, this must be taken into consideration.

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

Knowledge of the sewer system or stream flow is valuable in selecting the sampler site. This will also help in establishing where to place the sampler inlet device. When Item 5 above is met and the wastewater is sufficiently mixed that a uniform composition exists throughout the depth of the waste flow, the sampler inlet device should be located at mid-depth. Manual grab samples should be collected periodically at different depths and analyzed for suspended solids and TOD. These analyses should be compared with results from the automatic sampler to ensure the sample site is located in a thoroughly mixed portion of the sewer. Where stream or lake analyses are made for impact studies, samples should also be taken periodically at different depths to establish that the samples are representative of the main water body.

Sample Handling and Preservation

Plastic sample containers should be used for all sample collection except where grease and oil or pesticides and other trace organics are to be analyzed. Hard glass containers should be used where these analyses will be made due to the problems with adsorption. Sample containers should be thoroughly washed as previously indicated. The possibilities 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. Checks for sample adsorption on the container should also 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 storms. In this way the cleaning techniques used can be tested for thoroughness.

All samples should be kept in a refrigerated or ice cooled container during and after sampling. This cooling will slow the biological reactions and prevent significant changes in the nature of the sample. Although the ideal procedure for preservation would be to add chemicals prior to sample collection, this is not possible for storm generated discharges. Therefore cooling is recommended until the sample is brought to the laboratory for analysis. At this time, the volume needed for a specific analysis will be split off of the total sample and either analyzed immediately or preserved (as detailed in Section VI) for later work.

It is important to realize that the biological changes will affect the results of certain tests if they are not run immediately. This is especially true of BOD which should be run within 6 hours after collection of the sample. A maximum holding time of 24 hours may be allowed if the sample is kept refrigerated.

Bacterial analyses are also affected by biological processes and other factors. If bacterial analyses are to be run on the composite samples, this can only be used as a control for the system and not as a reportable value. The cross contamination due to a single sampling line and funnel in the sample and the lack of a dechlorinating agent in the sample bottle can invalidate the test. Bacterial tests on composite samples can be used if "in house" control is desired to get relative numbers, but should not be considered an absolute value. If a quantitative test is required by regulatory agencies, then the sampling and preservation techniques mandated by the agency should be followed for bacterial analyses.

SAMPLING ACCUMULATED ROADWAY MATERIAL

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, 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 (22).

Collection of Samples

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 $<4^{\circ}$ C., if possible. The analyses of the liquid fraction should be made as soon 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 (23).

If only physical loading information (such as kg [lbs] 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 (23).

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.

Table IV-6 (22) gives a specific stepwise sampling procedure for the collection of street surface contaminants.

The vacuum cleaner used for collection of roadway particulates consists of a pick-up head attached to a 38 l (10 gallon) 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 (22). 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 (22). It was found that a roadway area of 92 sq m (1000 square feet) could be thoroughly flushed with about 95 l (25 gallons) of water. In most cases, over 50 percent of the applied flush was recovered by vacuuming of the impounded water along the curb.

The data in Table IV-7 lists average percentages found in the flush fractions for specific components of dust and dirt. The standard deviations are also listed to indicate the constancy of this fraction. Arbitrarily selecting 80 percent or better as satisfactory recovery, it is apparent that most parameters are adequately recovered with the dust and dirt fraction. The dry weight, heavy metals, asbestos, oil and grease fractions, COD and others are all found largely in the dust and dirt fraction. However, a considerable percentage of BOD, Kjeldahl-N, water soluble amines and microorganisms are recovered with the water flush.

It is concluded from these data that flush fractions must be collected in order to obtain accurate values for some pollutants.

Sampling Site Selection

Sampling sites should be chosen that 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

Table IV-6. SAMPLING PROCEDURE FOR THE COLLECTION OF STREET SURFACE CONTAMINANTS

Equipment

Hard bristle broom, rake, shovel, and foxtail or paint brush

Alternator power plant, 3500 watt, Dayton Electric Manufactuing Company, Model 1W832A

Two wet and dry vacuum cleaners, 10 gallon, Dayton Electric Manufacturing Company, Model 2Z612, with sufficient filter bags. A new filter bag for each sampling (three vacuum passes).

Steel drum, 208 l (55 gallon) with lid and rim lock, containing 151-189 l (40 to 50 gallons) of water.

Rotary screw pump, 3.5 amperes, Dayton Electric Manufacturing Company, Model No. 3P569

Garden hose, 46 m (150 feet)

Galvanized garbage can with clamp fitting lid, one or more

Dual Motor shop wet and dry vacuum, Dayton Electric Manufacturing Company, Model No. 3Z107 mounted on a 208 l (55 gallon) steel drum

Sand bags - 5 to 7, .014 cu m (1/2 cu ft) bags

Procedure

1. Select a roadway sampling site 30.48 continuous curb meters (100 feet) 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 4.6 m (10 or 15 feet) 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 clean galvanized garbage can.

Table IV-6 (continued). SAMPLING PROCEDURE FOR THE COLLECTION OF STREET SURFACE CONTAMINANTS

Procedure

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

7. Place the intake hose from the rotary screw pump into the 208 l (55-gallon) 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 95 l (15 to 25 gallons) of water are required to flush 56-93 sq m (600-1000 square feet) of roadway. Generally greater than 50 percent of the flush water applied is recovered by the vacuum.

At the laboratory or on-site

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

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

3. 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.

Table IV-7. DISTRIBUTION OF POLLUTANTS BETWEEN DUST AND DIRT AND FLUSH SAMPLE FRACTIONS

Parameters	Avg. % in Flush	% Standard Deviation
Dry Weight	7	8
Volatile Solids	20	13
BOD	36	22
COD	16	12
Grease	19	15
Petroleum	19	13
n-Paraffins	19	14
Total PO_4-P	15	15
PO_4-P	43	42
NO_3-N	69	24
NO_2-N	97	7
Total Kjeldahl-N	33	23
Chloride	43	33
Asbestos	13	31
Fecal Coliforms	76	40
Fecal Strep	44	39
Lead	4	2
Chromium	17	15
Copper	5	4
Nickel	5	2
Zinc	2	1

could be combined for complete composite chemical analysis representing that land use.

For a 12-month field study in Washington, D. C. (22), seven area roadways were chosen for the field study 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 (24).

In addition, 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, 7.6 m x 12.2 m (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. The published results of previous sampling programs (24, 25, 26) may be useful in this design process.

Frequency of Sampling

As with the selection of the study area, the frequency of sampling will depend on the objectives of the sampling program. For the Washington, D. C. study (22) 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. Again, the published results of previous sampling programs may be useful in this design process.

SECTION V - MONITORING INSTRUMENTATION

FLOW MEASURING EQUIPMENT

Level Gaging

Devices for gaging wet weather sewage level in storm and combined sewerage systems vary in complexity from a dipstick or chalked length of rope to fairly sophisticated electromechanical and electronic instruments. Float gages and bubble tubes have found most common use to date, but ultrasonic level gages and conductivity gages are also beginning to be used in storm generated discharge measurement applications. Level determinations are important for tracing sewer levels during and after storms as a function of storm intensity, duration and location, for infiltration studies, for determining discharge flows in overflow sewers, and for determining storage capacity, routing programs, and gate control in "in-line" storage systems.

Dipstick and Chalked Ropes - The dipstick and flashlight (Figure V-1) while an inexpensive and reliable method, is best suited to slowly changing dry-weather flows and is obviously not adequate to measure the multitude of rapid level changes in a combined sewerage system or storm sewer under storm conditions. Some studies have used a chalked length of rope fastened vertically in a sewer to measure the peak level reached during a storm event. The chalk dust is washed off the submerged rope by the sewage, but remains on the exposed length. However to obtain a continuous record of level, more sophisticated devices must be used.

Floats and Scows - A buoyant float or scow connected via a cable to a clock driven drum recorder (Figure V-2) is a commonly used method. A simple float can be used in sewage applications if a stilling well provides an undisturbed liquid surface. Measurements directly in the sewage stream require a buoyant scow attached to a swivel as sketched in Figure V-3.

Recorder clock drives are either spring driven or synchronous motor driven. Spring drives provide continuous unattended operation for periods from four hours to eight days as required. Although direct and reliable, simple floats require a fairly costly stilling well, and they as well as scows are subject to fouling and submerging by passing debris, and therefore require frequent inspection and cleaning.

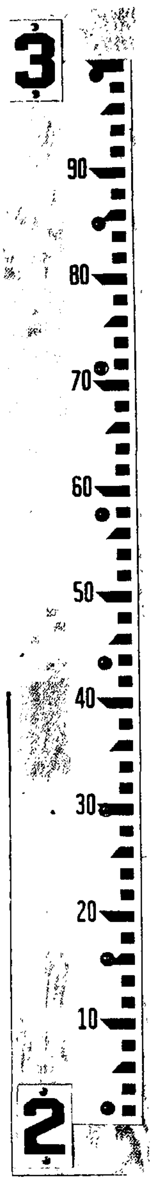


Figure V-1. Level gaging dipstick (courtesy of Leopold & Stevens, Inc.)

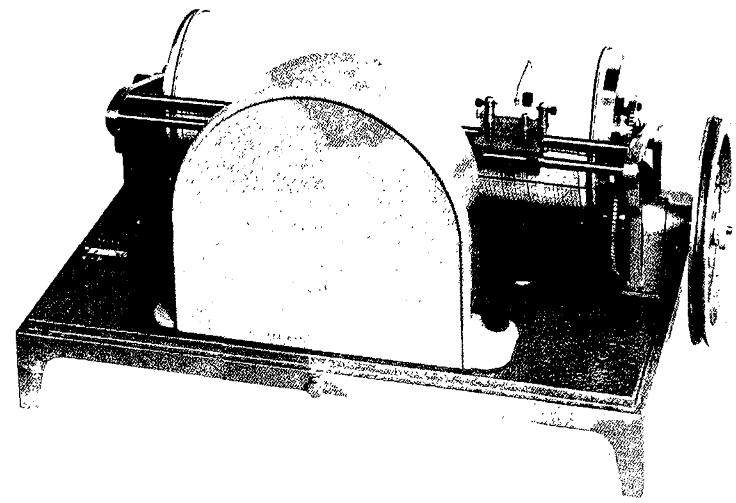


Figure V-2. Float driven recorder with clock drive (courtesy of Leopold & Stevens, Inc.)

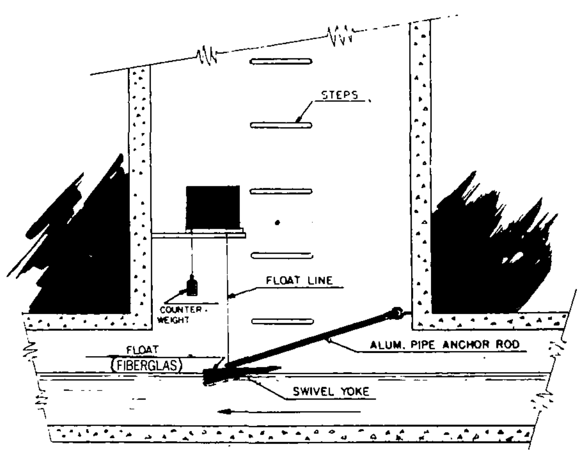


Figure V-3. Recorder with scow float used in a sewer manhole. (courtesy Leopold & Stevens, Inc.)

Bubbler Level Gages - The bubbler level gage sketched in Figure V-4 requires less maintenance because of self-cleaning features. A bubbler dip tube, often a 1.8 cm (0.5 in.) pipe cut off at a right angle, is immersed in the flow stream or inserted through the sewer wall and a constant flow of air (or other gas, e.g., nitrogen) is forced through the tube and bubbles to the surface. The back pressure in the tube is proportional to level, provided the sewage density is constant. A constant air flow can be provided by a rotameter/differential pressure regulator combination which maintains a constant differential pressure across the rotameter regardless of back pressure. The back pressure can be read out in a bourdon spiral pressure gage, or any of a variety of mechanical, pneumatic or electrical pressure transducers, and recorded. While widely used in sewage treatment plant applications where a supply of instrument air is readily available, bubblers are not so commonly used in sewerage systems because of the need for a motor-compressor or compressed nitrogen tanks for a gas supply. Occasionally pressure transducers are used to sense level head directly, but an inlet port or slack diaphragm at the sewer invert is easily fouled by sediment so this method is troublesome. The air flow through the bubbler dip tube keeps the exit port clear and eliminates the fouling problem. However, the method is subject to error due to a pressure reduction from the fluid velocity past the bubbler exit (Bernoulli effect), and occasional occlusion of the dip tube by solids which crystallize at the exit port.

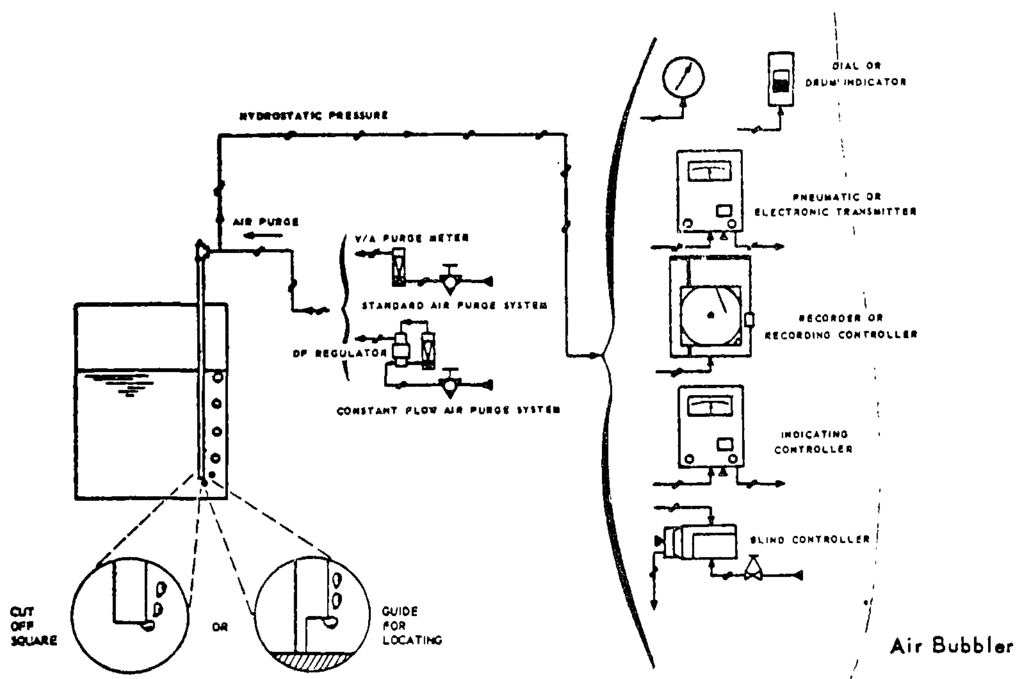


Figure V-4. Air bubbler level gage
(courtesy Fischer & Porter Co.)

Conductivity Level Gages - Another level gage designed to minimize fouling problems is the "dipper", a device which lowers a thin metal probe to the sewage surface, by unwinding a motorized wire spool. When the probe makes electrical contact with the sewage surface, the spool motor is reversed and the probe is retraced. Then it is lowered again until electrical contact is made and then again retraced. This dipping action is continuous at five second intervals with the probe position maintained just above the sewage surface. As in a float gage, spool position is a measure of liquid level. The probe is lowered from the bottom of a unit which houses the dipper mechanism and a level recorder as pictured in Figure V-5. The dipper spool drive is battery powered and the recorder is spring powered with either a 24 hour or 7 day clock drive.

A second electrical contact with the sewage stream, a ground return, is also required. A problem encountered in some installations is the coating of the ground return by grease which interrupts electrical continuity. Also, passage of large pieces of debris floating on the sewage surface can snag or hook onto the dipper probe, causing an erroneous reading, or in extreme cases, damaging the mechanism.

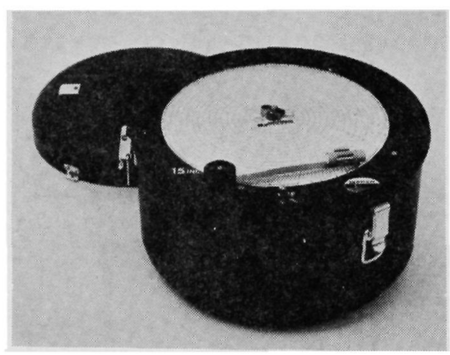


Figure V-5. "Dipper" level gage based on electrical contact with the sewage surface. (Courtesy Manning Environmental Corp.)

Ultrasonic Level Gages - A growing number of domestic companies are offering ultrasonic level gaging equipment for wastewater measurement applications. The major advantage is that no contact, electrical or mechanical, is required with the flow stream. A typical gage (Figure V-6) consists of an ultrasonic transceiver, a signal processor and a recorder. The gage operates by generating pulses of sound energy at a frequency above audibility and directing the pulses at the liquid surface from above. Each pulse is reflected by the liquid surface and a portion of the energy is received by the transceiver. The time required for the transit of each pulse from the transceiver to the surface and back again is measured by the signal processor. This time

Figure V-6. Portable ultrasonic flow gage
(courtesy of Rexnord Inc.)

duration is a measure of liquid depth, and is converted to an electrical output signal and recorded.

While more complex electronically than the other level gages described earlier, the method has attained a cost and reliability over the last several years which suit it to unattended sewage gaging applications. The portable unit pictured in Figure V-6 can be mounted in manholes for storm generated discharge and infiltration studies by affixing the transceiver probe to the manhole wall perpendicular to the sewage surface, and hanging the signal processor/recorder unit and battery on ladder rungs above. The gage is also being used in permanent level gaging installations in sewerage systems (e.g., a large installation in Rochester, N.Y.) and in treatment plant applications.

Summary, Comparison and Recommendations - In the preceding discussion of level measurement devices useful in storm generated discharge applications, little mention was made of other techniques which are in common and successful use for head meausrements in the process industries, such as force-balance and motion-balance differential pressure transducers, slack diaphragms, bourdon tubes and manometers. These devices are in general not well suited to sewage and storm generated discharge applications because of difficulties in keeping pressure sensing ports or surfaces free from fouling.

Continuous level recordings can be provided by floats, scows, bubblers, dippers and ultrasonic level gages. Float gages require stilling wells and in such installations serve reliably over the full range of sewage depths provided the well does not become fouled with grease, scum or other debris. Instrument cost is lowest in the group of continuous level recording gages, but capital cost of the stilling well must be added. Scows are most often used in connection with head measurements over a flume or weir, and like these flow structures, they operate over a limited range of depths and cease to function accurately when submerged. Discharge measurements over flumes and weirs become inaccurate when flow in the downstream channel becomes sufficient to reduce velocity and increase depth. In the absence of regular maintenance, scum and debris accumulation on scows can occasionally cause them to submerge completely in the flow stream during normal flows. A typical scow level sensor with a 25.4 cm (10 in.) circular chart recorder sells for about $950. Bubble tubes require a continuous gas supply and are not therefore very well suited to remote or standby service, although they are being operated with a small air compressor or nitrogen tanks in some applications, and they have the virtue of relative simplicity. Selling for about $1100, the "dipper" level gage appears best adapted to portable uses where levels are to be gaged for comparatively short periods of time at multiple sites, as in infiltration studies. The ultrasonic level gage also sells for about $1100 and is suited to both portable use and permanent installations. Because of this versatility and its lack of need for physical or electrical contact with the sewage, it is the recommended method for level gaging in storm generated discharge projects. When evaluating storm generated discharge treatment processes many of the gages are applicable depending on the exact situation. It is expected that the bubble tube, float, scow (for flume measurements) and the ultrasonic level gage will all find various applications depending upon the sewer or treatment process configuration.

Flow Gaging

Gaging of sewage flow in storm and combined sewer systems is the single most important measured parameter for overflow characterization and control. As such, sewer flow gaging has been the subject for considerable R&D effort in industry, government and universities here and abroad over the last several years, and a number of new measurement methods have been developed. In earlier years, most flow gaging research was directed toward metering in full pipes, particularly for process industry applications. The added complexities associated with open channel hydraulics, entrained solids and irregular sewer wall features make sewage gaging a more difficult problem, one that has been less susceptible to successful solution by conventional instrumental techniques.

Sewage flow is most commonly gaged using weirs (rectangular, V-notch, Cipoletti) and venturi flumes (Parshall, Palmer-Bowlus). Discharge through these structures is gaged in terms of the head over the structure, which is in turn measured by means of the level sensing devices described in the preceding section. Relationships between discharge and head for these structures are generally a power law function and are described in the general engineering literature. Many level gaging devices are available which automatically generate linearized flow information based on weir or flume depth measurements using electrical or mechanical function generators. In uniform sewers with a straight section at least 100 m (300 ft) long, relatively steady flow can be estimated from the slope of the sewer and sewage depth using the Manning formula. However, the sewer length chosen must be free of sudden expansions, contractions or drops and must have a uniform wall roughness. Because of the difficulty in satisfying the criteria for application of the Manning formula, it is seldom possible to compute flow much better than about 10% by this method. A properly applied weir or flume under free flow conditions on the other hand, can provide flow measurement accuracies of three to five percent.

Full pipe raw sewage flows are being measured successfully by electromagentic meters. A drop into a U-shaped configuration in the sewer line, typically at a treatment plant inlet, is used to obtain full pipe flows. Also tracer and chemical dilution techniques are in use for intermittent measurement.

Several new flow gaging methods for sewage applications have been advanced in recent years. These include open channel flow velocity gaging using ultrasonic techniques and electromagnetic techniques. The new activity in seeking improved sewer flow gaging technology has been stimulated by a growing need for gaging in connection with infiltration, inflow and overflow studies, and automatic remote control flow routing.

planning, justification, design and operation of added treatment plant and sewage collection system capacities, and are of direct importance in storm generated discharge considerations.

Weirs and Venturi Flumes - Weirs and flumes are flow structures designed to provide a known, repeatable relationship between flow and depth. Upstream flow is backed up due to the structure's contraction of the channel. The structure has a regular shape chosen to provide a convenient function relating flow and depth, e.g., rectangular weirs, trapezoidal weirs, and Parshall flumes: approximately 3/2 power law; V-notch weir: 5/2 power law. The chief disadvantage of the weir relative to a flume is its higher headloss and greater tendency to collect settled solids and debris upstream of the weir bulkhead.

In the case of flumes, there is only a slight depression in the floor of the flume, so most debris is carried right through, thereby minimizing cleanout requirements. A dual-range (or nested) Parshall flume is pictured in Figure V-7.

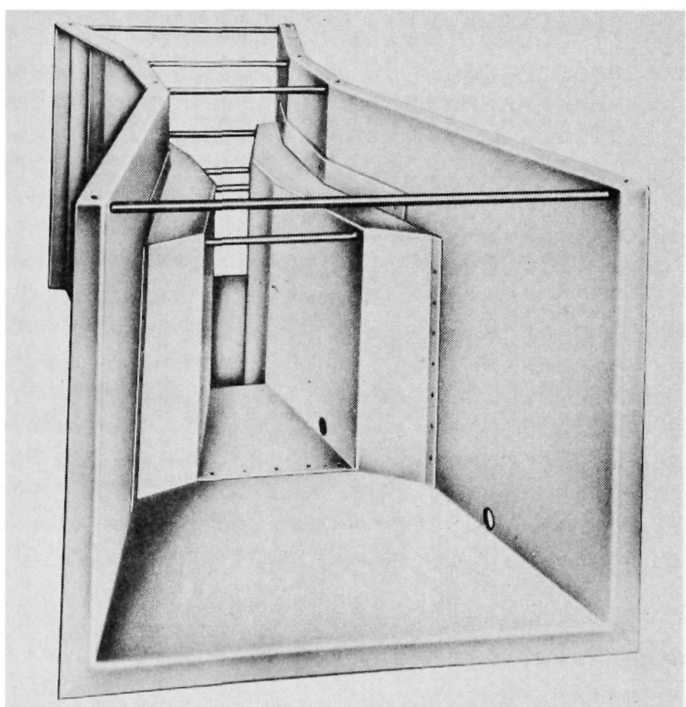


Figure V-7. Dual range Parshall flume
(courtesy Fischer & Porter Co.)

This flume is designed for application where there is a sizeable difference between initial and ultimate flow rates as occurs in sewers subject to storm flows. Flow is initially gaged by measuring head over the small flume. When this flume's capacity is exceeded, it is removed and the outer flume is used. A disadvantage of the Parshall flume in sewer manhole installations is its relatively long converging approach section and diverging head recovery section which require a sizeable laying length. A number of shorter form flumes have been introduced which can be more conveniently installed in manhole accesses (the Palmer-Bowlus flume). An example is pictured in Figure V-8.

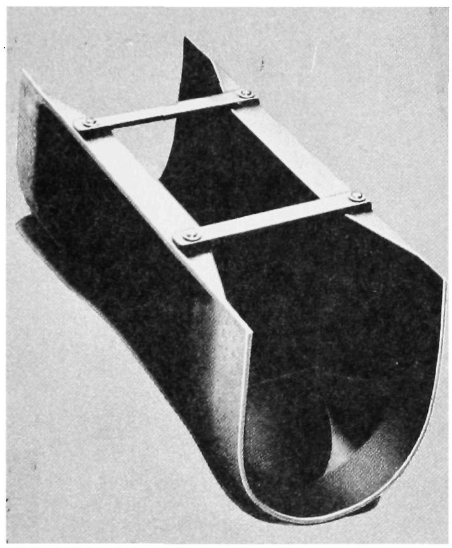


Figure V-8. Lagco flume
(Courtesy F. B. Leopold Co. Inc.)

Flow from a line discharging from above into a lower receiving stream can be metered using a weir, an open flow nozzle or an H-flume. The H-flume (Plasti-Fab Inc.) has a wide flow range, e.g., a 0.8 m (2.5 ft) flume handles flows from 0.05 to 30 cm/min (0.03 to 17.6 cfs) with accompanying head range of 0.03 to 0.75 m (0.1 to 2.4 feet).

Linear Flow Indication from Weirs and Flumes - Head, H over a weir is usually measured a distance $4H_{max}$ upstream from the weir. Head over a Parshall flume is measured at a point 1/3 of the distance into the converging section. Head measurement pressure ports are visible in Figure V-7. Head measurements in the Palmer-Bowlus and Lagco flumes are measured just upstream of the circular to trapezoidal or circular to rectangular transition section. These heads can be measured by any of the variety of level gages described in the last section. Some manufacturers provide flumes with built in bubble tubes, capacitance level gages or ultrasonic level gages. The measured depth generally has a power law relationship to flow rate, so some sort of linearizing device must be used to extract linear flow rate information from the head measurement. Pictured in Figure V-9 is a float actuated flow computer which uses a characterized cam for converting head to flow rate. The float measures level in a stilling well which is conversant with the bottom of the stream at one of the measurement points mentioned above. The float cable drives a drum and the cam is rotated by the drum. Cam rise is linear with flow rate and may be used to drive a recorder or indicator via a cam rider and linkage, or it can be integrated to register totallized flow. Note the counter in Figure V-9.

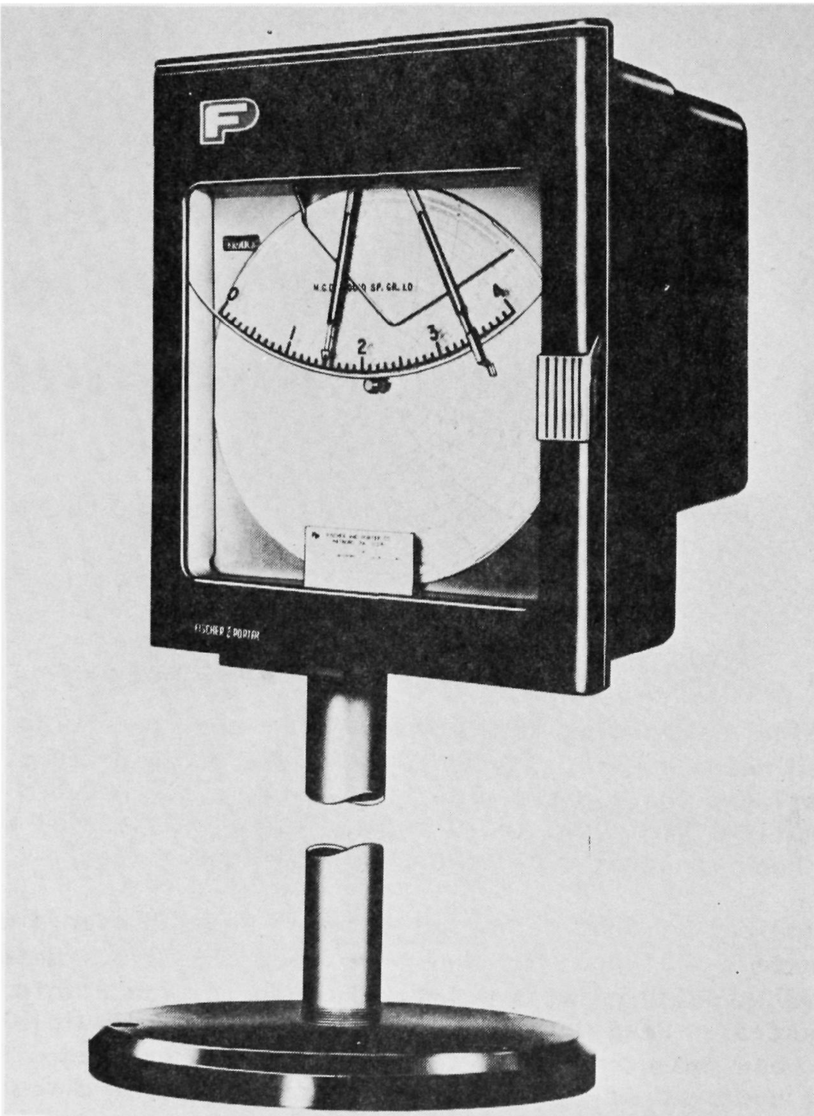


Figure V-9. Float actuated flow recorder
(courtesy Fischer & Porter Co.)

A similar flow computer actuated by an in-stream flow scow is pictured in Figure V-10. This device can be mounted directly on top of a flume structure or adjacent to a flow channel upstream from a weir.

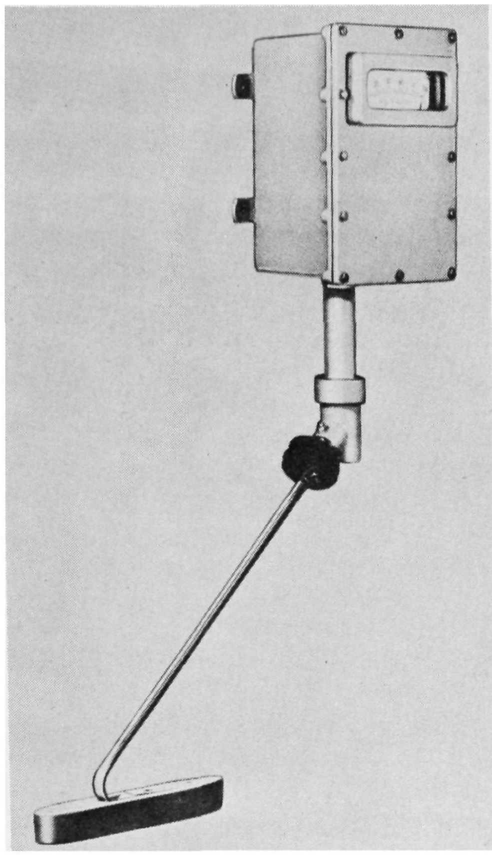


Figure V-10. Scow actuated flow indicator
(courtesy Fischer & Porter Co.)

Parshall flumes are available with bubble tubes built in to a vertical depression in the side wall of the converging section 2/3 of the way upstream from the entrance to the flume throat. A dished bottom section in the flume floor is provided for bubble egress. A portable bubbler unit for flow measurements on weirs or flumes is pictured in Figure V-11. In this device the bubbler gas is supplied from freon cylinders and flow linearization is performed electronically. Various flume and weir level to flow relationships can be accommodated using dial adjustments, and accuracy is given as within ±2% of the theoretical curve for the structure in use.

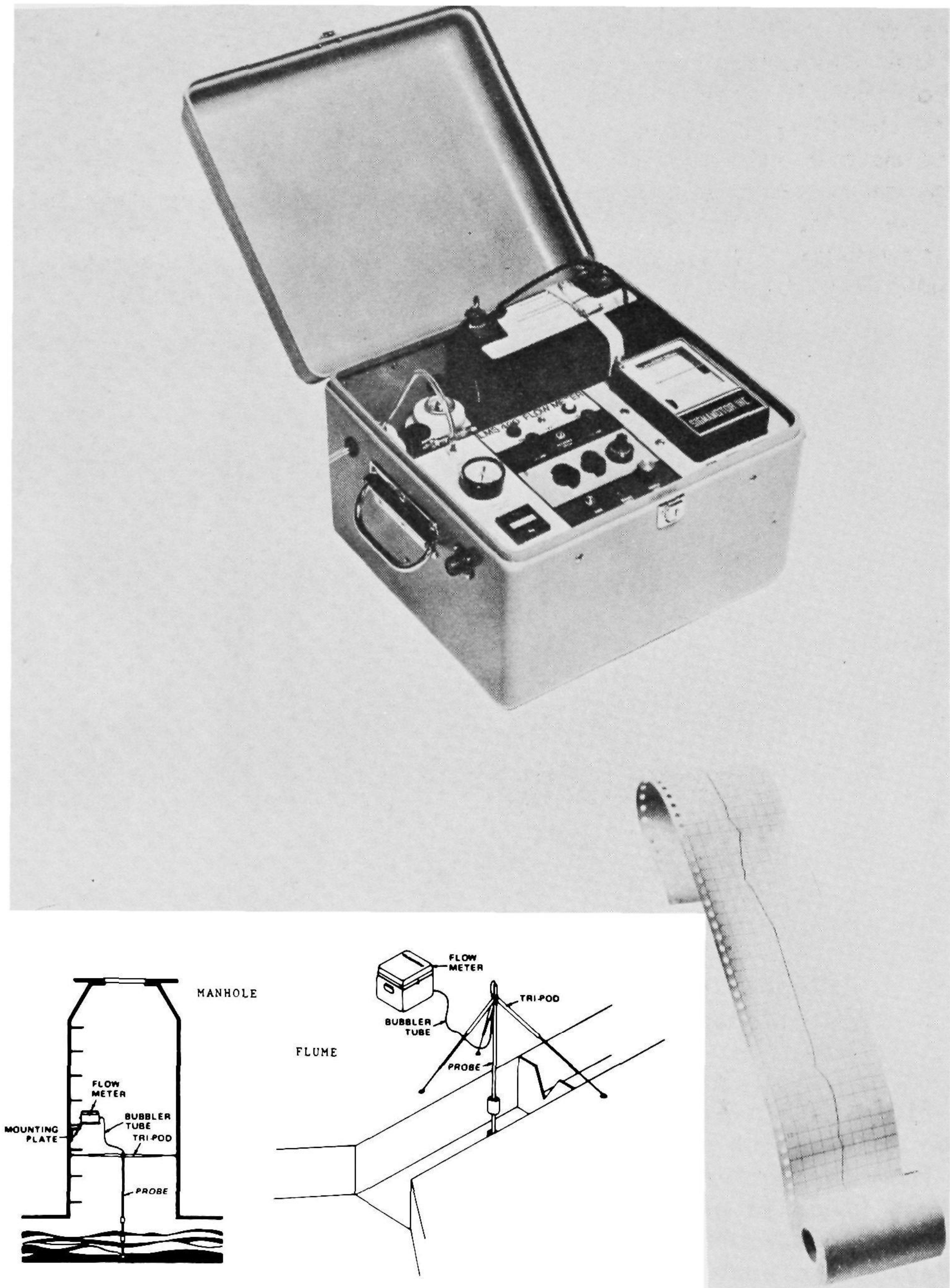


Figure V-11. Portable bubbler actuated flow recorder and totallizer (courtesy Sigmamotor, Inc.)

The conductivity or "dipper" type of level gage has also been adapted to flow gaging. Figure V-12 and V-13 are respectively the dipper level transmitter and total flow computer. A battery operated portable unit incorporating the functions of the transmitter and computer is pictured in Figure V-14. The dipper transmitter is mounted above the flume or weir at the appropriate head measurement position, and a signal proportional to level is transmitted to the flow computer. In the total flow computer, the flow equation is characterized digitally in a plug-in read-only memory unit which generates an output signal which is linear with flow rate. In the portable unit, Figure V-14, linear flow information is generated by means of an electronic servo. Accuracy for the dipper transmitter is stated as: linearity ±1% of reading; repeatability ± 0.003 m (0.01 feet) and resolution ±0.5% of full scale.

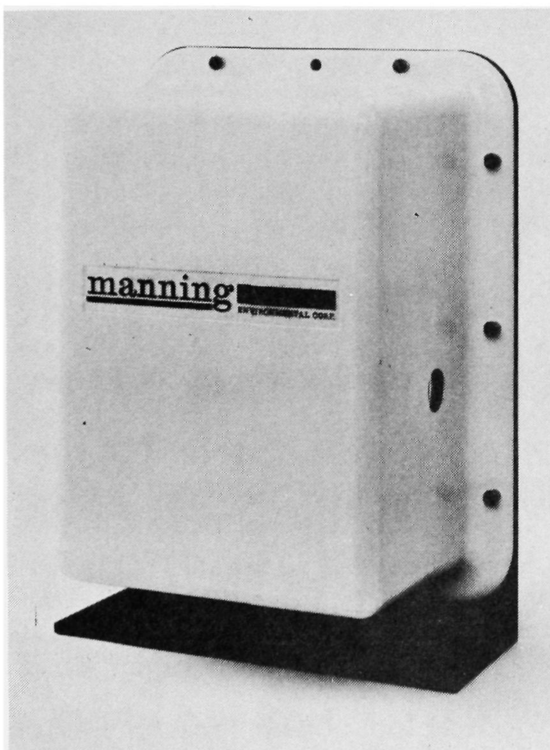


Figure V-12. Dipper level transmitter (courtesy Manning Environmental Corp.)

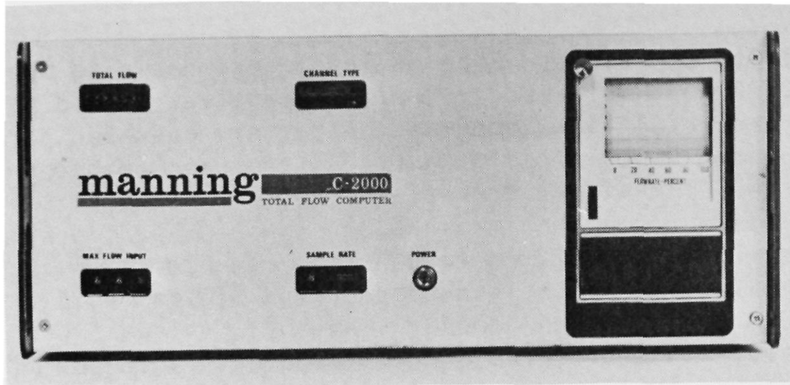


Figure V-13. Total flow computer-dipper system (courtesy Manning Environmental Corp.)

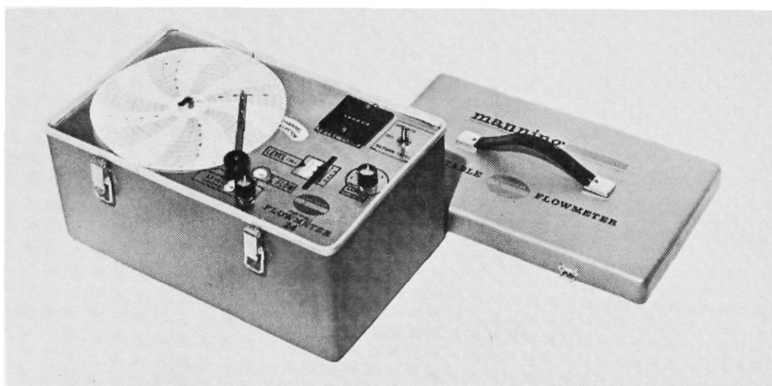


Figure V-14. Portable flowmeter-dipper system (courtesy Manning Environmental Corp.)

Level over a flume or weir measured ultrasonically is converted to flow rate in the instrument pictured in Figure V-15. Flow linearization is performed with solids state electronics in this instrument, and resolution, repeatability and linearity are each given as within 1%.

Another technique for generating linear flow information from a flume is the use of a characterized capacitance element mounted within a depression in the flume wall or molded within the flume wall itself. The shape of the capacitance element is designed to provide a capacitance change with changing head which is directly and linearly proportional to flow through the flume. Associated indicating and recording circuitry can therefore be linear.

Effects on accuracy of buildups of grease or other materials on the probe if in contact with the sewage stream can apparently be minimized by measuring the admittance of the sensing probe (the "Comad" circuit, Drexelbrook Engr. Co.), rather than its capacitive impedance.

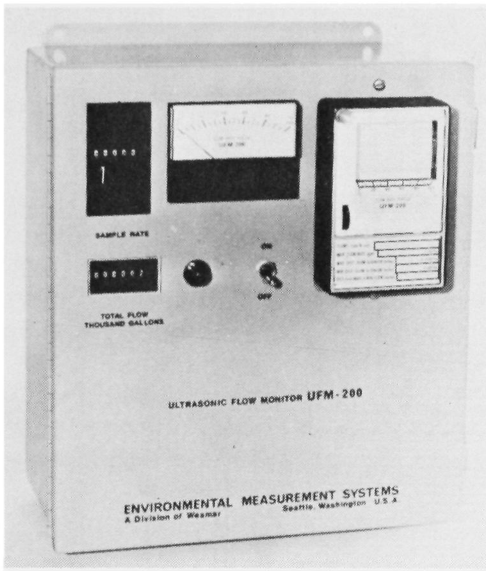


Figure V-15. Flow recorder, indicator and totallizer
actuated by ultrasonic level measurement
(courtesy of Environmental Measurement Systems Division of Wesmar)

Effects of Submergence and Surcharge on Flume Performance - When flow through a weir or flume exceeds a critical value, flow resistance in the downstream channel reduces the velocity, and backwater level begins to approach crest level. The ratio of backwater level to crest level is defined as submergence. Because of largely unknown effects of submergence on weir accuracy, weirs are generally operated in a free-flow, non-submerged condition. Flumes however retain acceptable accuracy in the presence of considerable submergence, i.e., with submergence ratios up to 70% in Parshall flumes 0.3 to 2.4 m (1 to 8 ft) wide. For submergences up to 95%, the Parshall flume can still be used for flow gaging if crest and backwater levels are both gaged, and the discharge calculation is adjusted as a function of the submergence ratio. The Palmer-Bowlus flume tolerates relatively higher submergence and has a shorter lying length than the Parshall flume, so it is recommended over the Parshall flume (and over weirs) when flows are within a flume's operating range.

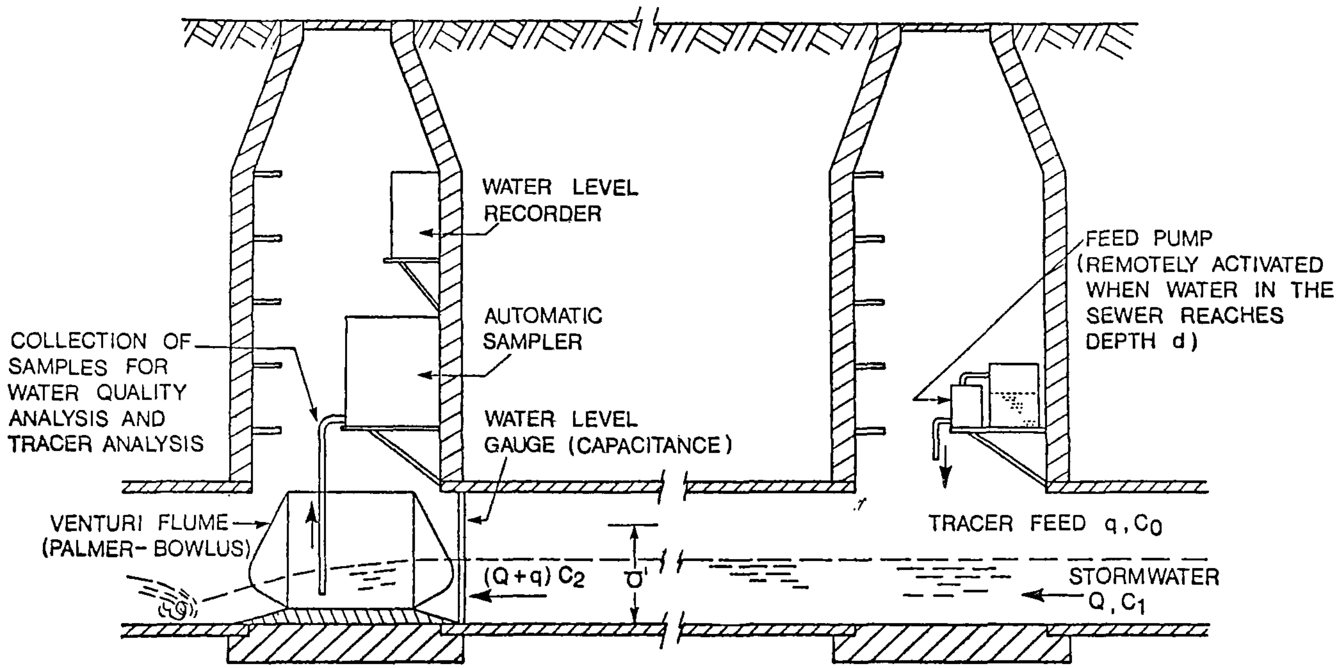


Figure V-16. Flume-tracer dilution combination for sewer flow gaging (courtesy J. Marsalek, Canada Centre for Inland Waters)

However, if a sewer is approaching a surcharged flow condition, the flume structure itself is submerged, and obviously can no longer be used for gaging. Surcharging occurs commonly in storm generated discharge measurements, as do rapidly changing flows, so a number of techniques have been advanced to maintain accurate measurement under these conditions. For example, the installation sketched in Figure V-16 combines a tracer dilution technique with a flume/capacitance level gage.

When the flume head measurement indicates that submergence is about to affect flume accuracy, an upstream tracer feed pump is turned on, and stormwater samples are collected at the flume for later analysis after the storm event. Tracer concentration in the samples carries the flow rate information.

Open Channel Flow Velocity Gaging - Another approach to circumventing flume submergence problems is to eliminate the flume structure and directly measure average stream velocity and depth instead. Flow can then be calculated automatically by multiplying average velocity by the cross-sectional area of the flow stream. One such system based on ultrasonic measurements of flow velocity and level was demonstrated in several sewers in Milwaukee under U.S. EPA sponsorship. Pictured in Figure V-17 is an open channel installation, the 2.44 x 3.05 m (8' x 10') main influent channel at the Milwaukee Jones Island Wastewater Treatment Plant.

Figure V-17. Ultrasonic flow velocity and level gaging on a raw sewage channel, (coarse screened) (courtesy Badger Meter Inc.)

Ultrasonic transceivers are located obliquely opposite each other on opposite sides of the channel wall at a depth equal to about 40% of the mean stream depth. Bursts of ultrasound are first sent in the downstream direction from one transceiver to the other, with the reception of each pulse triggering the transmission of the next. Moving generally downstream, the propagation of the pulses is aided by the motion of the stream. The "singaround" or pulse repetition frequency established thereby is counted for a fixed time period. Then pulses are transmitted upstream generating a lower singaround frequency, and are counted for the same fixed period. The difference between the upstream and downstream singaround frequencies is directly proportional to the velocity of the liquid averaged over the imaginary line connecting the two transceivers, and is independent of the velocity of sound in the measured liquid. Depth is measured using a conventional ultrasonic level gage, and the velocity times area multiplication to calculate flow is performed electronically, and indicated, recorded and totallized. Flow measurement accuracy is in the three to five percent range. Installation of ultrasonic velocimeter transceivers on the walls of a circular sewer is pictured in Figure V-18. A single pair of transceivers

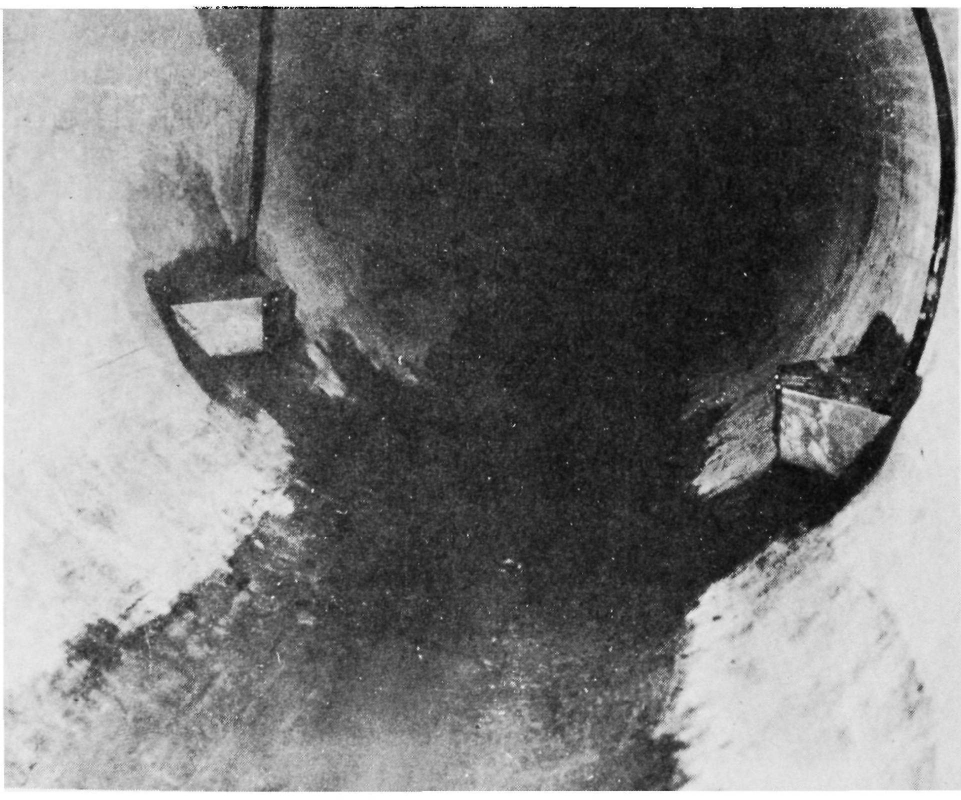


Figure V-18. Ultrasonic velocimeter probes installed on inside surface of a sewer wall (courtesy Badger Meter Inc.)

is customarily used, placed at a level corresponding to 25% to 40% of maximum flow. At low flows when the transceivers are close to the surface, the Badger unit automatically reverts to a flow calculation based on level only (Manning's equation). This is a reasonably good approximation because flow more nearly reaches free flow conditions for low depths.

The electromagnetic flow measurement technique is based on the fact that the motion of a conductive liquid in a magnetic field will generate a voltage in the liquid which is proportional to flow velocity and in a direction orthogonal to the field and flow directions. Embodiments of this principle in flow gages suited to open channel gaging are pictured in Figures V-19 and V-20.

The pitot-style transducer in Figure V-19 is 25.4 cm (10 in) in diameter and has AC field coils built into its cylindrical wall which generate a vertically oriented, sinusoidally varying magnetic field. The output voltage sensed by electrodes in the horizontal plane is a flow modulated carrier in which the amplitude is proportional to flow velocity. Stated accuracy is ±0.5% for maximum flow velocities between 0.92 and 9.5 cm/sec (3 and 31 ft/sec) flowing through the sensor, and ±1% for maximum velocities between 0.305 and 0.92 cm/sec (1 and 3 ft/sec).

A smaller electromagnetic velocity sensor is pictured in Figure V-20. The probe wand shown in the figure foreground incorporates a solenoid which generates an internal magnetic field parallel to the probe axis and an external field which is circularly symmetric about the probe axis. One or two sets of electrodes are mounted in the probe, each of which

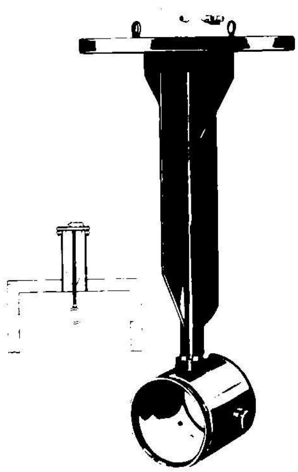


Figure V-19. Pitot-type electromagnetic flowmeter transmitter (courtesy Fischer-Porter Inc.)

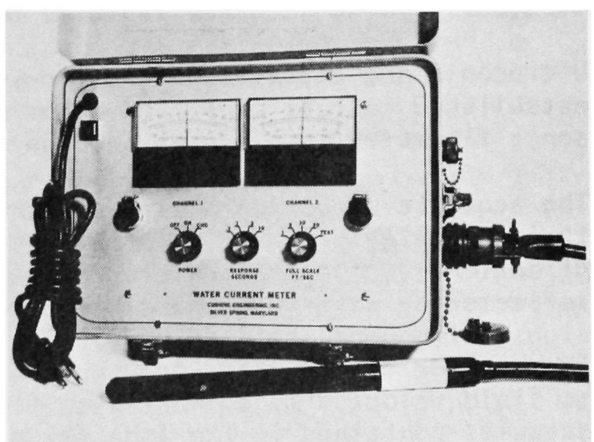


Figure V-20. "Velmeter" electromagnetic flowmeter transmitter and indicator (courtesy Cushing Engineering Inc.)

picks up an output signal proportional to the flow component which is perpendicular to the plane formed by the axis of the electrode pair and the probe axis of symmetry. With two electrode pairs, two components of flow velocity are measured simultaneously. Full scale velocities are selectable between 0.092 and 9.2 cm/sec (0.3 and 30 ft/sec). Linearity is stated as ±1% of full scale and zero flow offset as 0.003 m/sec (0.01 ft/sec). The instrument measures liquid velocity in the immediate vicinity of the probe, and traversals can be made to measure average area velocity.

In each case, the flow sensor represents an obstruction to flow, and liquid level must be measured by other means to determine total flow.

Sewage Flow Gaging in Full Pipes - A great many different types of flow meters are available for gaging in full pipes, but few are well suited to continuous or even intermittent measurements on sewage because of entrained debris and grease. An adaptation of a propeller which has been applied in New York for intermittent sewage gaging in manholes is sketched in Figure V-21.

An outer housing is wedged in place at the bottom of the manhole sealing the sewer inlet to the housing. Then a hinged flap gate is lowered into the housing causing the housing to fill and overflow onto the manhole floor and into the manhole outlet. Finally, the propeller flow element mounted within a cylindrical flow guide is lowered into the housing. The flow guide is completely submerged in the flowing sewage, and all flow passes through it, so the propeller is operating in a full pipe of known cross-section, and so that it can be calibrated directly in units of flow volume. The unit, pictured in Figure V-22, can be moved between similar manholes, and total installation time is said to be under three minutes. Stated accuracy is three percent on totallized flow.

Ultrasonic and electromagnetic flow gaging techniques are well established in full pipe flow metering applications. A Doppler ultrasonic flowmeter is pictured in Figure V-23.

The acoustic probe containing two transducers is positioned in the flow. It is normally oriented to point upstream, although the probe is bidirectional. One transducer projects an acoustic signal, which is reflected by waterborne particles and disturbances. The reflected signal, frequency shifted proportionally to the velocity of the fluid, is received by the other transducer. An electrical signal proportional to fluid velocity is converted to flow rate by means of processing circuits contained in the indicating receiver. The actual point of intersection of the two beams is 0.305 m (one foot) upstream from the probe, so that measurements are made in an undisturbed region of the flow field. Because the processing circuits are not sensitive to amplitude variations, the flowmeter is immune to changes in impurity concentration and peripheral noise.

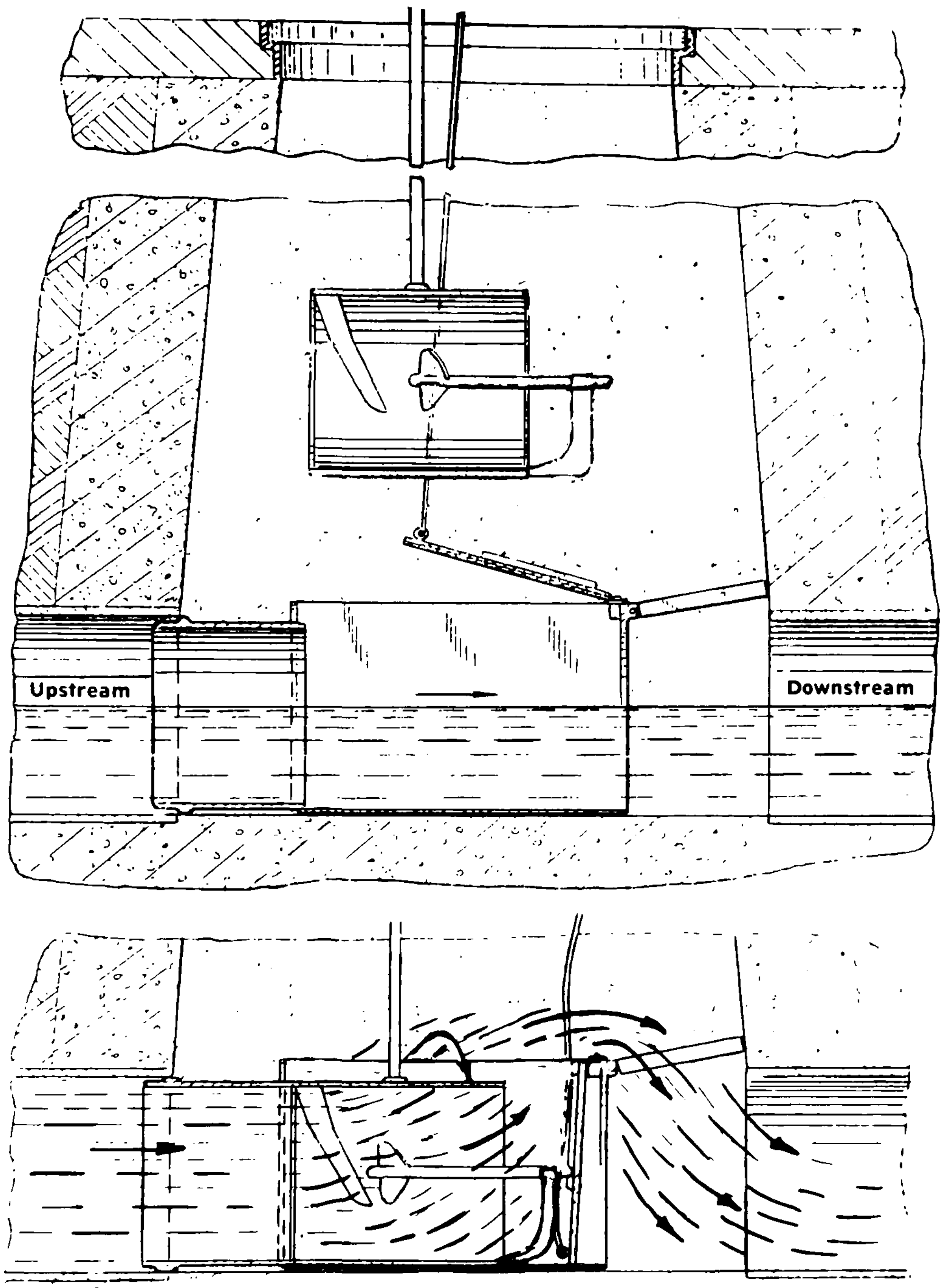


Figure V-21. Installation sketch, propeller meter for sewage flow gaging (courtesy Min-Ell Company Inc.)

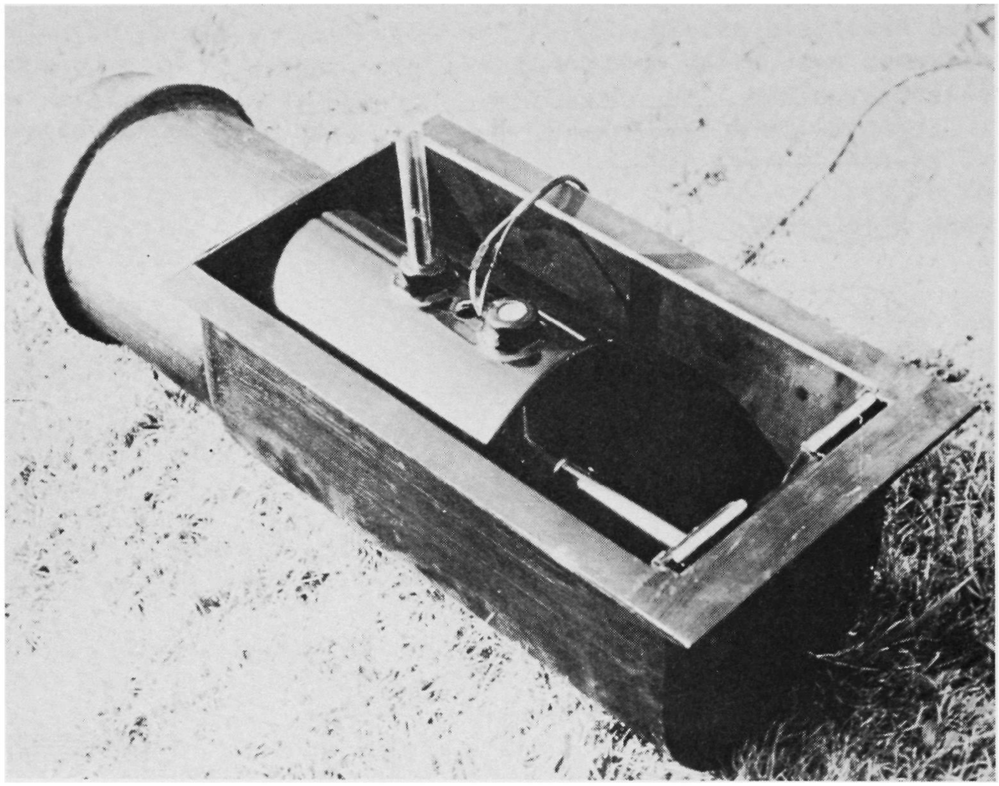


Figure V-22. Manhole insert housing and propeller meter for sewage flow gaging (courtesy Min-Ell Company Inc.)

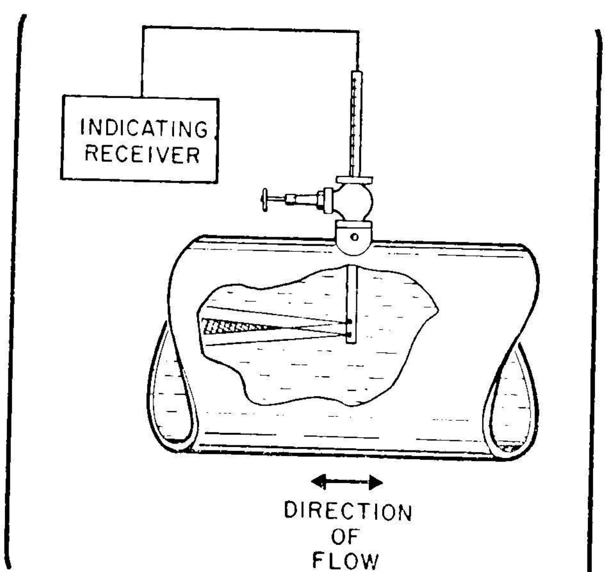


Figure V-23. Doppler ultrasonic flowmeter (courtesy Edo Corporation)

An automatic cleaning mechanism periodically withdraws the probe and reinserts it through wiping glands to remove any accumulated deposits. A portable version of this flowmeter is pictured in Figure V-24. Both units are designed for service in pipes from 0.15 to 2.4 m (0.5 to 8 ft) in diameter, measuring flow velocities between 0.03 to 4.6 m/second (0.1 to 15 ft/second) with a stated accuracy of 1.5%.

In Japan, a flowmeter of this general design has been successfully applied to measurement of biological sludges from clarifiers.

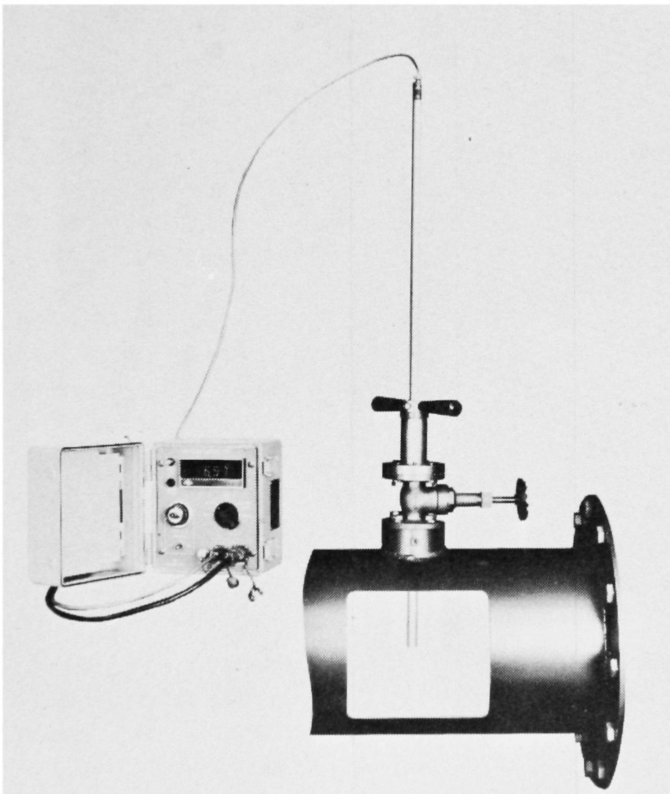


Figure V-24. Portable doppler ultrasonic flowmeter (courtesy of Edo Corporation)

The electromagnetic flowmeter (Figure V-25) is in fairly widespread use for sewage flow gaging in permanent, full pipe installations in diameters from 0.15 to 2.4 m (0.5 to 8 ft). Because the measurement is dependent upon sensing a voltage induced in the stream, it is essential that the pick-up electrodes be kept free of insulating deposits such as grease. Various methods of electrode cleaning have been employed by the manufacturers of this type of meter including mechanical scrubbers, heaters and ultrasonic cleaners. Stated accuracies are ±4% at 0.15 m/sec (0.5 ft/sec), ±2% at 0.3 m/sec (1 ft/sec), ±1% at 0.6 m/sec (2 ft/sec) and ±0.5% at flow velocities from 1.22 to 7.62 m/sec (4 to 25 ft/sec).

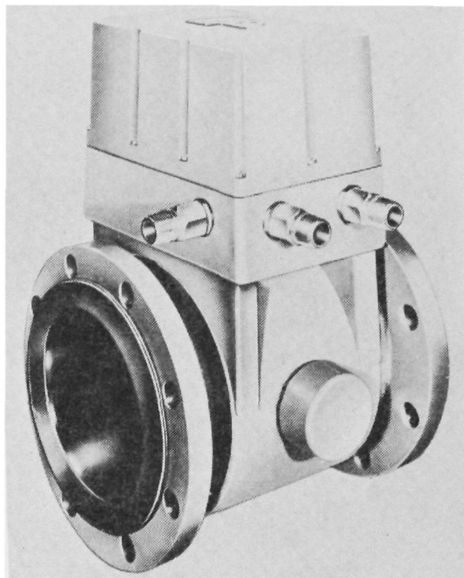


Figure V-25. Electromagnetic flowmeter for full pipe application (courtesy Fischer & Porter Company)

The singaround type ultrasonic flowmeter described earlier is also used in full pipe gaging applications. The meter pictured in Figure V-26 makes use of ultrasonic transceivers strapped to the exterior surface of the pipe wall. Deposits on interior pipe walls have not caused difficulties. Although flowmeters of this type were not extensively used in this country until recently because of circuit complexity and cost, several hundred are in service in Japan and Western Europe.

The use of modern electronic integrated circuits has markedly reduced the cost and improved the reliability of the ultrasonic flowmeter. The signal processing circuitry of one such meter is pictured in Figure V-27. Stated accuracy and resolution are ±1% of full scale, and bi-directional flows can be metered.

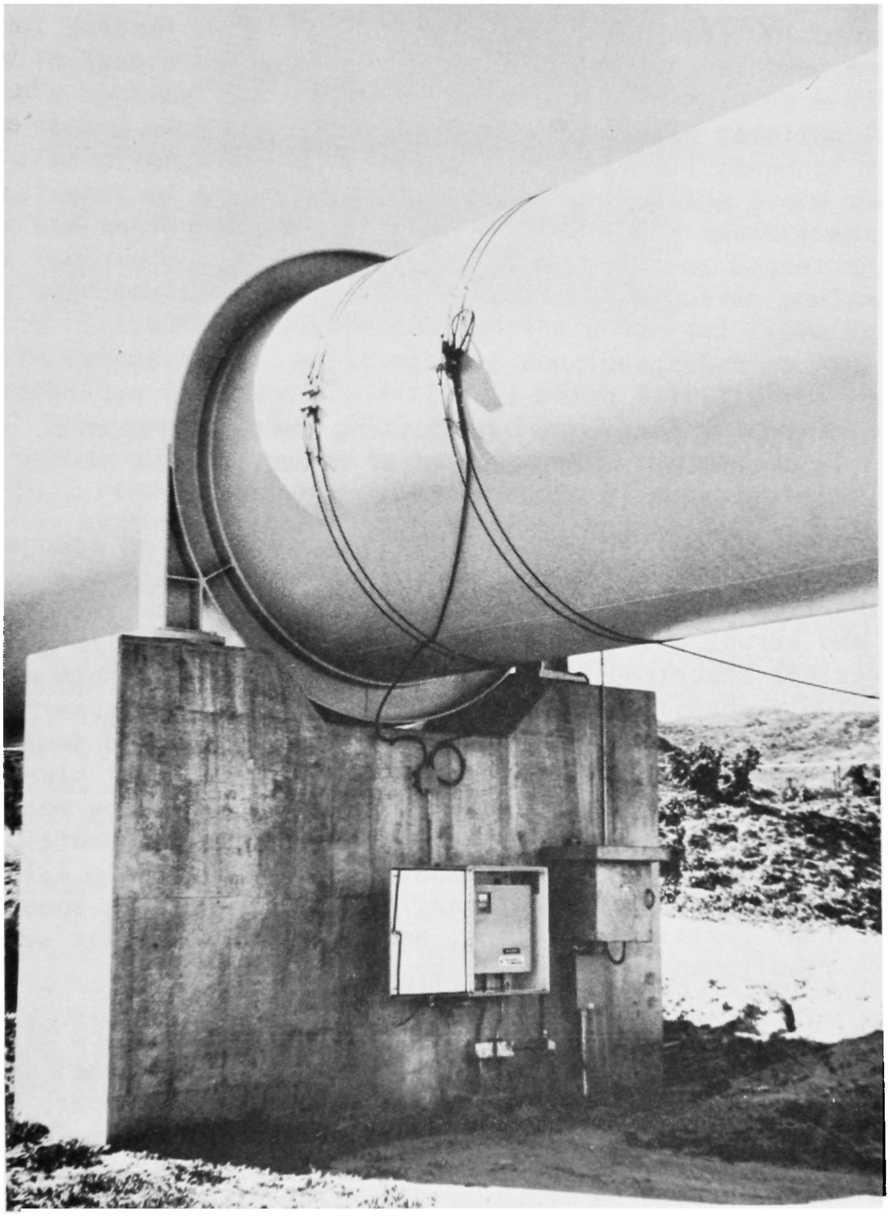


Figure V-26. Ultrasonic flowmeter for full pipe applications (courtesy Badger Meter Inc.)

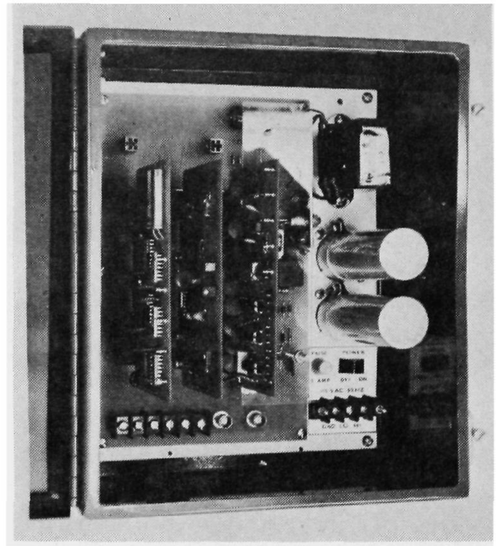


Figure V-27. Signal processing unit, ultrasonic flowmeter (courtesy Badger Meter, Inc.)

Summary, Comparison and Recommendations - Achievement of accurate flow gaging in a combined sewer system during and after a storm event requires the flow gages to perform accurately over flow ranges as high as 100:1, and abrupt changes in flow rate and level. While many of the metering devices described in the preceding sections perform well in measuring slowly changing dry-weather sewage flows, their performance suffers during storm flows. Ideally the flow gage should continue to function accurately from minimum dry-weather flow to full pipe, surcharged conditions. This requirement would clearly not be met by flumes or weirs which are totally submerged during surcharged conditions, nor by full pipe flowmeters which cannot handle flow in partially filled conduits. This ideal requirement can, however, be met by some of the techniques under certain conditions, and less stringent but still useful performance requirements can be met by others.

For example, if the hydraulics of a particular installation allowed flow to be gaged sufficiently accurately by means of level alone, using the Manning equation, and if the level probe (ultrasonic, dipper, bubbler, scow, float-drywell) had sufficient range to encompass the full pipe measurement, flow could be gaged over its entire range. Also, if flow average velocity were to be measured with sufficient accuracy, say by a multiplicity (three pairs) of ultrasonic transceivers, and flow area by an ultrasonic level gage, then flow could be measured over the entire range by multiplying velocity by area.

Another technique researched at the University of Illinois is a flume structure designed to generate a head differential useable for gaging under both partially filled and full pipe, pressure flow conditions. The structure consists of cylindrical segments whose diameter is smaller than that of the sewer, and which are attached to the sides of the sewer, leaving the invert and crown clear. It functions as a critical depth flume under open channel flow, producing critical flow and functions as a conventional Venturi meter under full flow conditions. Although demonstrated in laboratory scale, this method has not yet been evaluated in a full scale application on sewage. The method combining a flume for open channel flows, with automated tracer dilution and sampling for storm flows also offers flow information over the full range of flows, although attainment of adequate information rate for the storm event may well require the taking of a great many samples. The measurement based on Manning's formula could likely provide accuracies no better than 10%, the combined ultrasonic velocity/area measurement requires equipment costing in the $12,000-$18,000 range, and the universal flume has not yet been fully demonstrated, so it must be concluded that no generally applicable technique is presently available which fulfills the ideal requirement. However, as costs for ultrasonic signal processors continue their trend downward, this method appears to have the potential for meeting the full range of metering requirements at acceptable cost. It has the further advantages of no moving parts, and no requirement for electrical contact with the flow stream. The method seems well suited to measurements on grease and debris laden sewage, and for extended life in the sewer environment. A limitation of singaround type ultrasonic velocimeters is their susceptibility to entrained air bubbles. An excessive concentration of bubbles renders the stream opaque to ultrasound and the velocimeter inoperative. Accordingly the transceivers must be installed at sites where flow is fairly quiescent and sufficiently downstream from sidestreams falling into the main stream from above. Whether they would continue to function at most sites under the effects of agitation and air entrainment due to multiple stormwater inflows remains to be demonstrated.

In sewers not subject to surcharging where hydraulics allow the Palmer-Bowlus flume to operate within acceptable submergences, these structures are fully suitable, and flow head can be measured by any of the level gages described in the preceding section. The recommendations made there apply also when they are used for level gaging in flow measurement applications.

IN SITU MONITORING EQUIPMENT

There are two general categories of instruments suited for continuous, in-situ analysis of water quality parameters: those that make use of an in-stream sensor incorporating an optical, electrochemical, ultrasonic or electronic sensing device, and those that require the pumping of a side stream to a close-by analyzer which employs electrochemical,

chemical/photometric, oxidation, respirometric, optical, biochemical or other automated analytical methods. Parameters for which there are available commercial in-stream sensors are the following:

Chloride	pH
Conductivity	Salinity
Dissolved Oxygen	Suspended Solids
Fluoride	Turbidity
Nitrate	Temperature
Oxidation Reduction Potential	

Water quality parameters for which there are available commercial side-stream analyzers are:

Acicity	Silica
Alkalinity	Silver
Ammonia	Sodium
Ammonia Nitrogen	Sulphide
Biological Respiration	Sulphite
Bromide	TC
Cadmium	TOC
Chromate	TOD
COD	Total Chromium
Copper	Turbidity
Cyanate	Total Hardness
Cyanide	Nitrite
Iodide	Oil
Iron	Orthophosphate
Lead	Residual Chlorine
Suspended Solids	

The key chemical and biological measurements to be made regularly on storm generated discharges as recommended in Section VI include potential oxygen demand (TOD and BOD_5), particulate concentration (suspended solids), a pathogenic indicator (fecal coliform), and eutrophication potential (NO_2, NO_3, TKN and TP). Several of the in situ monitors listed above are in these general measurement categories, and a number of others can be used to monitor specific parameters known to be important at particular sites.

Potential Oxygen Demand

The TOD analyzers pictured in Figures V-28 and V-29 function by completely oxidizing the entrained oxidizable matter in a sewage sidestream and measuring the amount of oxygen depleted in the reaction. The analyzer pictured in Figure V-28 makes use of a 4 ml/min sidestream pumped to the unit where it is combined with a metered air stream. The mixture is delivered to a reaction chamber maintained at 850° C, and the combustion products then enter a liquid/gas separator where condensible vapors are

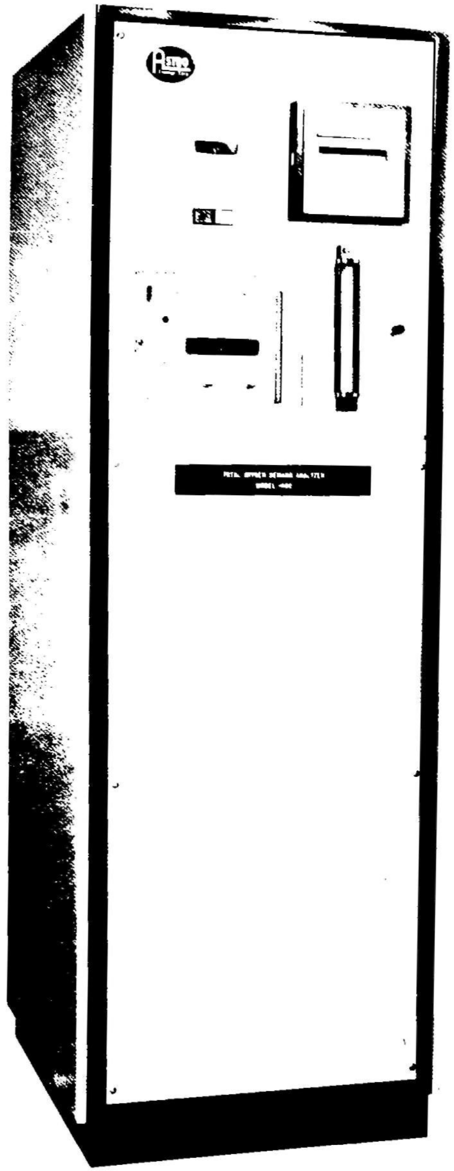


Figure V-28. TOD analyzer (courtesy Astro Ecology Corp.)

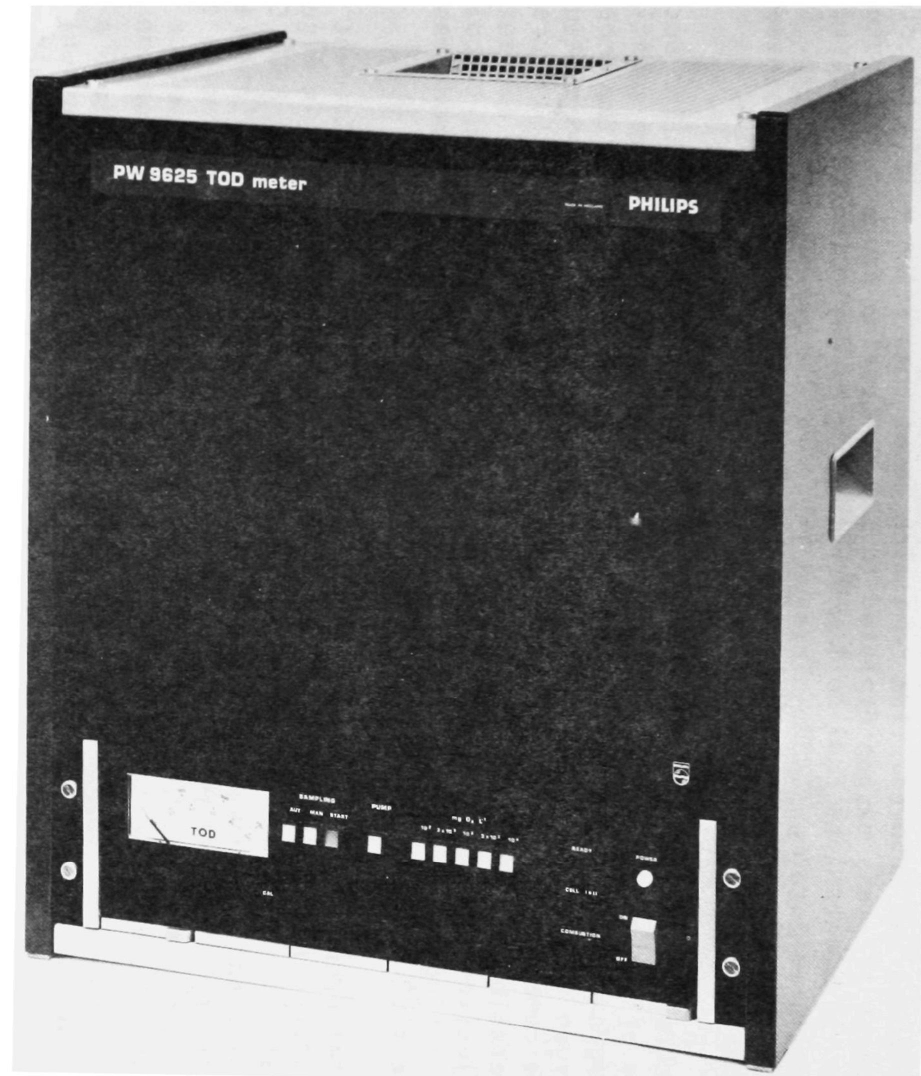


Figure V-29. TOD analyzer (courtesy Phillip, Holland) condensed and removed. The remaining gases consisting mainly of original metered air less oxygen depleted in the combustion process are routed to a solid electrolyte fuel cell where the oxygen depletion is measured and translated into mg/l TOD. This unit has TOD ranges from 0-100 to 0-20,000 mg/l full scale, has a ten minute response time, and stated repeatability is ±2% of full scale.

The TOD analyzer pictured in Figure V-29 is functionally similar but makes use of two zirconium oxide cells, the first to impart a known quantity of oxygen to a nitrogen carrier gas, and the second to restore the amount of oxygen to its original level and thereby measure the amount depleted in the combustion reaction. Sample size in this instrument is 10 microliters. Operation can be made stepwise continuous by means of a pump and automatic injection device. TOD ranges are 0-100 up to 0-10,000 mg/l full scale, measuring cycle in five minutes, and stated accuracy and reproduceability are ±10% of full scale.

Total organic carbon can be measured continuously by the instrument pictured in Figure V-30 and in discrete samples by the unit in Figure V-31. Total carbon is measured by oxidation of the sample at 850° C and subsequent measurement of the resulting carbon dioxide by an infrared analyzer. To measure TOC, the sample is first acidified to remove the inorganic carbon prior to combustion (Figure V-30). A second method is to measure the carbon content of the CO_2 released due to acidification and subtract this measurement from the measured total carbon to yield a measure of organic carbon (Figure V-31). For the Astro Ecology unit, sample flow is 4 ml/min, stated repeatability is ±2% of full scale, response time is five minutes, and full scale ranges vary from 0-25 to 0-5000 mg/l of carbon. In the Beckman unit, sample size is 250 microliters, response time is two to four minutes per sample, full scale ranges vary from 0-5 to 0-4000 mg/l of carbon, and stated repeatability is ±2% of full scale from 50 to 4000 mg/l of carbon and ±5% at 5 mg/l carbon.

Dissolved oxygen can be measured continuously by means of polarographic or galvanometric cells. One galvanometric type pictured in Figure V-32 makes use of a lead anode and platinum cathode immersed in a potassium iodide electrolyte which is retained by a teflon membrane. Since teflon is permeable to gases, oxygen diffuses to the cathode at a rate that is proportional to the partial pressure exerted on the membrane by the oxygen dissolved in the liquid. The cell generates a galvanic potential of 0.5 volts and if the circuit is closed through a resistor, a current flows which is proportional to the rate at which oxygen is reduced at the cathode. This rate is proportional to partial pressure and the dissolved oxygen level at a particular temperature. As temperature decreases, oxygen partial pressure decreases for a particular dissolved oxygen concentration, and resistance to oxygen diffusion through the membrane increases. Both these effects reduce output current as temperature decreases, so temperature effects are compensated electronically

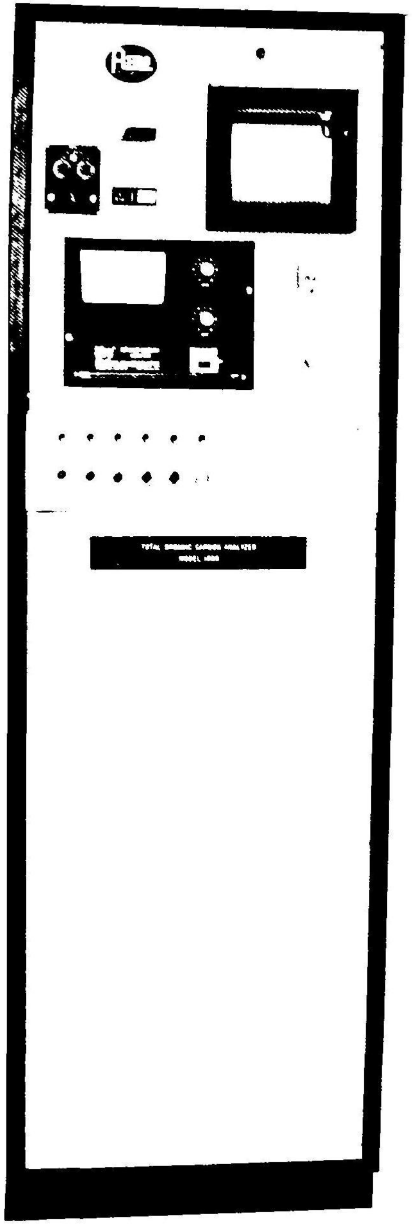


Figure V-30. TOC analyzer (courtesy Astro Ecology Corp.)

Figure V-31. TOC analyzer (courtesy Bechman Instruments, Inc.)

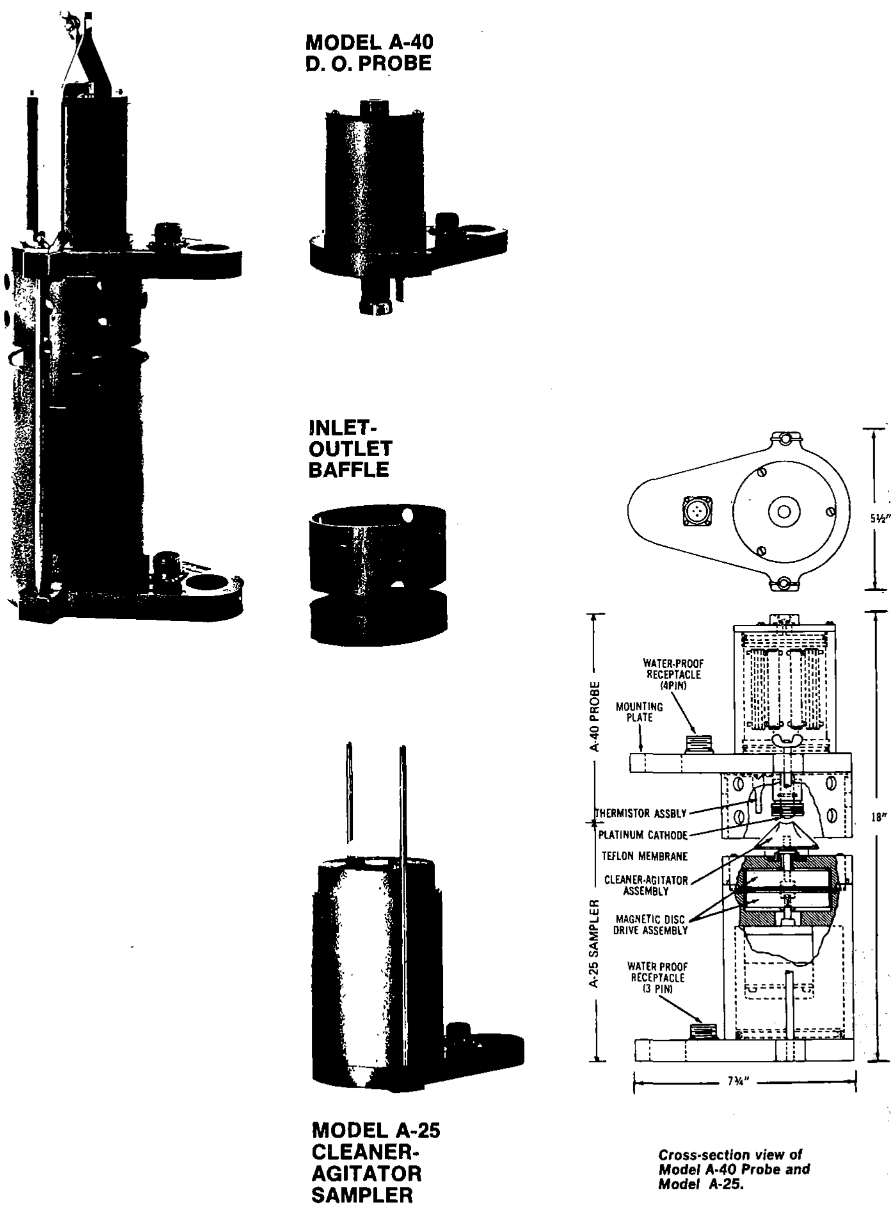


Figure V-32. Dissolved oxygen sensor
(Courtesy Rexnord Inc.)

based on a temperature measurement made with a thermistor. For a 1 mil membrane instrument response time is 30 seconds upscale and 90 seconds downscale. Ranges are available from 0-15 parts per billion to 0-15 parts per million, and stated accuracy is one percent of reading.

Particulate Concentration

A number of electro-optical instruments are available for measurement of turbidity, or suspended solids, some making use of an in-stream sensor, and others a side stream to the instrument. Pictured in Figures V-33, V-34, and V-35 is an instrument with a self-cleaning in-stream sensor that makes use of both measured light transmittance and light scattering to obtain a linear response and to eliminate color interference over a large range of suspended solids concentration. The probe is pictured in Figure V-33, the optical and self-cleaning features in Figure V-34, and the readout unit in Figure V-35. Various models of this instrument from 0-30 to 0-3000 mg/l suspended solids with a stated resolution of ±1% of full scale are available.

Another instrument developed under USEPA Contract No. 14-12-494 and now being demonstrated under USEPA Grant No. S802400 makes use of an incident beam of polarized light and measures the degree of polarization in light multiback scattered (150^{o}) from the incident beam. Earlier tests of this technique by American Standard Inc. on raw sewage and biological sludges inidcated that the method could be independent of particle size and color over useful ranges of solids loadings (53).

Turbidimeters which operate on a side stream are pictured in Figure V-36. The units pictured in Figure V-36 use a "surface scatter" principle where light scattered from an incident beam impinging on a liquid surface exposed at the top of an overflowing tube is measured with a photocell. Ranges for this instrument vary between 0-0.2 and 0-5000 nephelometric turbidity units. Side stream flow is 1 to 2 liters/minute (1/4 to 1/2 gpm), response time is 30 seconds, and standardization is performed with a standard reflectance plate having a fixed NTU value.

Eutrophication Potential

Nitrate concentration can be measured directly in the 10^{-1} M to 10^{-5}M range with a liquid ion exchange membrane electrode usually mounted in a side stream analyzer. Total organic nitrogen can be measured directly as ammonia with a gas sensing electrode after the sample is digested by the Kjeldahl method. Orthophosphate, nitrates and nitrites can all be measured instrumentally using automated wet chemical methods.

Monitoring of Other Specific Parameters

As mentioned earlier in this section, these are in-stream sensors available for pH, electrical conductivity, ORP, salinity, fluorides and

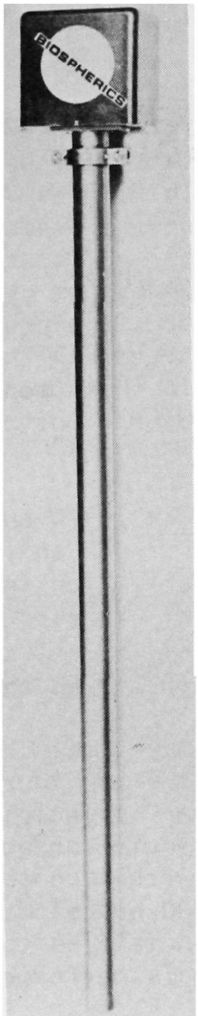


Figure V-33. Self-cleaning, submersible suspended solids sensor (courtesy Biospherics, Inc.)

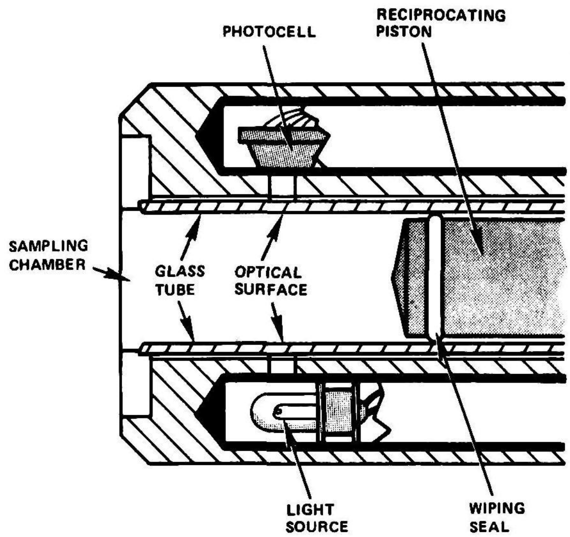


Figure V-34. Cross section of suspended solids sensing head (courtesy Biospherics, Inc.)

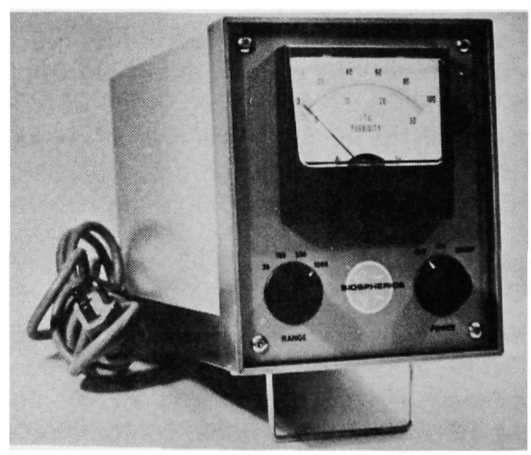


Figure V-35. Control unit for suspended solids monitor (courtesy Biospherics, Inc.)

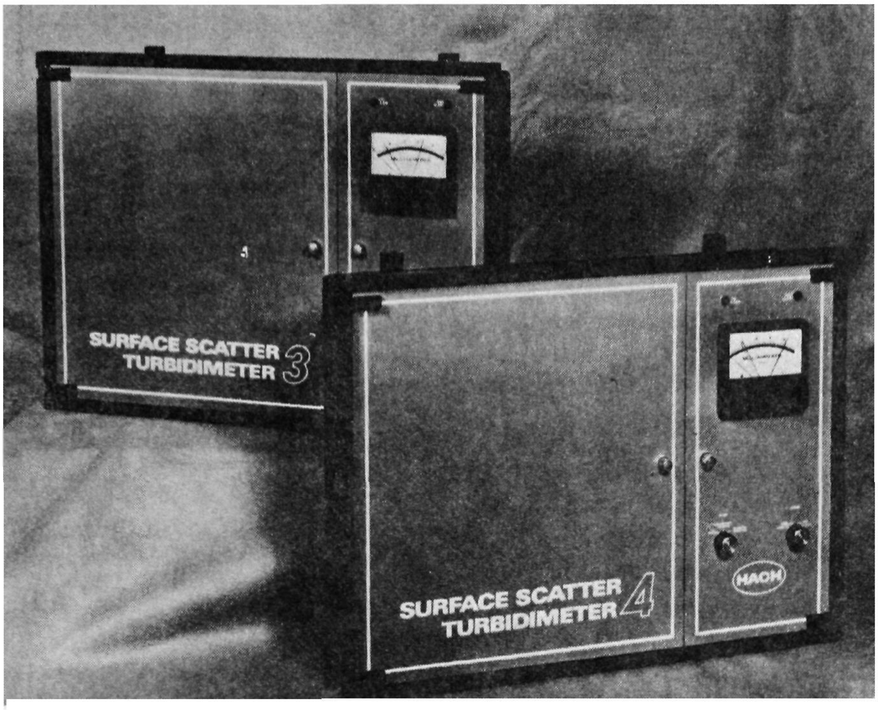


Figure V-36. Surface scatter turbidimeters (courtesy Hach Chemical Co.)

chlorides. Typical analyzers for pH and conductivity are pictured in Figures V-37 and V-38. A wide variety of in-stream, side stream electrode, and automated wet chemical analyzers are available for other specific parameters, e.g., oil concentration by ultraviolet absorption, oxygen demand by bacterial respiration, live cell concentration by bioluminescent reaction of ATP with luciferin and luciferinase, chemical and elemental ions by solid state, liquid, gas and flow-through electrodes.

In summary, of the water quality measurements on storm generated discharges recommended in Section VI, in-stream monitors are available for measurement of turbidity, suspended solids and nitrates, and side stream analyzers are available for TOC, TOD, orthophosate, nitrates and nitrites. Other in-situ monitors for parameters characteristic of particular storm generated discharges are also available. There continues to be a considerable need however for research, development and demonstration of new, more reliable, interference-free instruments, especially for organic loading, suspended solids, total phosphorus and pathogenic microorganism indication. Therefore, no in-situ measurements are recommended to replace any of the laboratory procedures recommended

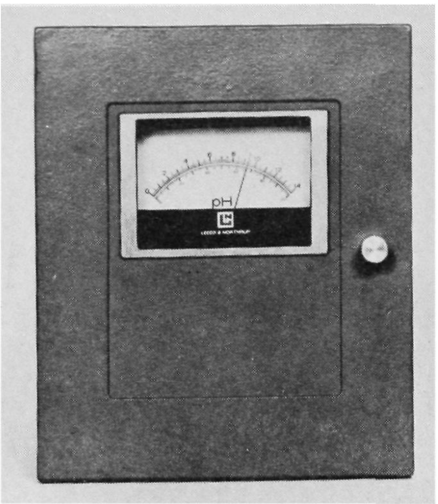


Figure V-37. pH analyzer (courtesy Leeds & Northrup)

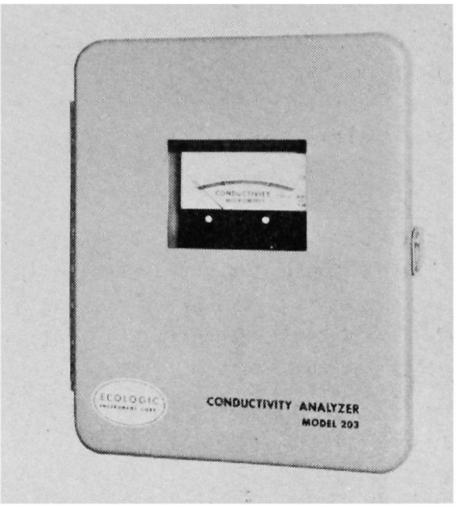


Figure V-38. Conductivity analyzer (courtesy Ecologic Instrument Corp.)

in Section VI. However, the in-situ monitors are recommended if they are used for flow control purposes, quick indicators of treatment efficiency, or for monitors of changes in sewage characteristics.

RAINGAGE NETWORKS

Rainfall-Runoff Relationship

Precipitation is a general term used by hydrologists to describe all types of moisture that can fall from the clouds to the ground. Rainfall is the primary form of precipitation which is of concern in storm generated discharge projects. Although a correlation has been found between the snow that fell when the ground was frozen and the early spring runoff (1), the term precipitation will be used interchangeably with the term rainfall.

For precipitation to occur, water vapor must be present in the atmosphere. Something must bring about a cooling of the air so that the moisture will condense to form water droplets. Cooling of large regions of air is necessary for any significant amount of precipitation to occur and this is usually achieved by a lifting of the air. Classification of precipitation can be made based on the factor causing the air lifting phenomenon. These classifications are, 1) cyclonic precipitation, 2) convective precipitation, and 3) orographic precipitation (2).

Cyclonic precipitation is caused by the movement of air masses from high pressure to low pressure areas. These pressure differences are caused by unequal heating of the earth's surface. Cyclonic precipitation can also be categorized as frontal or nonfrontal. There are two types of frontal cyclonic storms. In the warm front type, warm air replaces cold air; the second type of front is where cold air replaces warm air and is called a cold front. If there is no movement of the front, it is called a stationary front (3).

Convective precipitation is caused by the heating of the air near the earth's surface. The heated air expands and water vapor is taken up. As the warm moist air rises and is surrounded by cold dense air, precipitation occurs. These types of storms are usually quite variable or spotty and may produce light showers or high intensity rains often called thunder storms. Convective precipitation, because of its variability, is often the most difficult to accurately record and usually is the limiting factor in raingage network design.

Orographic precipitation is produced by rising air caused by the topography of the land. This type of rainfall can vary significantly in intensity and quantity. These variations are particularly pronounced in mountainous and hilly regions of the country. A rise of air on the windward side of a slope causes warm air to move upward and precipitation forms as the warm moist air comes into contact with the cooler air at higher altitudes. Thus, rainfall tends to occur on the windward side of major slopes or mountains.

Precipitation can also be classified as to form and intensity. A "trace" is recorded when precipitation is less than 0.127 mm (0.005 in.). A "drizzle" is usually less than 1.016 mm/hr (0.04 in./hr) and is made up of water drops under 0.508 mm (0.02 in.) diameter. "Rain" is classified as greater than 1.016 mm/hr (0.04 in./hr) and consists of drops larger than 0.508 mm (0.02 in.) (2). "Thunderstorms" are high intensity short duration (15-30 min.) forms of precipitation that are usually localized.

Both spatial and temporal variations in precipitation events cause major problems in measuring rainfall from which storm generated discharges result. A common term "areal rainfall" is defined as the average precipitation over an area during a given time period (4). Raingage data is usually weighted using the Theissen method (discussed later) (2)(5) or averaged to arrive at the areal rainfall value for a given storm. Variations in rainfall require an adequate raingage network to arrive at an areal rainfall value that will accurately predict the resultant storm generated discharges.

A greater raingage density is necessary to accurately describe precipitation in mountainous terrain than is needed in flat or gently undulating terrain. Mountains affect the quantity and distribution of rainfall as well as the areal variability. Hutchinson (6) studied the effect of topography on the areal variability in order to initiate a more quantitative procedure for determining necessary raingage densities. He was primarily concerned with improving the understanding of the areal variability of precipitation. According to Huff (7) factors that can contribute to significant variations in storm measurements include 1) stage of development of the storm, 2) size and complexity of the storm system, 3) rainfall type, 4) storm type, 5) location of sampling area with respect to the storm center, and 6) movement of the storm system across the sampling region. Many of these variations are due to the frontal variations and cellular nature of convective rainstorms. Huff (7) in studying heavy storm characteristics described four major types of storm patterns as, 1) closed elliptical, 2) open elliptical, 3) multi-cellular and 4) bonded. He was interested in modeling storms for hydrologic applications. The best correlation between actual storm data and predicted values from the model were obtained by relating the percent of storm rainfall to the percent of total storm time; the storms were then classified according to the quartile of heaviest rainfall. In developing this model, Huff defined each storm as the rain period which is separated from previous or successive rain by six hours or more. He also required that all raingages measure at least 12.7 mm (0.5 in.) and one gage had to measure more than 25.4 mm (1.0 in.).

A number of attempts have been made to predict various types of rainfall so that mathematical rainfall models can be used to study different characteristics of runoff hydrology (8)(9)(10). It has been necessary to develop these types of synthetic data because of the lack of adequate historical data for the spatial and temporal variations that often occur in convective storms. In order to accurately monitor these rainfalls, very dense raingage networks are necessary, and yet few of these types of networks are available. In runoff predictions an average or areal rainfall is determined over the watershed area in question. The average rainfall over an area can be determined by an arithmetic mean, the Thiessen method or the isohyetal method (2). The arithmetic mean technique is useful only where the gages are uniformly dispersed and the rainfall does not vary excessively throughout the area. The Thiessen method usually predicts a more accurate reading of areal rainfall. The polygons formed in the Thiessen method require that at least three raingages be spread over the watershed for proper weighting of the rainfall data. Every time a change is made in the raingage network, a new Thiessen diagram must be developed. The isohyetal method is the most accurate method for determining areal precipitation. However, an extensive raingage network is necessary and the analyst must carefully account for the watershed topography and the rain storm characteristics.

When insufficient data are available, rainfall formulas may be used (4). These formulas relate rainfall intensity (mm/hr [in./hr])with storm duration by use of constants that are tabulated for different regions. Areas of very high rainfall intensity variation use special charts and figures to determine rainfall intensity as a function of return frequency and duration for storm sewer design. Other methods have been established for predicting rainfall data where insufficient raingage information is available (7)(9). In all cases, great care must be taken when designing combined sewer overflow systems and predicting rainfall data in the absence of historical data. Storm variations can produce major errors in the prediction techniques and the use of historical data cannot be over emphasized for good designs.

In storm generated discharge studies, the primary interest in rainfall lies in the runoff that is produced. Combined sewer overflows caused from runoff in urban areas are significantly different than runoff from natural or rural areas, primarily because of the impervious nature of the watershed. Significantly less infiltration of rainfall to groundwater will occur in urban areas.

Several methods have been used to predict runoff for storm sewer design from precipitation data (4). A number of empirical formulas have been developed to relate one or more parameters with expected runoff rates and volumes (11). The Burkli-Ziegler and the McMath formulas relate runoff with maximum rate of rainfall, slope of the ground, area of watershed, and a factor to express the nature of the ground surface.

Burkli-Ziegler: $Q = CRA \sqrt[4]{S/A}$

McMath: $Q = CRA \sqrt[5]{S/A}$

where: Q = runoff, cfs
R = maximum rate of runoff, in./hr over entire area
S = slope of the ground surface, ft/1000 ft
A = area, acres
C = nature of ground surface or relative imperviousness

Runoff from areas greater than 405 ha (100 acres) has been related to the size of the drainage area (11). Several are listed below.

Metcalf and Eddy: $Q = \frac{25,000}{A + 125} + 15$

Fuller: $Q = CM^{0.8}$

Fanning: $Q = 200M^{5/8}$

Talbet: $Q = 500M^{1/4}$

where: A = area in acres
M = area in square miles

These rational type formulas vary greatly from each other primarily because they are developed for specific areas or conditions. In most cases the frequency of the computed flow is not known. The use of these formulas has greatly declined in favor of the Rational Method.

These designs do not relate storm flows to actual rainfall frequency. Factors such as variations in population have appreciable effects on this type of design.

The Rational Method of storm and combined sewer system design relates runoff to rainfall intensity, area of watershed, and a runoff coefficient or imperviousness factor. The Rational Method has been expressed as Q = ciA and as Q = AIR (11)(13). These two equations are equivalent since c = I, i = R, and in both cases A = A. The form Q = ciA will be used in this text, where the units are runoff, Q(m^3/hr[cfs]), intensity, i(cm/hr[in./hr]), and area, A(ha[acres]). The rainfall intensity factor i depends on the frequency of the storm selected and the duration of the storm which is chosen to be equal to the time of concentration of each drainage area. The time of concentration is defined as the maximum time required for a drop of runoff to flow from the furthest point in the drainage area to the point in question (13). This is usually divided into the inlet time, a time of flow across the drainage area, and the time of flow in the sewer. The time of concentration is used to determine rainfall intensity values from intensity-duration-frequency curves similar to Figure V-39. Frequencies of 1 to 10 years are commonly used where residential areas are to be protected. Higher return period storms may be used where high value districts are involved. The runoff coefficient c must be selected by the engineer, and requires some judgment to correlate local conditions. Typical values of c are shown in Table V-1.

The Rational Method should usually be used where drainage areas are smaller than 0.810 ha (2 sq mi). It should be emphasized that the Rational Method only predicts peak runoff flow rates. The unit hydrograph method has been used because it predicts the runoff characteristics throughout a storm. In the combined sewer overflow study at Bucyrus, Ohio (14) the Rational Method was not adequate to predict peak runoff values and a modified unit hydrograph was used.

Although the unit hydrograph is the most common hydrograph approach to rainfall runoff analyses, there are other approaches that have been used for specific types of problems. The unit hydrograph is linear and linear analyses are often used in other hydrograph techniques. The primary

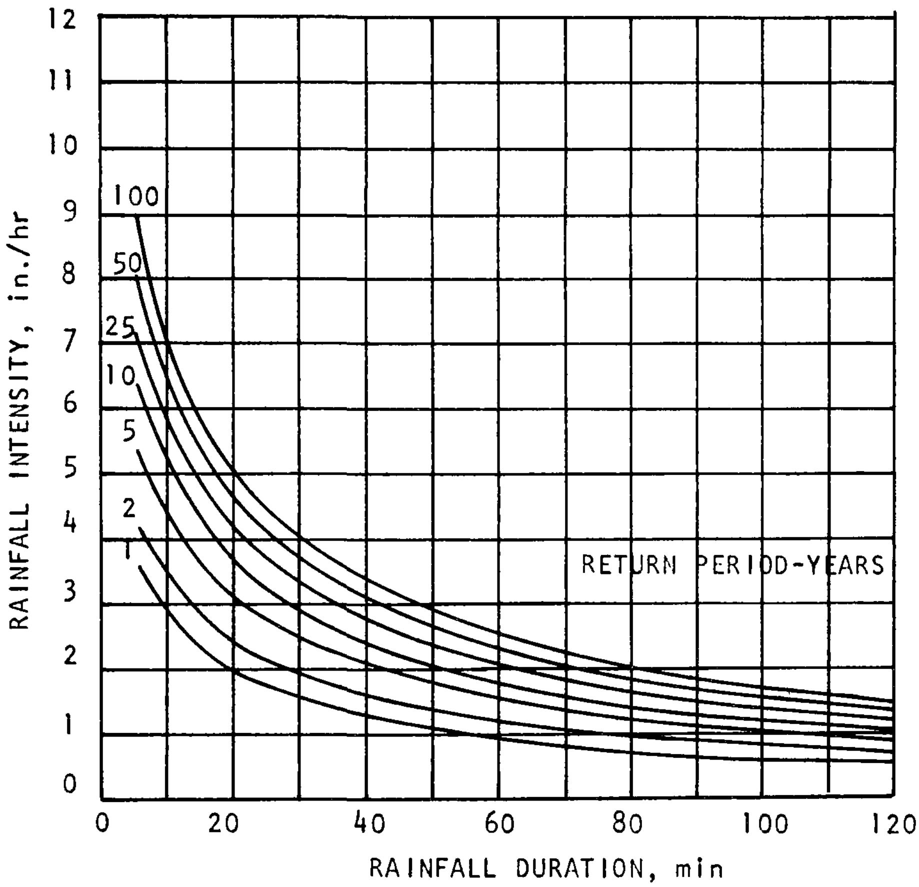


Figure V-39. Intensity - duration - frequency curves for Bucyrus, Ohio

From Reference 14

Table V-1. RUNOFF COEFFICIENTS C[a]

Surface Type	C Value
Bituminous streets	0.70 to 0.95
Concrete streets	0.80 to 0.95
Driveways, walks	0.75 to 0.85
Roofs	0.75 to 0.95
Lawns; sandy soil	
Flat, 2 percent	0.05 to 0.10
Average, 2 to 7 percent	0.10 to 0.15
Steep, 7 percent	0.15 to 0.20
Lawns; heavy soil	
Flat, 2 percent	0.13 to 0.17
Average, 2 to 7 percent	0.18 to 0.22
Steep, 7 percent	0.25 to 0.35

a. From reference 13

concept involving the linear analysis of hydrographs is that output is directly proportional to the input. In the case of runoff analyses, the peak discharges of two hydrographs are proportional to the amounts of rainfall producing runoff that constitutes the hydrograph. Mitchell (15) evaluated a large number of small drainage basins for culvert design where a more rapid method of analyses than the unit hydrograph approach was needed. He described linear hydrographs using five parameters: 1) the size of the drainage area, 2) the amount of rainfall producing runoff (rainfall excess), 3) the duration of the rainfall producing runoff, 4) the lapsed time from the end of the runoff produced by rainfall to the point of inflection on the recession limb of the hydrograph (translation time) and 5) a storage index. Using these parameters and a set of predetermined tables, any linear flood hydrograph for a given drainage basin can be determined.

A somewhat different approach was developed using a regression analysis of many urban basins throughout the United States (16). Hydrograph parameters were described by five equations using the area of the watershed, length of the main drainage channel, slope of the subarea and the impervious nature of the surface. These equations, however, do not take into account the rainfall intensity, duration, or antecedent rainfall. Eagleson and Schaake (17) have also used linear hydrograph analyses to analyze drainage basins. However, they converted from the time domain to the frequency domain using Fourier transformations and examined drainage basins as low pass frequency filters (analogous to electronic circuits). This approach permits a unique viewpoint and expands the knowledge of rainfall-runoff relationships. However, the difficulties in describing necessary hydrologic relationships mathematically makes this approach difficult to apply in storm generated discharge studies. Application of the unit hydrograph technique (subtracting infiltration and retention capacities) to predict the frequency of storm runoff of various magnitudes from rainfall or snowmelts on small drainage basins in various stages of urbanization was successfully performed in Michigan under USEPA Grant No. R-800941(11040 DRS). (54)

The unit hydrograph approach can be used in runoff studies or design and has been utilized in computer models that will be described briefly later. The primary disadvantage of the unit hydrograph method lies in that both rainfall and runoff data are needed for its derivation. Also, it is limited to a particular drainage basin (13). The unit hydrograph represents the runoff volume of 2.54 cm (1.0 in.) from a particular drainage area for a specified storm duration. Theoretically a different unit hydrograph is required for different length storms. However, unit hydrographs for short duration rainfalls can be combined into hydrographs for longer storms. Other hydrographs for the same drainage area can be derived from the unit hydrograph using the following relationship.

$$\frac{\text{Unknown discharge at } t_x \ (m^3/hr[cfs])}{\text{Volume of Rainfall producing runoff (cm[in.])}} = \frac{\text{discharge from unit hydrograph at } t_x}{2.54 \text{ cm (1.0 in.)}}$$

Thus the runoff at any time t_x can be determined for any rainfall volume that has the same duration as that used to produce the unit hydrograph. Unit hydrographs can be established for several different storm durations and maintained on file. The basic steps used to produce a unit hydrograph are (13):

1. Analyze the sewer flow hydrograph to permit separation of normal domestic wastewater flow from the storm generated runoff.

2. Measure the total volume of direct runoff from the storm producing the original hydrograph. The volume is equal to the area under the hydrograph after the domestic wastewater flow has been subtracted.

3. Divide the ordinates of the direct runoff produced by the storm by the total volume (cm[in.]) of stormwater runoff. A plot of these values versus time is the unit hydrograph.

4. The effective duration of the stormwater runoff producing rain for this unit hydrograph is found by evaluating the hyetograph of the rainfall.

Modifications of the unit hydrograph and methods of compositing individual hydrographs for different sewers and catch basins are described in the Los Angeles Method (18) and the Chicago Method (19). Unit hydrographs were used to evaluate storm discharges that flow to a river (14). The Rational Method was evaluated in this study but assumed runoff coefficient values (C) appeared to be in error. Peak discharges were predicted that were in excess of the sewer capacity. A straight line relationship was found between maximum rainfall intensity and peak overflow to the river for given storm durations.

The Rational Method was successfully used in the Des Moines, Iowa study where the C values were determined by comparing plots of rainfall intensity (in./hr) versus time and runoff flow (cfs/acre) versus time (20). The runoff coefficient C was determined as the ratio of runoff per acre to the rainfall intensity. It is necessary to determine C at the point of maximum rainfall intensity and to check that the storm duration is greater than the time of peak flow. Thus, the entire watershed will be contributing to the runoff flow and the peak flow can be assumed to occur at the time of concentration.

In most combined sewer systems the design and evaluation involving the use of rainfall-runoff data is complicated. Many other parameters are involved and simple evaluation using the Rational Method or the Unit Hydrograph Method is inadequate. Hence, several computer models have been developed which can calculate rainfall-runoff relationships, stormwater quality characteristics and other design and operational information. These models have been summarized (21) and are shown below.

1. Hydrograph-Volume Method - The Hydrograph-Volume Method (Ritter, 1971) was developed in Germany (22). This model calculates the dry-weather flow and storm runoff, and routes the combined flows through a complex sewerage network. Its benefits appear to be in conduit sizing and design. The model does not simulate flow quality or control regulators.

2. Road Research Laboratory Hydrograph Method - The British Road Research Laboratory (RRL) Method uses storm rainfall to provide a stormwater runoff hydrograph for the purpose of storm drainage design (23). Rainfall is applied to the paved area of the drainage basin which is directly connected to the storm drainage system. Travel time to the nearest storm drainage inlet is computed for various increments of the total paved area that is directly connected. From this time-area information, the surface hydrograph arriving at the inlet is computed. The surface hydrograph is then routed through the storage available in a particular section of pipe. The surface

hydrograph at the next downstream inlet is added, and the combined hydrograph is routed on downstream. Thus, the successive addition and routing of surface hydrograph produces an outflow hydrograph at the downstream discharge point. In the RRL method, the quality associated with the runoff is not computed. The application and use of the method is described in a recent USEPA report (24).

3. Stanford Watershed Model (Hydrocomp Simulation Program) - The Stanford Watershed Model (Crawford and Linsley, 1966)(25) along with its commercial successor, the Hydrocomp Simulation Program, is a comprehensive mathematical model that simulates watershed hydrology and flow routing. This model has been used extensively to simulate existing and planned surface water systems. Recently, it has been expanded to include water quality computations. It does not perform cost calculations, however, and has not been adapted to sewerage systems.

4. Urban Runoff Model - The Urban Runoff Model PDP-9 (UROM-9) was developed at the University of Minnesota for the Metropolitan Sewer Board, St. Paul, Minnesota (26). The purpose of this model is to predict discharges to the Minneapolis-St. Paul interceptor sewers, given rainfall readings at various points around the Twin Cities. The model computes storm runoff from major catchments, combines the runoff with estimates of dry-weather flow, routes the combined flows through the interceptor system to the treatment plant, and computes overflows to the receiving water at control regulators. It uses monitored rainfall and flow level data from various points for real-time control of the overflows. The model has not been adapted to consider water quality aspects of the overflows. It is not intended for use for design purposes.

5. Urban Wastewater Management Model - The Urban Wastewater Management Model (Battelle-Northwest and Watermation, Inc., 1972) is a comprehensive mathematical model developed to continuously simulate time-varying wastewater flows and qualities in complex metropolitan combined sewerage systems (27)(28). The model simulates major sewerage system components, such as trunk and interceptor sewers, regulators, storage facilities, and treatment plants. It provides a means of evaluating the time-varying performance of a planned or existing sewerage system under a variety of rainfall conditions (considering both time and spatial rainfall variations) without simulating every pipe or manhole. The model simulates seven wastewater quality parameters: SS, BOD_5, COD, phosphate, nitrate, ammonia, and Kjeldahl nitrogen. The required operation of control regulators during real-time rainstorm events to minimize overflows is modeled. The model can also be used

for design and planning studies. It computes sizes and costs of structural sewer system modifications, such as sewers, regulators, and storage and treatment facilities, that will result in the least-cost combination of alternatives for improving system performance.

6. Storm Water Management Model - The Storm Water Management Model (SWMM) (Metcalf & Eddy, Inc., University of Florida, and Water Resources Engineers, 1971) was developed under the sponsorship of the U.S. EPA (29)(30)(31)(32). It is a comprehensive mathematical model capable of representing urban stormwater runoff, storm sewer discharge, and combined sewer overflow phenomena. The SWMM has been demonstrated at more than 20 sites throughout the country ranging from 76 to 8,100 ha (187 to 20,000 acres). During demonstration, the SWMM has been verified to be capable of representing the gamut of urban stormwater runoff phenomena for various catchment systems (30). This includes both quantity and quality from the onset of precipitation on the basin, through collection, conveyance, storage and treatment systems, to points downstream from outfalls that are significantly affected by storm discharges. The SWMM is intended for use by municipalities, governmental agencies, and consultants as a tool for evaluating the pollution potential of existing systems, present and future, and for comparing alternative courses of remedial action. The use of correctional devices in the catchment, along with evaluation of their cost effectiveness, has also been demonstrated.

Rainfall Measurement

There are basically two types of raingages. The non-recording type measures total precipitation and is manually read using a measuring stick which is calibrated to 0.254 mm (0.01 in.) of rainfall. The standard raingage used by the U.S. Weather Bureau has a 20.32 cm (8 in.) diameter collector which directs the rain into a measuring tube. The measuring tube is 1/10 the area of the collector, thus 2.54 mm (0.1 in.) rainfall will fill the measuring tube to a depth of 25.4 mm (1 in.).

The recording type raingages measure the intensity of rainfall by continuously recording the amount of rainfall throughout the storm. This is achieved by use of a tipping bucket gage (U.S. Weather Bureau) or a weighing-type gage. The tipping bucket gage measures rainfall intensity by recording the number of times a small bucket is filled and tipped or dumped into a reservoir. Two buckets are used so that one bucket is emptying into the reservoir while the other is filling from the rainfall. Each bucket is calibrated so that 0.254 mm (0.01 in.) of rainfall will tip the bucket into the reservoir. The weighing type raingage utilizes a weighing mechanism to continuously measure the rainfall as it passes into a large bucket. The increase in the weight of the bucket is related to the amount of rainfall. Heating devices or other types of raingages are used where excessive snowfalls contribute to a major amount of moisture to the precipitation.

Errors that arise from raingage measurements include 1) mistakes in reading the scale of the stick or chart, 2) evaporation of water in the gage, 3) improper placement of the gage, and 4) instrument error. It has been suggested that 6 hour recording gages be used instead of 24 hour to facilitate the reading of short time interval rainstorms when weighing type raingages are used (33). It was found that errors caused by skewness of the charts was significantly reduced for three different types of recording raingages when six hour charts were used. Errors in translating recorded data to runoff should be random in nature and tend to cancel each other out over a period of time. Most evaporation errors would be insignificant in the high intensity, short duration, storms of importance in storm generated discharge studies.

The best site for raingage location is on level ground with no trees or buildings in a proximity such as to affect the capture of rainfall. Distant trees and buildings that tend to break up wind currents are advantageous. Errors due to wind affecting measured rainfall have been rated as the most serious problem in precipitation measurement (2). Wind shields are available and should be used where winds are expected to cause measurement errors. Errors due to gage location have been minimized by choosing raingages with the lowest variance as permanent stations (34).

Raingage Density

Variation in precipitation with topography, season, time, type of rainfall, and other factors has been briefly discussed. Because of these spatial variations, the concentration of raingages for any given watershed must be carefully evaluated if accurate rain patterns are to be measured. A precise method of determining the proper number of raingages for a given area has not been developed. It has been suggested that a large number of temporary gages may be required before the unnecessary gages can be determined and a selection made for the permanent stations (35). It is important in establishing an optimum raingage network to carefully consider the limits and requirements that the rainfall data will be used for. What are the objectives of the project? Climatic conditions, topography, and normal type of rainfall should also be considered in establishing raingage networks.

A number of investigations have been conducted to specify an adequate raingage density to characterize precipitation patterns and/or runoff from watersheds. These studies follow two basic approaches: 1) mathematical approach to describe the watershed basin (36) and 2) empirical approach to correlate historical data with equations or curves (34)(35) (37). Examples of the different design methods will be discussed next.

Correlation fields (distance plotted for equal values of the inter-station correlations of daily precipitation for each of the raingage stations) were developed by Hendrick and Comer from extensive historical data (35). Raingage distance, azimuth, and minimum precipitation were used to derive a combined correlation coefficient. Using this combined correlation coefficient, 0.9 correlation ellipses were used to graphically determine the gage network that would be required for the 112 sq km (43 sq mi) watershed to predict summer precipitation. When distance was considered alone, the raingages needed to be about 1.21 km (0.75 miles) apart for a correlation of 0.80. The correlation coefficient decreased with distance at a rate of 0.062 per km (0.1 per mile) for summer storms. This resulted in a 0.0445/sq km (0.21/mi) raingage density requirement for the 112 sq km (43 sq mi) basin. These authors, however, point out that major errors in precipitation pattern measurement may occur due to periodic severe storms. Correlation criteria used in developing raingage networks is useful in minimizing errors over extended periods of time, but the networks may not accurately measure any one specific storm.

Taking a mathematical approach, Eagleson (36) devised several equations for which graphs were presented to relate raingage density requirements with watershed area and storm size. Table V-2 below shows the number of raingages that were necessary to predict the error in maximum runoff discharge for different size cyclonic storms.

Table V-2. NUMBER OF RAINGAGES NECESSARY TO PREDICT RUNOFF FOR CYCLONIC STORMS[a]

Runoff Error	Ratio of Watershed Length to Effective Storm Radii: 1 No. Gages	2 No. Gages	4 No. Gages	10 No. Gages
5%	4	7	24	46
10%	2	4	10	14
15%	1	2	5	7

a. From reference 36.

Eagleson pointed out that fewer raingages are required to predict runoff from watershed dynamics than when rainfall patterns are to be determined. No actual verification was made to determine if the mathematical predictions of Eagleson were actually valid. However, it is important that the number of gages required increases as the watershed area becomes greater than the effective storm area. Thus more raingages are required for thunderstorms than for uniform rainfall. Eagleson stated that two properly located raingages are adequate to determine long term average rainfall at many watersheds.

Osborn, et al, (37) used a 150 sq km (58 sq mi) watershed in southeastern Arizona with 95 recording raingages to study the optimum raingage density for thunderstorms. They were interested in the raingage network necessary to measure the rain volume and intensity for individual storms and to predict the runoff from specific watersheds. Osborn used the maximum 15 minute rainfall and the total storm rainfall to investigate the optimum raingage density required to describe individual storms and to correlate rainfall with runoff. Table V-3 shows the results expressed as the range of simple correlation values between each raingage for several different watersheds.

Table V-3. SIMPLE CORRELATION COEFFICIENT RANGE BETWEEN RAINGAGES[a]

Raingage spacing, feet	Correlation coefficient based on: Total rainfall	15 minute maximum rainfall
506 - 926	0.91 - 0.96	0.86 - 0.92
2100 - 3,000	0.82 - 0.91	0.73 - 0.90
4200 - 8,550	0.00 - 0.71	0.00 - 0.57
3800 -19,300	0.00 - 0.80	0.17 - 0.84

a. From reference 37.

Each watershed was chosen based on the distance between raingages. A plot of all their data showed that the simple correlation decreased roughly by 10% for every 304.8 m (1000 ft) of distance between raingages. Their results showed that gages should be placed every 548.4 m (1800 feet) to describe the total rainfall for a correlation of 0.90. To describe the maximum 15 minute rainfall, gages must be every 304.8 m (1000 feet) for a correlation of 0.90 and about 1400 gages would be required for the 150 sq km (58 sq mi) watershed or about 9.3 gages/sq km (25/sq mi). The costs for this extensive raingage network would be prohibitive and the real concern in most cases is the accurate prediction of storm runoff, so another approach was taken.

Eagleson (36) and others have shown that the runoff from watersheds tend to smooth out rainfall variations. Osborn therefore decided to investigate the relationships between rainfall, raingage density, and storm runoff using a multiple linear regression program. From the basis of this study, they concluded that the following gage densities are necessary to relate watershed runoff to rainfall:

1. One centrally located gage for watersheds up to 48.5 ha (0.48 sq km)[120 acres(0.187 sq mi)].

2. Three evenly spaced gages for a 260 ha (2.6 sq km)[640 acres (1 sq mi)] watershed with a length to width ratio of 4.

3. Five evenly spaced gages for a 2600 ha (26 sq km)[6400 acres (10 sq mi)] watershed with gages spaced about every 2.42 km (1.5 miles).

These conclusions are not a great deal different from the results of Hendrick and Comer (35) when only interstation distance was considered for a correlation of 0.8. However, Osborn, et al (37) developed these raingage density guidelines to predict runoff while Hendrick and Comer were concerned with accurate precipitation analysis. Osborn, et al, also found that areal rainfall estimated by the Theissen weighting procedure produced better correlations than average raingage data.

Radar patterns were compared with data from twenty-one recording gages and eight non-recording gages in a California watershed. Twenty of the recording gages were located in approximately a 26 sq km (10 sq mi) area that included stations in the urban area of the City of Davis (34). The maximum distance between gages was 4.5 km (2.8 miles) and the minimum distance was 0.8 km (0.5 miles). Data from individual gages were compared with the mean using a simple regression equation of the form:

$$\overline{X} = b_o + b_1 x_i$$

where: $\overline{X}$ = the mean precipitation of the entire array

x_i = cumulative precipitation value of an individual gage at each 5 minute time interval

b_o, b_1 = regression coefficients

The gages which produced the most consistent data from storm to storm were selected as permanent raingage stations. These authors found that corrections should be made for systematic errors due to instrument characteristics, gage location and other factors. After corrections were made for the systematic errors, runoff hydrographs were made based on the mean network hyetograph and on individual gage hyetographs. Comparison of these two runoff hydrographs showed that similar runoff hydrographs were obtained for each of the corrected gage data because of attentuation characteristics of the watershed. They concluded that any single gage record was as representative of the area mean as any gage after each gage was corrected for systematic errors. Also, it was suggested that since any gage or group of gages were equivalent, lumped-parameter methods for storm runoff could be used in design applications. While these results were derived for topography variations that included both rural and urban characteristics, it is likely that mountainous and other varied terrain will require more sophisticated raingage networks. Also, more extensive raingage networks will be necessary for watersheds that receive convective precipitation or thunderstorms.

Raingage Density in Storm Generated Discharge Projects

The number of raingages necessary for any network is related to the size and number of the catch basins or runoff areas in a municipality. In reviewing ASCE's Program Technical Memorandum No. 10 (38), it was noted that for four cities one-fourth of the catchment basins are smaller than 2 to 26 ha (5 to 65 acres); one-half are smaller than 2 to 81 ha (5 to 200 acres); and three-fourths are smaller than 20 to 200 ha (50 to 500 acres) (see Table V-4) (39). It was suggested that pilot raingage networks over 20 ha (50 acres) would be representative of a large number of catchments particularly in suburbs beyond the corporate city limits.

Table V-5 shows a list of raingage densities for different storm generated discharge studies. Six studies had raingage network densities of 3.85 gages/1000 ha (1 gage/sq mi) or more. With a uniform grid of raingages this would put the maximum distance between stations at 2.24 km (1.4 miles). The lowest raingage density network was for the southerly district of Cleveland, Ohio (40) where one gage was used with difficulty to correlate wet weather flow. It was noted that heavy rainfalls near the treatment plant could produce significant combined sewer overflows when no rainfall was being recorded at the raingage station.

The rainfall data at Minneapolis-St. Paul (41) was used to determine when to inflate or deflate fabridams in order to direct stormwater runoff to maximize storage of the runoff in the sewers. Rainfall data was also used in the mathematical model to determine overflow volumes and other rainfall-runoff information. This information was coupled with monitoring information on the depth of flow in the interceptor sewers so as to maximize flow routing and storage. During this study the thawing of snow and ice caused runoff to the sewers that was relatively easy to handle because the thaw process is slow and predictable.

Seattle sewers (42) were pumped out before storm runoff arrived to maximize in-sewer storage. However, at least a two hour notice was needed in order to empty the sewers; this was achieved by using rainfall data from the outlying regions of the metropolitan area. Rainfall data were also used to predict sewer flows and estimate runoff volumes. At the time of this report (1974), correlation studies were to be made to determine if more stations are needed. Eventually rainfall data will provide input to a model that will be used to develop system hydrographs. These hydrographs will be used to route stormwater discharges through the sewers and maximize in-line storage.

In a Cleveland study (43) rainfall data were used to characterize variations in rainfall over a large area and design storm rainfall data were developed from these characteristics. Runoff discharges were compared for a 1 year storm rainfall using the Rational Method, the Routed

Table V-4. DISTRIBUTION OF SEWERAGE DRAINAGE CATCHMENT SIZES IN SOME MAJOR CITIES

City	Total area of city, sq km	Total area of city, sq mi	No. of catchments	Largest drainage area, ha	Largest drainage area, acres	Average drainage area, ha	Average drainage area, acres	Median drainage area, ha	Median drainage area, acres	Upper quartile drainage area, ha	Upper quartile drainage area, acres	Lower quartile drainage area, ha	Lower quartile drainage area, acres	Upper limit of size of catchments representing half of total drained area of city, ha	Upper limit of size of catchments representing half of total drained area of city, acres
San Francisco	114	44	42	830	2050	227	560	77	190	184	455	26	65	850	2100
Washington	158	61	93	2500	6180	152	375	26	65	108	265	10	25	912	2250
Milwaukee	246	95	465	740	1820	38	95	10	25	28	70	4	10	174	430
Houston	1160	444	1283	1040	2550	26	65	2.4	6	19	46	0.8	2	134	330

a. From Basic Information Needs in Urban Hydrology (39).

Table V-5. RAINGAGE DENSITIES FOR DIFFERENT STUDIES

Drainage area	Area ha	Area sq mi	No. of recording raingages	Gage density, no/1000 ha	Gage density, no/sq km	Gage density, no/sq mi	Reference
Minneapolis, St. Paul	58,200	225.00	10[a]	0.017	0.172	0.04	41
Seattle	21,000	81.20	6[b]	0.029	0.286	0.07	42
Cleveland	15,600	60.60	6[a]	0.038	0.385	0.10	43
Cleveland Southerly Dist.	25,000	96.90	1[c]	0.004	0.040	0.01	40
Bucyrus, Ohio Basin No. 8	72	0.28	1	1.390	13.890	3.57	14
Basin No. 17	182	0.71	1	0.550	5.490	1.41	14
Basin No. 23	151	0.59	1	0.660	6.620	1.69	14
Roanoke, Virginia							
Murray Run	736	2.84	1	0.140	1.360	0.35	45
24th Street	419	1.62	0[d]	0	0	0	45
Trout Run	404	1.56	0[d]	0	0	0	45
Philadelphia, Cobbs Creek	4.5	0.017	1	22.200	222.000	58.82	46
Boneyard Drainage	1,040	4.00	4	0.380	3.850	1.00	47
Des Moines	19,800	76.56	8[e]	0.040	0.404	0.10	20
Detroit Milk River Drainage	1,610	6.23	3	0.190	1.860	0.48	48
Racine, Wisconsin	325	1.25	3	0.920	9.230	2.30	49
San Francisco	11,300	43.70	19	0.160	1.550	0.43	50
Kenosha, Wisconsin	540	2.08	3	0.560	5.600	1.45	51
Humboldt Avenue, Milwaukee	230	0.89	2	0.870	8.700	2.25	52

a. One was an official U.S. Weather Bureau Gage.
b. Three additional raingages outside study area.
c. Only one gage was used in study
d. One non-recording raingage.
e. Two were official U.S. Weather Bureau Gages

Hydrograph Method (Modified Chicago Hydrograph) and the Unit Hydrograph Method. The Routed Hydrograph Method was found to be the best method to obtain peak discharge rates and total volumes of runoff. Areal rainfall was determined using the Isohyetal Method. Incremental rainfall was determined between each pair of isohytes and summed. Weighted average rainfall was then calculated by dividing by the total area. Then using the design storm rainfall, hydrographs were developed for 1, 3, and 5 year storms and used in the design of the collection system for combined sewer overflow. The retention basin volume was designed on the basis of expected storm runoff from the combined sewer overflows and streams caused by a three consecutive day rainfall that had a three year recurrence interval. Design volume was adjusted for expected wave action from Lake Erie.

In another Cleveland study (40) rainfall data was used from a single gage 16.1 km (10 mi) from the treatment plant. Due to the large size of the drainage area, rainfall data could not be correlated with the combined sewer overflow. This was not an important aspect because this was a pilot plant study and the primary emphasis was in the evaluation of the treatment process. Combined sewer overflow was pumped into two 16.4 cu m (5,000 gal.) tanks for use in extended filtration runs.

Rainfall intensity data were plotted in the form of hyetographs and compared with overflow (from the sewer system) hydrographs at Bucyrus, Ohio (14). The time between the start of significant rainfall and the time overflow began was determined. Although a raingage was used in each of the three watersheds, data was taken from the "Rainfall Frequency Atlas of the United States" (44) to plot rainfall depth-duration-frequency curves. The unit hydrograph was used to determine the shape of the overflow hydrographs. Then the peak runoff and total runoff volume were determined by the Rational Method and the Hydrograph Method. From this comparison a modified hydrograph was adopted for designing the stormwater facilities. Antecedent rainfall was considered and straight line relationships were found for curves of peak overflow and overflow volume plotted against peak rainfall intensity.

In the Roanoke, Virginia (45) study two non-recording raingages and one recording raingage was used. The non-recording raingages were found to be inadequate for measuring areal variations in rainfall intensity. Rainfall tended to follow the mountain ridges in the summer months but large rainfall variations were found. Considering the total area involved, the recording raingage density was 0.64 gages/1000 ha (0.17 gages/sq mi). Hyetographs and sewer hydrographs were plotted and the relationship between surface runoff and total rainfall were determined for each study area. The intensity and duration of rainfall was also used as an input in a computer program that determined the location and amount of overflow in the interceptor for each drainage area. Rainfall data from the "Local Climatological Data" published by the U.S. Weather Bureau of the U.S. Department of Commerce were used to determine total overflows for different total rainfall amounts. Based on the rainfall studies and other water quality studies alternate methods were considered to reduce or treat sewer overflows.

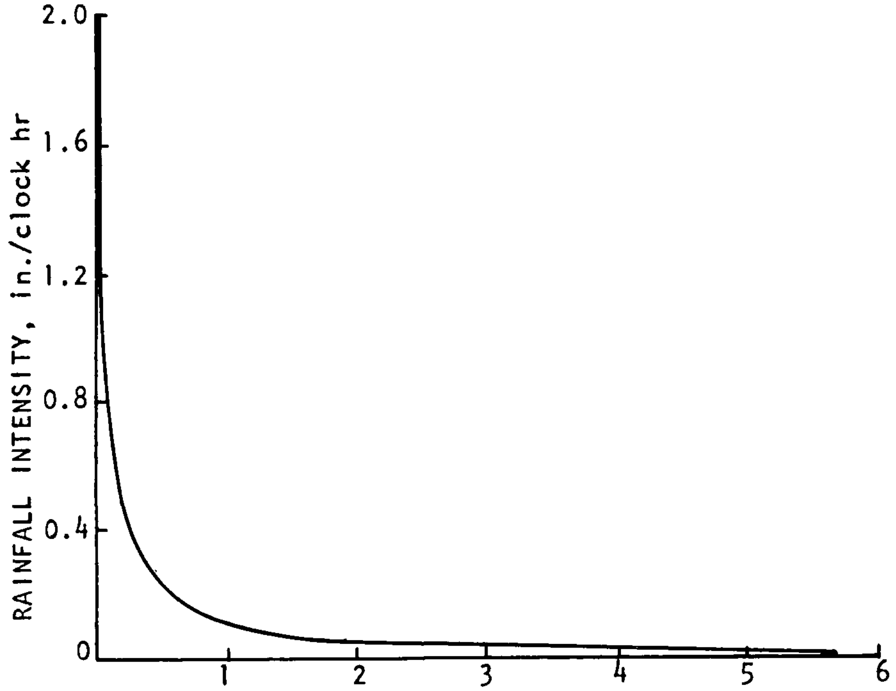
The small area of Cobbs Creek drainage in Philadelphia (46) was studied using one raingage. Because of the small area a large raingage density existed. The treatment system studies required 0.51-0.76 cm/hr (0.2 to 0.3 in./hr) for one hour in order to produce enough overflow for a test run. Rainfall intensity-duration was measured with the single raingage located 91.4 m (100 yards) from the treatment plant. The runoff coefficient was determined for the study area. The primary interest in this study was the treatment system and the rainfall data were used to correlate overflow data after the treatment plant had been installed.

The Boneyard Drainage Basin in Champaign, Illinois (47) has been used for a number of studies. The data reported in Table V-5 were developed for the evaluation of methods for determining cumulative storm generated runoff volume and rates (EPA Contract 68-03-0302).

In the Des Moines, Iowa study (20) eight raingages were spread around an area of 19,800 ha (76 sq mi). However, four study areas (total study area was 1,420 ha [5.5 sq mi]) actually monitored did not have raingages within their boundaries. Hence a modified Thiessen method was used to determine rainfall in the study areas. Intermediate points called "dummy rainfall stations" were established on a line connecting existing raingages. Rainfall at the dummy rainfall stations were determined by interpolation; these data were checked to see that relatively uniform rainfall occurred at each raingage station. The total depth of rainfall was found to be the best parameter to correlate with the volume of runoff. Curves of rainfall intensity versus percent clock hours in which a given intensity is equaled or exceeded (Figure V-40) were used to determine the amount of combined sewer overflow that could be expected annually from a given watershed as described below.

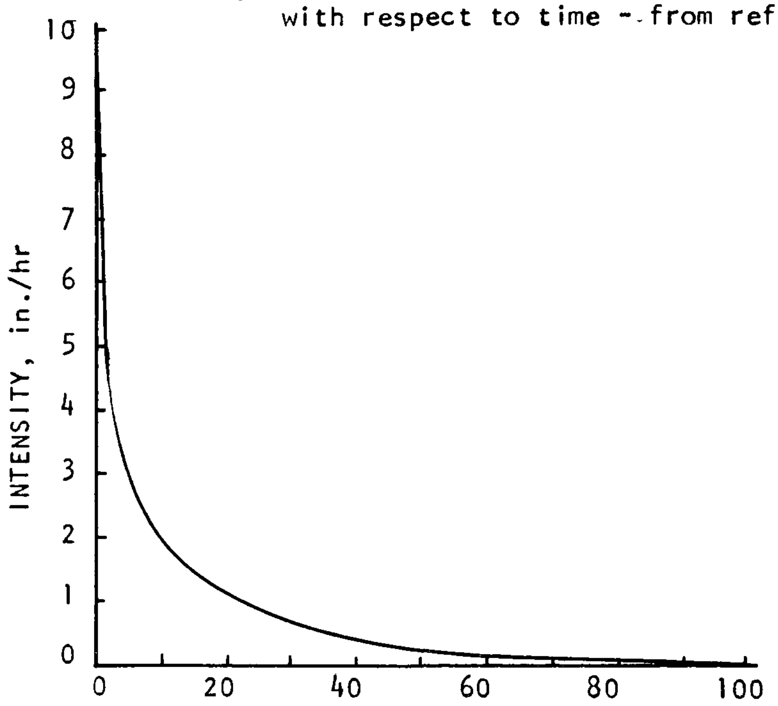
> "Given the area of the watershed, the capacity of the combined sewer, and coefficients of runoff as previously described, the intensity of rainfall that can be contained by the system can be calculated by the Rational Formula. From this, the percent of time annually that overflow will occur can be predicted by use of a curve such as shown in Figure V-40. For example, if it were determined that a given combined sewer would contain the runoff from a rainfall of up to 0.8 inches per hour intensity before overflowing, overflow would be expected to occur 0.1 percent of the clock hours or approximately 9 hours annually. From this, an estimate of sanitary sewage overflow is possible." (20)

Rainfall intensity was also related to the total rainfall depth which occurs at or greater than a given intensity (Figure V-41). As shown in this figure, two sources were used to develop this curve.



PERCENT OF CLOCK HOURS WITH RAINFALL INTENSITY EQUAL TO OR GREATER THAN GIVEN INTENSITY

Figure V-40. Distribution of rainfall intensity with respect to time - from reference 20



PERCENT OF ACCUMULATED RAINFALL EQUAL TO OR GREATER THAN GIVEN INTENSITY

Fiugre V-41. Distribution of rainfall intensity with respect to accumulated rainfall - from reference 20

"The curve shown in Figure V-41 may be used in much the same manner as that developed for the clock hours exceeding a given intensity. For example, if a given facility has the capacity to handle the runoff resulting from a rainfall of 1.0 inch per hour intensity, approximately 22 percent of the average March to November rainfall would be expected to occur at intensities greater than this. From this the quantity of overflow can be evaluated." (20)

The rainfall data taken during this study were used along with historical data from the U.S. Weather Bureau to determine the basis of design for storm flow treatment facilities and for evaluating the effectiveness of alternate systems.

During eight years of studying the Milk River Drainage Basin in Detroit (48), long term average rainfall data were found to vary by 50%. Because of the extreme variations in storm patterns, runoff data were analyzed for selected storms rather than for average hydrological data. Data from these raingages were averaged using the Thiessen weighting method. It appeared that overflows at the Milk River basin would be more a function of total rainfall than intensity of rainfall. Combined and storm sewers in the Milk River Drainage Basin were sized using the Rational Method to determine runoff.

Racine, Wisconsin (49) used three raingages for 325 ha (1.25 sq mi) so that the Thiessen Method could be used to determine average rainfall. It was necessary to use the Thiessen Method to determine the areal rainfall for use in the U.S. EPA Stormwater Management Model (see Figure V-42). The model was used to correlate predicted runoff hydrographs with measured hydrographs. Interestingly, it was found in these comparisons that the resulting hydrographs were very sensitive to changes in rainfall input being changed from a change in the number of raingages. In San Francisco 19 gages were used to study rainfall-runoff relationship over the 11,300 ha (43.7 sq mi) area (50). Twenty storms were monitored for six basins for which the land use varied from single family residential to industrial. Profiles of quantity and quality of combined sewer overflows occurred for rainfall intensities greater than 0.51 mm per hour (0.02 inches per hour). A one year analysis of rainfall intensity and duration was made for 1969-1970 and assumed to be about normal for that area. These and other data were used to evaluate several possible methods of handling their combined sewer overflow.

A contact stabilization biological treatment system was evaluated at Kenosha, Wisconsin (51). Three raingages were used for the 540 ha (2.1 sq mi) area so the Thiessen Method of determining areal rainfall could be used. During this five month study twenty-five rainfall events were recorded for volumes over 0.25 cm (0.1 in.). No direct correlation between rainfall volume or intensity with overflow volume or flow rate could be determined.

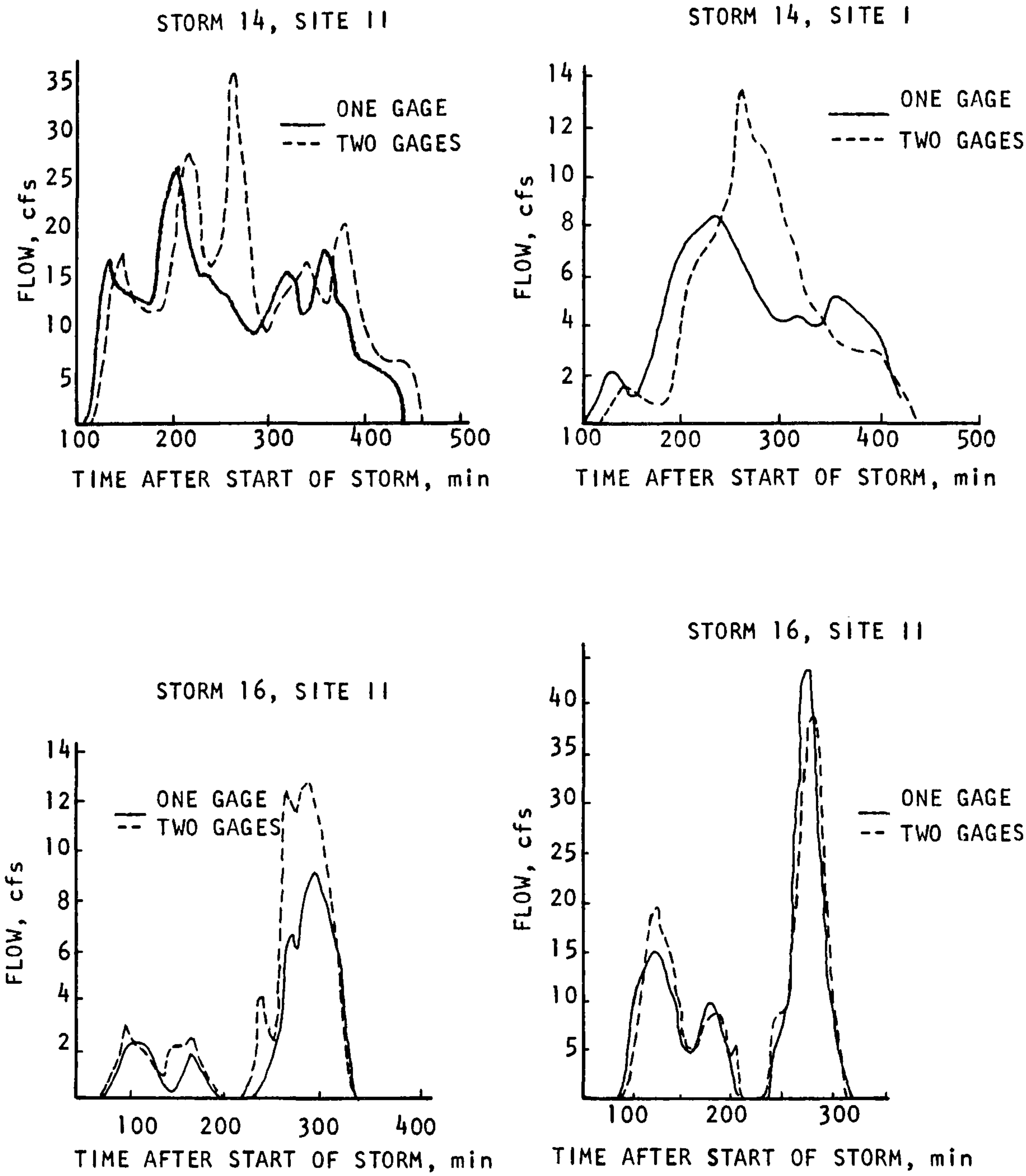


Figure V-42. Graphs from Racine, Wisconsin illustrating the effects of multiple raingages on the U.S. EPA Stormwater Management Model

A study in Milwaukee to evaluate storage of combined sewer overflows utilized three raingages for a 230 ha (0.89 sq mi) area (52). Studies were planned to evaluate the time of day storms occur, antecedent rainfall and influence of intensity and duration of storms on the average overflow quantity and quality. The effects of these parameters on the variation in overflow quantity and quality were determined.

High initial concentration or first flush conditions were noted during this study. No other correlation was found between combined sewer overflow qualities and specific storm characteristics. During this study, runoff coefficients were found ranging from 0.3 to 0.8. BOD and suspended solids were subjected to linear regression analysis for 97 storm events. Correlation coefficients between 0.81 and 0.92 were obtained for BOD and suspended solids data taken at the beginning of the storm, the maximum point and for zero to 30 minute average values. No correlation was found in combined sewage quality variations with storm characteristics and a very low correlation coefficient was found relating the maximum BOD to the interval between storms.

A summary of the raingage densities recommended in the literature (both mathematical and empirical studies) is shown in Table V-6. It is significant that the recommended raingage densities necessary to describe areal rainfall or runoff increase as the runoff area decreases. This would occur if any fixed number, for example three, raingages were used for different runoff basin areas. However, the number of gages required for any fixed area also tends to increase as shown in Table V-6. The fourth study shown in Table V-6 is out of line with the other recommended raingage densities because it was conducted in a part of California where relatively uniform rainfalls are experienced. In comparing these data with the raingage densities for storm generated discharge studies with drainage areas less than 25.9 sq km (10 sq mi), it can be seen that six out of eight raingage networks were essentially the same as recommended in the literature (see Figure V-43). In many cases, the raingage networks in Table V-5 were used to establish rainfall relationships of existing pilot and full scale treatment plants. Because evaluation of the treatment system was the primary focal point of the investigation, the raingage data were not as complete or thoroughly studied as they would have been if the studies had been made to design the treatment system. In the Detroit and Racine projects, raingage densities were exactly the same as that recommended in the literature. On the other hand, the Cleveland study at the southerly district was a pilot project to evalute a treatment system, and a very low raingage density was used.

Recommended Raingage Density

In recommending a raingage density or approach for arriving at a density to be used in storm generated discharge projects, it is necessary to establish clearly the use of the precipitation data. When modeling studies are being conducted, extensive raingage networks will be necessary to accurately measure areal precipitation patterns in order to

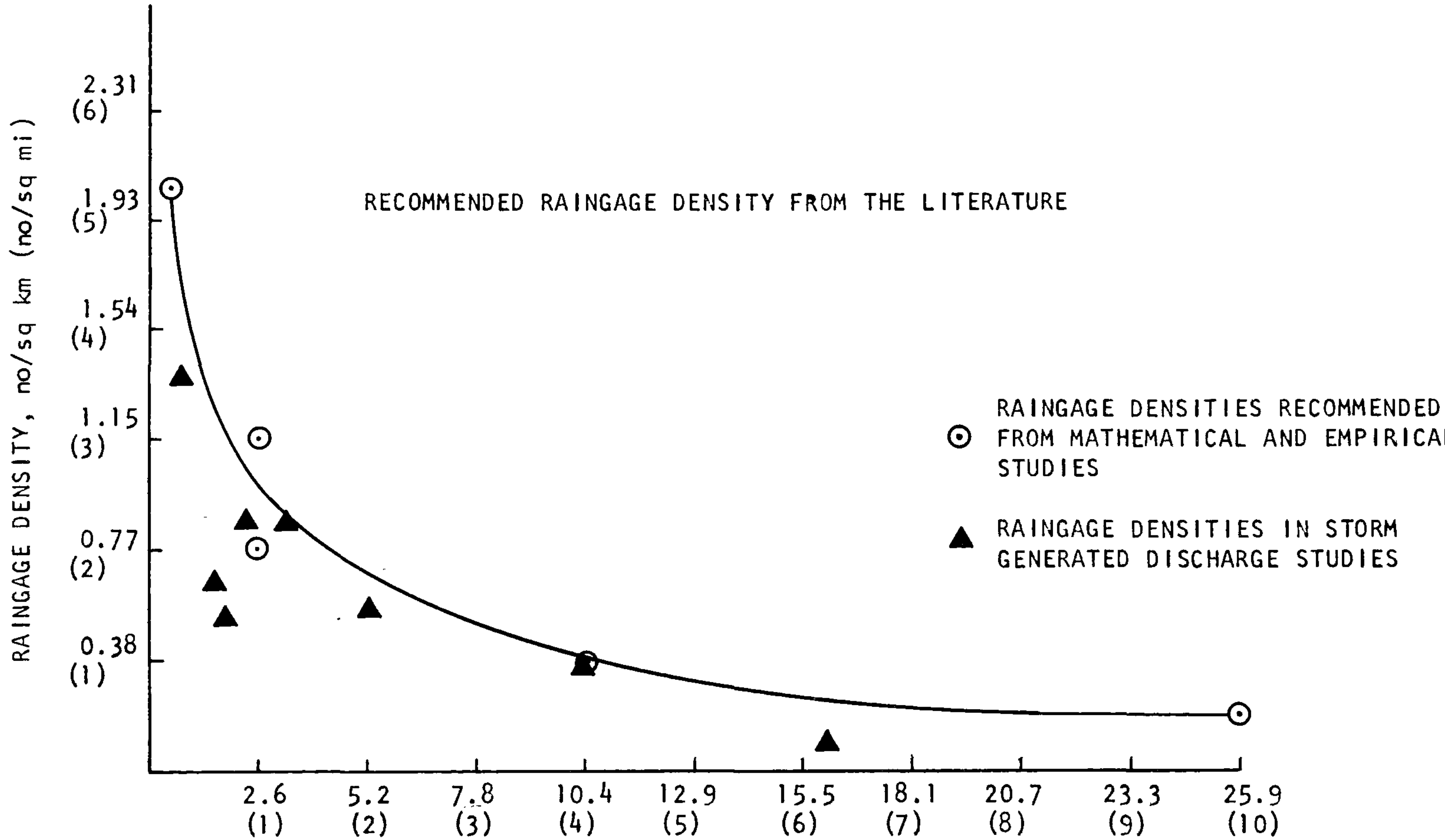


Figure V-43. Comparison of raingage densities recommended in the literature with those in storm generated discharge studies

Table V-6. RECOMMENDED RAINGAGE DENSITY FROM LITERATURE

Runoff Area, sq km (sq mi)	gages/sq km	gages/sq mi	Reference
1. 25.9 (10)	0.054	0.14	39
2. 111.4 (43)	0.081	0.21	35
3. 64.8 (25)	0.096	0.25	39
4. 25.9 (10)	0.039	0.1	34
5. 25.9 (10)	0.193	0.5	37
6. 10.4 (4.0)	0.386	1.0	39
7. 2.5 (1.0)	0.772	2.0	39
8. 2.6 (1.0)	1.157	3.0	37
9. 0.65 (0.25)	1.54	4.0	39
10. 0.49 (0.19)	2.045	5.3	39

verify the model which ties subcatchments together. Extensive historical precipitation data is essential in either storm sewer design or combined sewer overflow treatment plant design. In most cases historical data can be obtained from the periodical "Local Climatological Data" which is published by the U.S. Weather Bureau of the U.S. Department of Commerce. More detailed rainfall intensity-duration data can be obtained from the "Rainfall Frequency Atlas of the United States" Technical Paper No. 40, published for the Department of Agriculture by the U.S. Department of Commerce (44). These historical data can be very useful in storm flow design projects where peak flow is determined using the Rational Method. If these sources of data are not sufficient, it is possible in many cases to obtain copies of the original raingage charts from the U.S. Department of Commerce, NOAA, Environmental Data Service, Asheville, North Carolina 28801 (National Climatic Center, Federal Building). However, the historical data must include sufficient rainfall intensity-duration data to develop the "i" value in the Rational Method equation, otherwise additional data may have to be taken from raingage networks.

Rainfall data alone is not sufficient to use the hydrograph methods previously described. These procedures require a known rainfall-runoff relationship; hence, raingage networks will be necessary if the entire runoff hydrograph is needed. The length of a study relating rainfall to runoff may be too short to ensure that the correct storm frequency has been encountered for design. For example, a 2 year study may not measure a 5 or 10 year storm. Thus, it is likely that a combination of actual rainfall data and historical data will be necessary for storm generated discharge design projects. When sufficient historical data is not available, longer term rainfall data from extensive raingage networks will be necessary.

The need for rainfall intensity-duration data is also related to the type of project or to its extended use. Table V-7 shows four main study areas and their need for raingage networks.

Table V-7. RAINGAGE NETWORK NEEDS FOR DIFFERENT STUDY AREAS

	Need for Network
To define areal rainfall and its variations	yes
Mathematical Model verification	yes
Sewer, Treatment Plant, or System Design	varies
Operation of Storm Generated Discharge Systems (Treatment or Holding Basin)	no
Operation of In-line Storage or Selective Discharge Systems	yes

In cases where the interest is primarily in rainfall characteristics, it is necessary to determine spatial rainfall variations or areal rainfall and extensive networks will be necessary. A minimum raingage density for this type of study would be given by the curve in Figure V-43. A minimum of three raingage stations should be used in any network system so the Thiessen weighting method can be used. A digital computer can be applied to the Thiessen system thereby reducing the inherent problem of establishing a new weighting system every time the rainfall stations are changed (5).

Where mathematical models are used to predict runoff volumes and other characteristics, raingage networks are also needed, because of the major contribution rainfall has to these characteristics. When modeling studies are being conducted in large municipal areas, the cost of raingage installation and maintenance can become excessive. Models can be verified by selecting smaller catchment areas for detailed study. Raingages can be located in one or several of these smaller areas and the storm generated discharge can be characterized to establish the model's parameters. After the model has been verified in these small catchment regions, it should be checked at several points throughout the municipal watershed before it is used.

The need for raingage networks in the design of sewers or conveyance systems, treatment plants or holding basins is not as clear cut as the previous two types of studies. These systems usually are designed on the basis of total volume and peak runoff rate. If sufficiently accurate C values can be predicted for the runoff area and historical rainfall intensity data is available for the design storm, then the Rational Method can be used. However, if sufficient historical data is not available to determine the rainfall-intensity-duration curves, raingage networks will be necessary. The curve in Figure V-43 provides a suggested raingage density, but in system design a somewhat lower density may be satisfactory. This is especially true in regions of the country where uniform rainfall patterns are encountered.

Hydrograph methods of predicting runoff may be used for system design in areas where runoff surfaces are not expected to change. However, in newly developed areas or where expansion of peripheral suburban areas are involved, the runoff will be difficult to measure and rainfall-runoff relationships will be impossible to predict from hydrograph techniques. In this case, values can be established for the expected land use of the drainage area and the Rational Method used for design.

Raingage networks are not needed for the operation of storm generated discharge facilities, treatment systems or holding basins (except of course where the rainfall pattern is used to operate the sewerage system flow control system). A non-recording raingage at the treatment plant will be sufficient to determine daily and yearly average rainfall. Where storm generated discharge treatment plants are expected to be built in the future, more extensive raingage networks may provide essential data for design.

SECTION VI - QUALITY CHARACTERISTICS AND LABORATORY PROCEDURES

Virtually any water resources problem or study which involves storm generated discharges depends greatly upon an accurate knowledge of the physical, chemical and biological characteristics of these flows. Experience in past years with the analysis of wastewater, plant effluents and river, estuary and lake waters is very helpful in suggesting the characteristics which most likely are of primary concern. The peculiar properties of combined sewer overflows and strom runoff preclude the direct usage of these commonly used characteristics without some changes or modifications. As an example, while coliform counts have been and are still being used to assess the sanitary quality of a water body for the purpose of a municipal water supply source, the use of this same characteristic to assess the sanitary quality of runoff from an urban area could result in very misleading conclusions.

What is stated above applies not only to the characteristic itself, but also to the procedure used for its analysis. The experience with the laboratory analysis of combined sewer overflows and storm runoff is much more limited than the case of other liquid and sludge samples in the general water resources and water pollution control field. Thus the use of "standard" laboratory procedures as is done with most wastewaters may not produce satisfactory results in some stormwater cases. The procedures or modifications of established procedures recommended in this section take into account actual laboratory experiences in the analysis of combined sewer overflow and storm runoff samples.

QUALITY CHARACTERISTICS FOR STORM GENERATED DISCHARGES

Purpose

Knowledge of the quality characteristics of storm generated discharges is useful for a number of reasons. First of all this information is necessary to assess the impact of these discharges on the aquatic environment. As in the case of wastewaters and treatment plant effluents, storm generated discharges can cause an alteration in the physical, chemical and biological quality of receiving waters. A significant alteration in water quality can result in a situation which is harmful to the indigenous biota or impair the use of the water for drinking, recreational, industrial and other purposes. Combined sewer overflows and storm runoff contain constituents that do affect the criteria frequently used in water quality standards.

Quality characteristics are also required for the specific design of facilities used for the treatment of combined sewer overflows and storm runoff. Some design procedures require that the characteristics be expressed in terms of a concentration unit such as mg/l or a gross loading unit such as kilograms (pounds) per unit time. It is also often helpful to know the variation of the quality characteristics with time of rainfall. Data obtained in this form are commonly referred to as "time series".

In addition to the design of treatment facilities, quality characteristics are needed to evaluate the treatment process. Naturally, influent and effluent quality characteristics must be obtained to make this appraisal. It is important to establish treatment unit efficiencies under various loading or flow conditions. These data are also essential for developing appropriate cost information and as a guide for the selection, design, and operation of additional or furture combined sewer overflow or storm runoff treatment facilities.

Pertinent Quality Characteristics

If one considers all of the organic and inorganic compounds which can get into wastewaters of various types and in storm generated flows from a multitude of different sources, it is apparent that the list of possible quality characteristics which can be run on these samples is almost endless. However, experience with wastewaters through the years plus the more recent experience with combined sewer overflows and storm runoff have suggested a limited number of these characteristics to be particularly useful. It will be noted that these quality characteristics are not necessarily specific compounds or elements but rather refer to gross groupings or general categories. For example, the particulate concentration in a given combined sewer overflow sample consists of a myriad of different organic and inorganic undissolved solid particles. In most cases the major concern is the total concentration of the particulates which are present in the samples, and possibly, the overall percent which falls in the organic and inorganic categories. Identification of the specific organic and inorganic compounds is normally not of interest, though the possiblility should be kept open that in certain restricted applications it may be.

Presented below is a brief description of the quality characteristics considered to be important for storm generated discharge applications. More detailed descriptions plus recommendations regarding laboratory procedures are presented in the subsequent portions of this section. Also, at this point, the characteristics are discussed under broad categories rather than specific analyses. The latter will be presented in subsequent portions of the section also.

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. The 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.

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.

Pathogenic Microorganism Potential - Any discharge which includes some amount of domestic wastewater or 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. For a number of reasons which will be considered in detail further on in this section, the coliform group is not necessarily the most sensitive indicator as far as storm generated discharges are concerned.

Eutrophic Potential - In addition to sunlight and carbon dioxide, aquatic plants like terrestial 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.

Toxicants - The presence of high concentrations of toxic materials in combined sewer overflows and storm runoff is obviously undesirable. Toxic materials in these discharges can have a deleterious effect on the aquatic biota. Some toxic materials are more harmful to higher life forms such as crustaceans and fish while others may have a greater effect on plankton or possibly aquatic insects. Both categories are of concern if one considers the entire ecological balance in a water body. The disruption of one portion of the life chain eventually has an effect on the entire biological balance.

Higher life forms including man can also be adversely affected by the presence of toxic materials in storm generated discharges. Receiving water used for water supplies and for recreational purposes such as swimming, fishing and boating must be carefully monitored for the presence of toxic materials.

A larger 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.

Other Characteristics - In addition to the quality characteristics already noted, there are a number of relatively simple analyses that are used frequently to characterize the physical state or condition of water and wastewater samples. These same may be of interest in the case of storm generated discharges. A number of these analyses are run routinely on water samples. The other characteristics most likely of concern are pH, temperature, conductivity, color, odor, and oils and grease among others.

Origin in Storm Generated Discharges

The fact that discharges from combined sewer overflows can be grossly polluted is obvious because of the mixing of the storm runoff with municipal sewage. Discharges from separated storm sewers and direct runoff can also be polluted. From the time rainwater falls on an urbanized area until it is ultimately discharged to a receiving body of water it encounters and conveys pollutants from many different sources. Rainwater itself has been found to become polluted as it passes through the hydrologic cycle. The suspended solids and COD loading, g/day/sq m (lb/acre/day) from rainwater can be higher than sanitary sewage during actual periods of precipitation (1). Overland travel of the rainwater, or runoff, results in contact with rooftops, gutters, lawns and parklands, streets, alleys, sidewalks, parking lots, etc. Following the overland travel the runoff may then enter ditches, culverts, catch basins, sewers, flood channels, or holding tanks before discharging to a watercourse.

It is during these travels that the various contaminants and pollutants are gathered. The pollutional effect from these mateials is measured by the presence of pathogenic bacteria, oxygen demanding materials, toxic substances, nutrients, inorganic salts, particulates and coarse solids as described previously. Of course, many materials can be classified under more than one of the above classes. For example, pieces of plastic, wood, or rubber will eventually exert an oxygen demand. However, when in the particulate or coarse solid form they are of more concern because of their undesirable effect on the visual quality of a water. Table VI-1 contains a partial classification of pollutants and contaminants found in storm runoff and combined sewer overflows, along with examples and their primary sources.

The fact that many pollutants in storm generated discharges originate from the land surface of urban areas introduces much variation in the resulting quality characteristics. Raw wastewaters, while also exhibiting variation in characteristics, do have fairly predictable diurnal and weekly patterns in their characteristics. Storm generated discharges, on the other hand, originate from many different types of land surface ranging from relatively clean residential areas to grossly littered industrial work and storage yards. Thus a myriad of different materials which randomly end up on the earth's surface as a result of the usual activities of man, deliberate or accidental spillage, natural forces, etc., will be found in storm generated discharges over extremely wide ranges of concentration. Superimposed on these variations is the variation introduced by the hydrological cycle itself. Runoff from an urban area following a long dry period has the potential for conveying large quantities of pollutants "stored" in the area during that period. And if the precipitation producing the runoff is of high intensity and short duration, the concentration of the various constituents can be much higher than is ever experienced in municipal wastewaters during dry-weather. This is even further compounded if there is a build-up of materials in the combined sewer during dry-weather. It is for these reasons that the term "typical" when applied to the quality characteristics of storm generated discharges can be a serious misnomer.

PAST PRACTICES RELATIVE TO STORM GENERATED DISCHARGES

Quality Characteristics

A review of past investigations in the area of storm generated discharges can provide a valuable insight as to the quality characteristics considered to be the most useful to researchers from different parts of the country. With this objective in mind, a survey was made of thirty-eight reported studies to establish the frequency with which various characteristics were employed (1-38). Of the 38 studies, 31 were reported in U.S. EPA final reports and 7 were reported in technical journals. Thirty-five of the 38 studies were published in the 1969 to 1973 period, and of the remaining three, one was published in 1968, the other in 1966 and the earliest in 1942.

The results of the survey are summarized in Tables VI-2, VI-3, VI-4. Table VI-2 presents the results of all 38 studies, that is, studies which involve some treatment facilities, as well as studies which were simply concerned with the quality of storm generated discharges. As

Table VI-1. CLASSIFICATION, EXAMPLES, AND PRIMARY SOURCES OF POLLUTION FOUND IN STORM RUNOFF AND COMBINED SEWER OVERFLOW

Classification	Examples	Primary Sources[b]
Nutrients	Nitrogen, phosphorus	Lawn fertilizers, excreta
Organic matter	Waste food, excreta, decaying vegetation, humus	Litter, animals, lawns
	Oil, gasoline, other hydrocarbons[a], and various organo-industrial wastes	Motorized vehicles, industrial discharges and spillage
Inorganic salts	$CaCl_2$, NaCl	Roadway deicing
Toxic substances[a]		
Heavy metals	Zinc, copper, lead, nickel, mercury, chromium	Motorized vehicles, atmosphere washout, metallic corrosion and industrial discharges
Pesticides	Chlorinated hydrocarbons, organo-phosphorus	Spraying of lawns and gardens
Pathogenic bacteria	Fecal, total coliform, and fecal streptococci[c]	Excreta, garbage, soil
Particulates	Glass, stones, plastics, metals, aggregates from construction, inorganic portion of dust and dirt	Streets, sidewalks, buildings, litter and construction sites

a. Primary concern of these parameters is the aesthetic nuisance and danger to macroorganisms rather than oxygen demand.

b. In separate storm sewers these are the sources of contamination; in combined systems these are added to those already in the municipal wastewater.

c. Microorganism groups which serve as indicators of possible pathogens.

Table VI-2. USAGE FREQUENCY OF VARIOUS QUALITY CHARACTERISTICS IN PAST STUDIES INVOLVING STORM GENERATED DISCHARGES[a]

Quality characteristic	No. of times employed	Quality characteristic	No. of times employed
Biochemical oxygen demand (BOD)	34	Turbidity	5
Suspended solids (SS)	34	Organic nitrogen	5
Volatile suspended solids (VSS)	27	Conductivity	4
Total coliforms	25	Soluble phosphorus	3
Chemical oxygen demand (COD)	22	Chlorine demand	3
Total solids	20	Floating material	3
Total volatile solids	19	Total alkalinity	3
Settleable solids	19	Particle size distribution	2
Total kjeldahl nitrogen	18	Total hardness	2
Total phosphorus	18	Chlorine residual	2
Fecal coliforms	17	Ortho phosphorus	2
pH	17	Heavy metals	2
Fecal streptococci	11	Phenols	2
Oil and grease	10	Pesticides	2
Ammonia nitrogen	8	Calcium hardness	1
Nitrate nitrogen	6	Total inorganic carbon	1
Temperature	6	Dissolved BOD	1
Chlorides	6	Dissolved organic carbon	1
Total organic carbon	6	Dissolved solids	1

a. Survey of 38 studies.

Table VI-3. USAGE FREQUENCY OF VARIOUS QUALITY CHARACTERISTICS IN PAST STUDIES INVOLVING TREATMENT OF STORM GENERATED DISCHARGES[a]

Quality characteristic	No. of times employed	Quality characteristic	No. of times employed
Biochemical oxygen demand (BOD)	22	Ammonia nitrogen	3
Suspended solids (SS)	22	Chlorine demand	3
Volatile suspended solids (VSS)	19	Conductivity	3
Total coliforms	16	Nitrate nitrogen	2
Settleable solids	13	Particle size distribution	2
Total solids	13	Floating material	2
Total volatile solids	13	Chlorides	2
pH	12	Total hardness	2
Chemical oxygen demand (COD)	11	Organic nitrogen	2
Fecal coliforms	10	Soluble phosphorus	2
Total kjeldahl nitrogen	9	Calcium hardness	1
Total phosphorus	8	Total inorganic carbon	1
Oil & grease	7	Chlorine residual	1
Fecal streptococci	6	Ortho phosphorus	1
Turbidity	4	Total alkalinity	1
Temperature	4	Dissolved BOD	1
Total organic carbon	4	Dissolved organic carbon	1

a. Survey of 22 studies.

Table VI-4. USAGE FREQUENCY OF VARIOUS QUALITY CHARACTERISTICS IN PAST STUDIES INVOLVING ONLY IMPACT ON RECEIVING WATER[a]

Quality characteristic	No. of times employed	Quality characteristic	No. of times employed
Biochemical oxygen demand (BOD)	12	Oil & grease	3
Suspended solids (SS)	12	Organic nitrogen	3
Chemical oxygen demand (COD)	11	Temperature	2
Total phosphorus	10	Total organic carbon	2
Total coliforms	9	Total alkalinity	2
Total kjeldahl nitrogen	9	Heavy metals	2
Volatile suspended solids (VSS)	8	Phenols	2
Fecal coliforms	7	Pesticides	2
Total solids	7	Soluble phosphorus	1
Settleable solids	6	Floating material	1
Total volatile solids	6	Turbidity	1
Fecal streptococci	5	Conductivity	1
Ammonia nitrogen	5	Chlorine residual	1
pH	5	Ortho phosphorus	1
Nitrate nitrogen	4	Dissolved solids	1
Chlorides	4		

a. Survey of 16 studies.

might be expected, the BOD and SS were the most commonly used analysis, reflecting, no doubt, the common practice employed in the case of wastewaters and effluents. The second group in preference includes the total coliform, COD, kjeldahl nitrogen, total phosphorus, fecal coliform and a number of the solids analyses. Many of the remaining analyses were probably employed in individual studies for reasons specific to the given study. For example, heavy metal analyses were employed on only two of the occasions presumably because there was an interest in toxicant levels. The results in Tables VI-3 and VI-4 are much the same. It is interesting to note that in the case of the former, the BOD analysis was employed considerably more than the COD analysis for studies involving treatment of storm generated discharges. In the case of studies involving only impact on receiving waters, the BOD and COD analyses were employed with about the same frequency.

It is not being suggested that because certain quality characteristics were most commonly employed in the past that they necessarily become the characteristics of choice for future work. Most storm generated discharge studies are of fairly recent origin. In comparison, quality characteristics have been used in the area of water resources and water pollution control for many years. It would stand to reason that when interest in storm generated discharges began to increase sharply, analysts and other workers in the field looked to these related areas for guidance in the selection of quality characteristics. Experience in the last half dozen years or so has demonstrated that characteristics which have been suitable in the areas of water resources and water pollution control are not necessarily so for storm generated discharges. It is primarily this past experience which serves as the basis for the recommendations which will follow in subsequent portions of this section. It should also be kept in mind that the recommendations presented in this section reflect the results of experiences up to this point. It is reasonable to expect that future recommendations will change as additional experience with quality characteristics is gained and as environmental concerns and objectives are changed or altered.

Quality Characteristics Analysis Procedures

The usual approach for an analyst who is to conduct a given analysis on a water, sludge, or related sample for the first time is to first examine a procedure which has been recommended for the particular analysis. After examining the procedure critically he must determine if it is applicable to the sample involved. The physical characteristics of the sample and interfering materials often preclude the use of the recommended procedure as written. The analyst must modify the procedure to fit the situation at hand. Modifications to recommended procedures are developed by consulting recommended procedures used for other types of but related samples, by examining the current technical literature for published modifications, through the use of ancillary studies set up by the analyst himself in which a "recovery" approach is employed, by direct communications with other researchers or workers in the field, and by consulting with manufacturers of equipment used for laboratory analyses.

The above approach would be employed in the case of storm generated discharges and residues associated with these discharges. The recommended procedure which most logically would be examined initially is the one which appears in the latest edition of Standard Methods (39). An excellent companion reference which should be consulted at the early stages is the U.S. EPA publication entitled, Methods for Chemical Analysis of Water and Wastes (40). Many of the procedures in this manual are based on the recommendations found in Standard Methods (39) and ASTM Standards (41), but modifications are made in those instances where experience gained in federal water quality laboratories indicates an improvement in the accuracy and precision of a given analysis. In addition to the above, a number of other sources are available for the examination of recommended procedures. The Manual of Sea Water Analysis (42) may be helpful in those instances where high salinity or brackish waters are involved. For the analysis of residues resulting from storm runoff and combined sewer overflow applications, it might be helpful to consult the Methods of Soils Analysis (43) and the Methods for the Collection and Analysis of Water Samples (44). The latter, published by the U.S. Geological Survey, includes well proven analytical procedures for relatively unpolluted waters. In addition to the above, two recent publications of the U.S. EPA (45) (46) include useful information on the analysis and monitoring of wastewaters, though the information is not as detailed in the area of specific analysis as in the other references cited.

Recommended laboratory procedures are included in the discussions on the various quality characteristics which follow. For the most part the procedures recommended follow those presented in Standard Methods (39) and Methods for Chemical Analysis of Waters and Wastes (40). In each case modifications and cautionary comments are made based on the experience derived in recent years working with combined sewer overflows and storm runoff samples.

RECOMMENDED OXYGEN DEMAND POTENTIAL INDICATOR

The level of oxygen is critical for many types of aquatic life. A small decrease in the amount of dissolved oxygen (D.O.) in natural waters can result in stream deterioration and the disappearance of higher species of fish. A serious lack of dissolved oxygen can result in fish kills, odors and unsightly appearance of the body of water. An oxygen demand test is used as an indirect measure of the degradation of both chemical and biological matter by microorganisms and other chemical reactions. Since the effect of the decomposition is to use oxygen and this oxygen consumption has a critical effect on the environment, the oxygen demand test will measure the amount of oxygen consumed during microorganism activity and chemical oxidation. Although streams do have a limited capacity to absorb the oxygen demand of discharged materials through natural processes, there may be an excess of demand which results in a drop in the D.O. level in the stream itself. Therefore it is critical to have a method of measuring this demand so that the effect on the receiving stream may be evaluated. This is extremely critical in warm weather or climates where the rates of the oxidation reactions are increased and the solubility of the oxygen in the water is decreased.

Storm generated discharges have certain characteristics different from municipal sewage that affect not only the D.O. 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 69-87 percent (47) which is considerably higher than the 30-50 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.

When determining the effectiveness of the oxygen demand indicator it must be considered that the material may be in the aquatic environment for a considerable amount of time. Solids are deposited and resuspended over and over again and each time they may exert a reduced demand. Therefore a test of limited time may not indicate the true demand of the material.

Consideration of the importance of the oxygen demand test has led to the establishment of two criteria that must be satisfied to get a reasonable estimate of the oxygen demand. First the method should indicate the effect of the addition of the discharge on the oxygen content of the receiving water. That is, it should give an indication of the total oxygen demand on the water. Second, the method should have a standard procedure and precision so that valid comparisons may be made for overflow samples entering widely different types of receiving waters.

Due to its present and historical importance, oxygen demand should be comparable to results previously obtained. The oxygen demand tests in this report will be evaluated according to these criteria and the final selection of method will then be made.

Tests Available for Use as Potential Oxygen Demand Indicators

BOD_5 - This test is the most widely used in the analysis of oxgyen demand. BOD is defined as the amount of oxygen required by bacteria to stabilize decomposable organic matter under aerobic conditions (48). The standard procedure consists of placing a known amount of sample in a bottle and diluting it with specially prepared water containing appropriate nutrients and saturated with D.O. The initial dissolved oxygen content is noted and then compared to that measured after five days of incubation in the dark at 20°C. The amount of oxygen consumed by the microorganisms is assumed to be directly related to the organic material decomposed in the waste and therefore represents the oxygen demand on the simulated environment.

The advantages of the test are the following:

1. The biological conditions are somewhat similar to environmental conditions. The BOD test is the only biochemically oriented of the common oxygen demand procedures. This is the only test that approximates what may happen in the natural environment.

2. The test has been used for many years so a large amount of data is available for comparative work.

3. Little sophisticated instrumentation is needed. An incubator, standard size bottles and an oxygen measuring device are all of the special equipment that is required.

4. The test has achieved wide acceptance in the field of environmental control. Therefore almost all wastewater laboratories are equipped to analyze for BOD and they have a system of control based on this procedure.

However, the disadvantages must also be considered:

1. Toxic materials may suppress the BOD result. Since storm generated discharges may contain a large amount of heavy metals (11) and other materials which are toxic to the biochemical processes, the BOD may be lower than the actual oxygen demand.

2. The test has a five day lead time; thereby making immediate process control impossible.

3. The dilution theory of analysis is based on the assumption that the metabolism is proportional to the amount of material available to the microorganisms rather than the concentration of this material (49).

4. Seed bacteria are required perferably acclimated to the waste and this is not generally available with storm generated discharge samples.

5. Particulate matter may exert a large percentage of the BOD, and the oxygen demand of the particulates that settle during the incubation period may not be completely measured (47). Also, variation of particle size and density causes different rates of deoxidation due to metabolic surface to weight or volume relationships of the particles.

6. The nitrification demand may or may not be included in the standard five day test period.

7. The test may not be a good indication of what will actually occur in the environment. The turbidity and nutrient content of the receiving stream are different from the artificial aquatic environment created in the dilution water and the affect of sunlight and natural biological population are not simulated.

8. Since the test is run only five days, the actual percentage of the demand measured is unknown so the total oxygen demand is not determined. However, various techniques have been developed that will allow the calculation of the ultimate BOD and the reaction rate constant. A first order reaction equation is generally used to describe the BOD progression with time; namely,

$$y = L(1-10^{-kt})$$

in which, y = BOD, L = carbonaceous ultimate demand, k = reaction rate constant and t = time of sample incubation in days. Using this equation and a series of BOD determinations at varying time intervals, the values of "L" and "k" can be estimated by a number of different methods which vary in complexity and degree of accuracy (50)(51)(52)(53)(54).

Although it has been historically assumed that the k value for domestic waste is approximately 0.1 and therefore that the 5 day BOD is nearly 67 percent of the ultimate, this has been found inaccurate for a number of wastes. Therefore estimations of this type are incorrect and the only way to find the actual value of the ultimate BOD is to have a series of values determined at varying times. Figure VI-1 illustrates how different wastes could have the same BOD_5, but because of different rates of deoxygenation, the ultimate demands are significantly different.

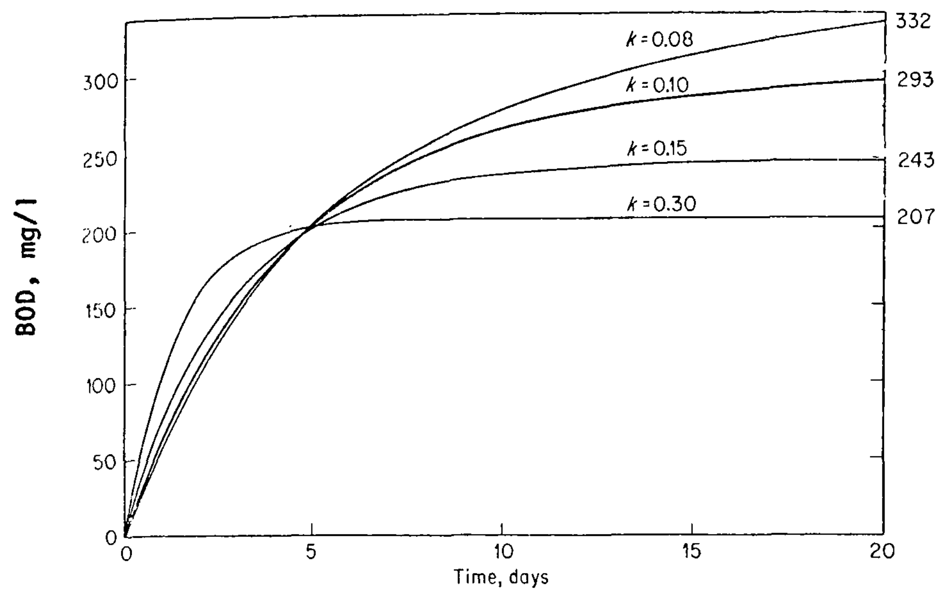


Figure VI-1. Illustration of the danger in estimating the ultimate demand without knowledge of the rate of deoxygenation (k)

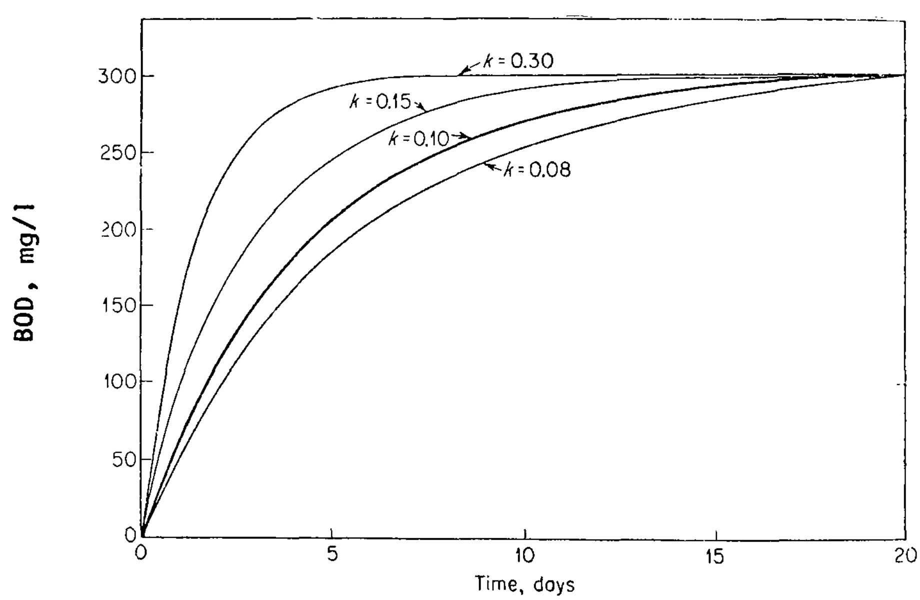


Figure VI-2. Illustration of how the BOD_{20} lessens the effect of different rates of deoxygenation (k)

(Figures based on those in reference 48.)

When evaluating the advantages listed, it seems the most important advantage is that the test is well known. It has been standardized and large amounts of historical data are available. It must also be recognized that the performance of this test is required for many regulatory agencies. Another important advantage is that the BOD_5 test directly measures the biochemical demand, and an equation can be used to compensate for temperature changes in the receiving water.

However, ther are certain disadvantages that are more critical with storm generated discharges. The presence of toxic material can cause a reduction in the total demand without the knowledge of the analyst, since the seed does not have enough time in the five days to acclimate sufficiently to exert the full BOD. Also the particulates in the sample may not be completely included in the result and the nitrogenous demand may not be included. The knowledge of the exact percentage of total demand exerted is unknown and the artificial environment created may cause the biochemical demand measured to be different from the actual demand under natural conditions (48). Therefore the criteria of a measure of the total demand for oxygen is not sufficiently met. However, the need for a standard procedure has been accomplished.

<u>BOD_{20}</u> - The BOD_{20} test is used to better estimate the ultimate or final oxygen demand of a waste. The main advantage is that the importance of estimating the correct k value is reduced. It can be seen in Figure VI-2 that as the BOD approaches the ultimate value, the variation caused by different k values is lessened. Therefore, the advantage of a longer incubation time is apparent. Other advantages include the fact that a significant percent of the nitrogenous demand is included and the effects of toxicity are less since the organisms have had sufficient time to adapt to the environment (49). The major disadvantage is the time needed to achieve results.

<u>BOD_x</u> - The BOD_x test can be run for times less than five days or greater than twenty days. For the longer period of time, the advantages and disadvantages of a BOD_x are the same as for BOD_{20} with one exception. The longer the time allowed, the closer the test approaches the ultimate value of BOD and therefore eliminates the guesswork in determining the final effect on the environment.

Short term tests are used to allow the BOD to be estimated over a shorter time and possibly used for control purposes. This has been found successful in certain areas but considerable testing is usually necessary to allow correlations to standard tests. Another problem is that this is not a standard procedure and good comparative data are not available.

<u>ΔCOD Test</u> - The delta COD test is used to give a better measure of the true biochemically oxidizable matter without having some of the inherent difficulties of the standard BOD test (11) (55). In the ΔCOD test a

wastewater is put in an Erlenmeyer flask with a stirring magnet, and the flask is incubated at 20°C. By measuring the COD initially and at various time increments it is possible to get the decrease in COD with time, and determine a rate constant (k). The COD will decrease to a certain level and then decrease at an extremely slow rate thereafter. The difference between the initial COD and the COD when the decrease becomes asymptotic is considered to be the biodegradeable COD and analagous to the BOD. Figure VI-3 below illustrates this concept.

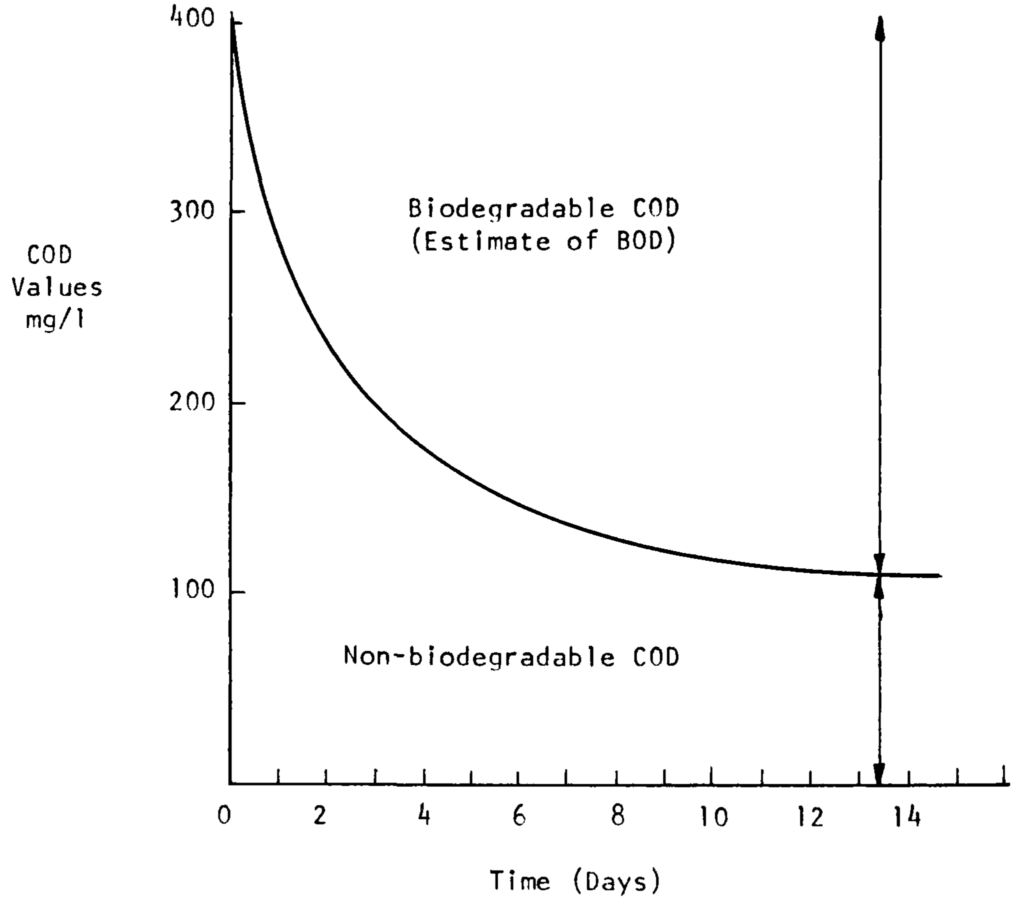


Figure VI-3. Illustration of the COD value becoming asymptotic with time when held at 20°C

This test was developed as a substitute to the BOD to eliminate problems with variable dilutions causing inconsistency in data. However, it must be remembered that since no dilution water is added in the ΔCOD test, the ultimate concentration of toxic materials would be higher, further slowing the degradation process. Therefore the potential toxicity problem would also be greater. The dilution factor as discussed by Colston (11) may become an asset when it is considered that once a material is discharged into an aquatic environment it is naturally diluted. Therefore the dilution which is apparent in the BOD test may more closely simulate the environmental conditions. Finally it must be remembered that this test is subject to the limitations of the COD test which can be considerable in storm generated discharges as discussed in this section.

Other Biochemical Demand Tests - Other tests are also used to determine total oxygen demand and employ the use of various instruments. The Warburg test and other short term uptake tests allow an unlimited supply of oxygen with intermittent readings taken in order to determine the rate curve. Also BOD tests with continuous mixing (e.g. Hach Method) have been developed and will consistently yield higher values of demand since fresh interface is constantly available to the microorganisms (56). However, all of these tests are subject to the same type limitations as the BOD and have the additional disadvantage of not being routinely used or standardized.

COD (Chemical Oxygen Demand) - The COD test is not an attempt to reproduce the biological conditions of oxidation, but instead the wastes are chemically oxidized. There is no inherent relationship between the COD and BOD tests because the mechanisms of reaction are different.

The actual test is based on the principle that most types of organic matter are decomposed when boiled in a mixture of potassium dichromate and sulfuric acid. Known amounts of potassium dichromate and sulfuric acid are refluxed with the samples for two hours. Mercuric sulfate is added to complex the chlorides and silver sulfate to catalyze the hydrocarbon oxidation. The excess dichromate is titrated with ferrous ammonium sulfate and the amount of dichromate consumed is related to the oxygen demand of the material.

The following list of advantages will indicate why the COD test has received relatively wide acceptance.

1. The short amount of time for analysis (two to four hours).

2. Particulates have little effect.

3. Relatively little attention or equipment maintenance required.

4. Not affected by toxic wastes.

However, as with the BOD test, there are serious disadvantages which must be considered.

1. The most critical problem has been the chloride interference. The chloride ion will react with the dichromate in the following manner:

$$Cr_2O_4^{=} + 12Cl^{-} + 14\ H^{+} \rightarrow 2Cr^{3+} + 2Cl_2 + 7H_2$$

   Although the effect is stoichiometric and can be corrected, there are other mechanisms which complicate the system. A silver sulfate catalyst is added to allow the complete oxidation of the short chain hydrocarbons and the chloride ion will form a silver chloride complex that is not completely oxidized. Mercuric sulfate is used to tie up the chlorides as mercuric chloride (57)(58), a soluble complex, however the actual percentage of the chlorides affected is dependent on the waste and the apparatus. At low COD values that may be present in storm generated treatment process effluents, the presence of chloride ions (especially from salt laden ice and snow melt) will significantly affect the results (59)(60). Also, some inorganics, such as bromides and iodides, which would normally not cause an oxygen demand are oxidized and included in the COD value.

2. Not all of the organics are oxidized, notably the aldelydes and fatty acids.

3. The nitrogenous demand of the material is not included in the determination.

4. Chemical costs are high, and toxic chemicals such as mercury and silver are wasted to the environment. Also, operating and labor costs outweigh the gain in less expensive equipment costs.

In evaluation of the COD test, the advantage of relatively wide field acceptance is important. In storm generated flow work the fact that the COD test is relatively unaffected by toxic materials, particulates and materials with variable rates of deoxygenation is a major advantage. However, the problem with the chloride interference may be paramount. Although many studies have been made, the use of mercuric sulfate is still the recommended way to remove the chloride interference and this is not acceptable when dealing with storm generated flows. The nitrogenous demand is not satisfied and some inorganics are included that would not exert a demand. Therefore the actual significance of the value determined is not known.

TOC (Total Organic Carbon)- The TOC analysis is a measure of the amount of organic carbon in the sample and this theoretically can be related to an oxygen demand. In the TOC analysis, the sample is injected into a stream of oxygen passing through an oven at 950°C. The carbonaceous material is immediately oxidized to CO_2 and H_2O. The CO_2 is measured by an infrared analyzer or converted to methane where it is measured by a flame ionization detector. The inorganic carbon is either removed by acid pretreatment or analyzed in a separate channel to allow calculation of organic carbon by difference. There is an automatic recording of all readouts so a continuous record is available (61)(62). The advent of sophisticated instrumentation allows this analysis to be performed in a matter of minutes.

The advantages of the TOC are listed here.

1. Quick method of analysis.

2. Simple procedure.

3. Accurate in measuring the carbon since there are few interferences.

4. Not affected by toxic materials.

The disadvantages are:

1. No direct relationship to oxygen demand since only carbon is measured.

2. The nitrogenous demand and inorganic oxygen demand are not included. This is especially true of sulfides and nitrites that can be present in storm flows.

3. It is assumed all organics are oxidized.

4. Particulates may interfere with the operation of the instrument.

5. Expensive equipment is needed which may require considerably maintenance.

Although TOC is an accurate method of measuring carbon with reproducible results, the exact relation to oxygen demand is unknown. Even though the theoretical relationship of carbon to oxygen is straight forward,

$$C + O_2 \rightarrow CO_2 \qquad \text{and} \qquad O_2/C = 2.66$$

the actual calculation is complicated because carbon is available in many forms, some of which include oxygen. Therefore the theoretical value cannot be found unless the exact chemical formula of the constituents of the waste is known. This lack of a direct relationship to oxygen is the most critical factor in evaluating this analysis and is the biggest disadvantage. The major disadvantages are the high equipment cost, the possibility of extensive maintenance, and the fact that any demand exerted by a material other than carbon cannot be measured.

TOD (Total Oxygen Demand) - The TOD analyzer is an instrument that has been developed to measure total oxygen demand directly. The sample is injected into a stream of nitrogen and a known amount of oxygen. As the material passes over a platinum catalyst at 900°C, the oxidizable portions of the sample are oxidized and there is a momentary depletion in the oxygen on the platinum surface. This is replenished by the gas stream and simultaneously the reduction of oxygen in the gas is measured by a silver-lead fuel cell detector and recorded. The amount of oxygen needed to oxidize the materials in the sample is used to determine the Total Oxygen Demand (63).

The advantages of this analysis are:

1. The actual total oxygen demand is measured.

2. Common ions, including chloride, have little or no effect.

3. All organics are oxidized over the catalyst.

4. Results can be obtained in minutes.

5. Accurate and precise measurement is possible.

6. Toxic materials have no effect.

The disadvantages are:

1. More materials may be oxidized than will actually exert a demand on a receiving stream.

2. Expensive instrumentation is needed.

3. Particulates may clog instrument thus necessitating blending.

When the criteria for optimum oxygen demand tests are examined, the TOD satisfies the need for complete demand measurement. The direct measure of oxygen demand is a great advantage and the speed of analysis enhances the procedure. The high cost of equipment and of possible maintenance may be a problem. The fact that this is a relatively new type of instrument can be a disadvantage since large amounts of comparative data are not available. Another problem is that the TOD may overestimate the oxygen demand since it is a chemical rather than a biochemical test.

Other Chemical Oxidation Demand Tests - In order to reduce the time needed for traditional COD tests, a number of techniques have been developed. Twenty and thirty minute tests have been tried and they result in standard values for certain materials. An instrument which can establish a COD value in two minutes is termed the CO_2D analysis (64). In this system the sample is injected into a carrier gas of carbon dioxide in a combustion furnace where the organics are oxidized to carbon dioxide, carbon monoxide and water. The water is removed and the carbon dioxide converted to carbon monoxide which is measured by an infrared detector. The value is directly related to the COD of the sample and is interpreted as COD through a calibration chart. Another device pyrolyzes the sample and uses a gas chromatographic analysis of the constituents (65). The major problem with these tests is that they must be standardized against the normal COD test which has well documented disadvantages as discussed earlier.

Recommendations

When the two established criteria, 1) the measurement of a total oxygen demand on the environment and 2) a standardized test procedure, are applied to the tests outlined as oxygen demand indicators, it becomes apparent that none of the avialable analytical tests alone can satisfy both requirements. Therefore, it is recommended that two tests, the TOD and BOD_5, be used to give a satisfactory measure of the potential oxygen demand and to allow the desired historical data comparisons. The TOD test was chosen as the indicator of total potential oxygen demand and the BOD_5 test, run with minor modifications for storm flows, satisfied the need for a comparative and biochemical test. Although it is not convenient to run both tests as an estimate of a single parameter, the importance of the oxygen demand indicator needs special treatment.

The rationale behind the choice of TOD is based on the theoretical concept of oxygen demand. Most of the tests outlined equate the carbonaceous oxygen demand to the total oxygen demand and this is not necessarily true. Organic nitrogen, sulfur, ammonia, sulfides, nitrites and other reduced compounds exert an oxygen demand and they can be present in storm flows. Therefore the COD and TOC tests which do not include these materials cannot be correlated with a TOD in many cases. Another consideration is that a large amount of particulate organic matter will be suspended and resuspended over long periods of time in the aquatic environment, and this may cause a considerable change in the D.O. content of a receiving body of water. Therefore, the test must include the long term demand to allow correct determination of the effects on the aquatic area to which the material has been discharged.

The TOD test has other advantages, especially the lack of interference which is a serious problem with other tests, notably COD. Although the chloride ion affects TOD results at chloride values greater than 20,000 mg/l, compensation may be made by spiking the standards with the chloride ion at the same concentration. Therefore the troublesome ion has little permanent effect.

The disadvantages of TOD are mainly the high cost of equipment and the possibility of extensive maintenance. Another disadvantage is the lack of a distinct stoichiometric relationship between nitrites and sulfides and the oxygen demand (66). However, since most other tests neglect these demands completely, at least the TOD includes some measure of them so that a certain effect can be determined.

The BOD_5 test is also recommended because the TOD test cannot satisfy the need for a standardized, well-documented test for oxygen demand. The use of BOD_5 is so widespread and so often required by regulatory agencies that elimination of this test would be difficult. Therefore, the BOD_5 test, with minor variations for storm flows which would allow the measure of BOD_5 to be more representative, is recommended. These modified procedures include the use of wide mouth or broken tip pipettes, specific dechlorination and desaturation procedures and well mixed samples. Although the test does have numerous disadvantages, results can be compared with the immense amount of histroical data available and this yields valuable information. The problem of toxicity effects on the BOD_5 can be used to advantage. Comparison of the BOD_5 and TOD results could yield some qualitative information about the degree of toxicity present in a sample and the possible effect on the natural environment.

A comparative representation in summary form of the qualitative merits of the various available tests discussed is found in Table VI-5. This table includes the major parameters that are important in determining a potential oxygen demand indicator. Table VI-6 presents an arbitrary representation of certain key variables on the ideal test for oxygen demand. It can be seen that the TOD and BOD_5 tests had scores closest to the ideal. However, it is interesting to note that the lowest and highest rating are different by the same amounts as the ideal rating and the best rating.

Procedures for Oxygen Demand Indicator Tests

The following procedures are recommended for the determination of oxygen demand. For the instrumental method tests, operation of the instrument according to the manufacturers specifications is recommended.

General Sample Storage - Sample storage for oxygen demand tests is generally refrigeration at 4°C. Acid pretreatment may be used but it should be avoided in samples that are to be biochemically analyzed (specifically the BOD tests), in samples where an emulsion is broken with acid addition, or in samples where the nature of the particulate

Table VI-5. SUMMARY COMPARISON OF VARIOUS POTENTIAL OXYGEN DEMAND TESTS

Parameters	BOD_5	BOD_{20}	COD	TOC	TOD
Organics	indirectly	indirectly	indirectly	directly	indirectly
Inorganics	no	no	yes	no	some
Biochemical demand	yes	yes	no	no	no
Chemical demand	some	some	yes	no	yes
Toxic materials	yes	yes (less than BOD_5)	no	no	no
Interferences	toxic	toxic	Cl	none	none
Initial cost	medium	medium	medium	high	high
Operating cost	average	average	high	low	low
Maintenance cost	low	low	some	high	high
Routine analysis	yes	yes	yes	no	no
Nitrogenous demand	no	yes	no	no	yes
Particulate effect	partly included	partly included	included	included	included
Sand/grit effect	no	no	no	yes	yes
Kinetics	yes	yes	no	no	no
Time for analysis	days	many days	hours	minutes	minutes
Pretreatment	none	none	blending preferred	blending/ microblending	blending/ microblending
Storage time	6-24 hours	6-24 hours	1 week w/acid preservation	2 wks w/acid or freezing	2 wks w/ acid or freezing

Table VI-6. EFFECT OF IMPORTANT VARIABLES ON POTENTIAL OXYGEN DEMAND TESTS

Variable	Ideal oxygen demand test	BOD_5	BOD_{20}	COD	TOC	TOD
Biodegradeable organics measured	1. Measure all O_2 needed	3. Some-not all (approx 70%)	2. Most-not all O_2 needed	2. Most-not all O_2 needed	1. Measures all O_2 needed	1. Measures all O_2 needed
Non-biodegradable organics (cellulose, plastics, etc.) measured	1. Should have no effect	1. No effect	1. No effect	3. Most-not all O_2 needed	4. Measures all O_2 needed	4. Measures all O_2 needed
Reduced inorganics (NO_2^-, $SO_3^=$, $S^=$ etc.)	1. Measure all O_2 needed	1. Measures all O_2 needed	1. Measures all O_2 needed	1. Measures all O_2 needed	4. No effect	1. Measures all O_2 needed
Kjeldahl nitrogen measured	1. Measure all O_2 needed	3. May measure some O_2 needed	2. Measures almost all O_2 needed	4. Measures none of O_2 needed	4. No effect	1. Measures all O_2 needed
Inert inorganics measured (Cl^-, $SO_4^=$, NO_3^-, Na^+, Ca^{++}, etc.)	1. Should have no effect	1. Little or no effect	1. Little or no effect	3. Measures some chlorides & other halides	1. No effect	1. No effect
Toxic materials effect (Hg, Pb, CN, Phenol, etc.)	1. Should have no effect	4. Serious effect	3. Serious effect	1. No effect	1. No effect	1. No effect
Time of analysis	1. Results in minutes	3. Results in days	4. Results in weeks	2. Results in hours	4. Results in minutes	1. Results in in minutes
Historical data available	1. Much data	1. Much data	4. Little data	2. Some data	4. Little data	4. Little data
Total points	8	17	18	18	20	14

Rating points:
1. Matches ideal test.
2. Slightly different than ideal.
3. Greatly different than ideal.
4. Completely opposite from ideal.

matter has an effect on the analysis. Generally, for any procedure that is affected by the addition of acid, the sample should not be preserved with acid. Therefore, only refrigeration is recommended.

Specific Procedures - TOD Analysis -

1. Sample pretreatment - Samples should be homogenized at nameplate high speed in a Waring blender immediately after being received in the laboratory in order to reduce the size of the particulate matter to less than the size of the syringe (150 microns). A tissue grinder can be used if the blender is not satisfactory.

2. Special considerations for storm flow samples.

    a. Prior to actual analysis of the sample in the instrument, the material should be further homogenized using a tissue blender.

    b. It is critical that when removing a sample from the large container, that the material be well mixed to insure inclusion of a homogenous mixture of all solids that exert an oxygen demand.

3. Sample storage and preservation.

    a. Samples should be analyzed as soon as possible and can be held 48 hours with refrigeration at 4°C in most cases.

    b. Sulfuric acid or freezing can be used to preserve the sample up to two weeks if this produces no apparent physical change in the sample. The formation of free oil or the precipitation or coagulation of solids is to be avoided.

4. Analysis for oxygen demand.

    a. Follow manufacturer's instruction for analysis.

    b. Calibration curves are recommended for all ranges of TOD used.

Specific Procedures - BOD Analysis -

1. Sample pretreatment - none.

2. Special considerations for storm flows.

    a. Samples should be well mixed before they are removed from the original containers. Some type of stirrer or shaker is recommended when the aliquot is being withdrawn so that a representative amount of a homogenous mixture of all solids is included in the analysis.

    b. Large mouth or broken tip pipettes should be used to insure inclusion of large particulates.

    c. Homogenization of the sample is not recommended for routine analysis. This process could change the characteristics of the waste and give an erroneous representation of demand.

    d. The recommended seed is untreated storm flow that has been settled for one hour. The normal concentration is 1 ml/BOD bottle or approximately 3 ml/l.

3. Sample storage and preservation - Samples should be analyzed within six hours if possible or twenty-four hours maximum. They should not be preserved with acid. Refrigeration at 4°C is recommended.

4. Analysis for oxygen demand.

    a. This procedure is found in Standard Methods, p. 495, Method 220, (39).

    b. The direct pipetting technique is recommended for analysis of storm flows. The desired aliquot should be directly pipetted into the BOD bottle and the material diluted to the specified volume with the special dilution water.

    c. The initial DO reading is taken using a membrane electrode with bottle stirrer and meter.

        1) The meter should be standardized using the manufacturers instructions and checked at each standardization by

titration against the Winkler/Azide method for dissolved oxygen. Correlation should be within 0.1 mg/l.

2) If a probe is not avialable, duplicate bottles should be used and a Winkler/Azide modification titration run in one bottle while the other is incubated (Standard Methods, p. 477, Method 218B (39)).

d. A glucose - glutamic acid test should be run periodically to check the method. It is important that this be run each time new nutrients are made and periodic checks are highly recommended.

5. Special attention should be given to the following.

a. Bottle Washing - Special care must be taken to insure that the bottles used in the analysis are free of all organic contamination. Chromic acid wash is recommended followed by thorough rinsing.

b. Dilution Water - This is freshly prepared by adding the proper amount of nutrients to a high quality distilled or demineralized water, aerating, and allowing it to stand until it stabilizes. The quality of the water used to prepare the dilution water should be checked periodically for toxic metals (e.g. Cu) when distilled water is used or for organics when demineralized water is used. Water should be stored in dark containers.

c. Dechlorination - All samples should be spot checked for chlorine content. The dechlorination procedure outlineed on page 491 of Standard Methods (39) should be followed.

d. Supersaturation Removal - The temperatures of the samples should be ckecked and if they are under 20°C the material may be supersaturated with oxygen. The sample should be warmed to 20°C and aerated to remove excess oxygen.

e. A water seal should be present on all bottles and a cover provided during incubation. The bottles recommended are described in Standard Methods (39).

Specific Procedures - COD Analysis -

1. Sample pretreatment - Sample should be homogenized in a blender immediately after received in the laboratory.

2. Special consideration for storm flows.

   a. Extra clean glassware is necessary at all times because the percent of organic matter oxidized must be the same and small contamination can cause significant error. Therefore cleaning with chromic acid and special rinsing is recommended. It is also recommended that flasks and condensers used for the COD digestion be segregated and not used for other purposes involving organics.

   b. A well mixed sample should be taken before and after homogenization to include a representative amount of solids in the aliquot.

3. Sample storage and preservation - Samples can be stored up to one week when preserved with 2 ml of concentrated H_2SO_4 per liter and refrigerated. Acidification should be avoided, however, if free oil is present or if the sample is altered in some manner it is difficult to obtain a representative sample.

4. Analysis for oxygen demand.

   a. The method as outlined in Standard Methods, pp. 495-500, Method 220, (39).

   b. The dilute method on p. 498 (Section 4c) of Standard Methods is recommended for samples having low COD values.

   c. Be sure sample containers are very clean to prevent contamination.

Specific Procedures - TOC Analysis -

1. Sample pretreatment - Samples should be homogenized in a blender (in the same manner as the TOD test) and placed in test tubes or small jars and covered.

2. Special considerations for storm generated discharges.

   a. Prior to analyzing the actual sample, homogenization in a tissue blender is required.

   b. The sample must be kept well mixed whenever an aliquot is withdrawn.

3. Sample storage and preservation.

   a. An acidified sample, refrigerated, can be stored up to two weeks.

   b. Analysis should be done within forty eight hours on refrigerated samples with no acid pretreatment.

4. Analysis for oxygen demand.

   a. For actual analysis, follow the procedure outlined by the manufacturer of the instrument.

   b. Calibration curves are necessary for all ranges.

Analysis of Dissolved Portion - When it is desired to determine what fraction of the demand is in the soluble form, the sample should be double filtered since storm flow samples are quite often high in particulate concentrations. First the sample should be filtered through Whatman 40 or 541 filter paper followed by a second wash through .45μ Milipore filters that are prewashed with distilled water.

RECOMMENDED MEASUREMENT OF PARTICULATE CONCENTRATION

One of the quality characteristics of greatest interest in the case of storm flows is the particulate concentration. For the purposes of this discussion only, particulate matter is defined as solids which are retained on a filter medium following passage of a water sample. The fraction retained depends to some extent upon the medium selected. This matter, as well as other possible particulate parameters will be discussed in a subsequent portion of this section devoted to recommended laboratory procedure. The solids which pass the filter can be characterized as dissolved and colloidal. These solids are too small to be influenced by the forces of gravity or buoyancy. Most particulate solids on the other hand are influenced by these forces, but there is a wide variation as to the extent of this influence depending upon the size distribution and specific gravity of the particulate fraction involved. These properties of the particulate solids conveyed by combined sewer overflows and storm runoff are of interest in that they have a significant effect on the design and operation of treatment devices used, as well as the impact of these flows on receiving waters.

Nature of Particulate Solids

There is a tremendous array of particulate solids that can be conveyed by storm generated discharges. The solids can be divided into the common broad categories of inorganic and organic. Much of the inorganic particulate solids originate from storm runoff and infiltration. Included in this category are the clays, the fine to coarse sands, pea gravel, weathering fragments from concrete and bituminous pavements, walkways and parking lots, metal filings and pieces, etc. The scouring potential of high intensity rainfall requires that stones, rocks, and even larger inorganic debris be added to this particulate fraction. The wastewaters mixed with the storm runoff can also contribute inorganic particulates but this contribution is usually minor in comparison to storm runoff. Zanoni and Rutkowski (67) for example, found that the total suspended solids in a strictly domestic wastewater averaged 175 mg/l and of this total, only 19 mg/l or 11% was in the "fixed" or inorganic category.

The organic particulate solids in storm flows can originate from the dry-weather wastewaters and storm runoff. These solids are conveyed easily by storm runoff because their specific gravity is generally very close to that of water. Included are wood chips and fibers, pieces of leaves, stems, grass particles and related plant parts, seeds, grain parts, pollen, remnants of fruits and vegetables, paper and cardboard bits, organic fragments from peat, loam and similar soils, animal droppings, industrial spillage, vehicle residue plus an almost endless list of related materials. The extent of the contribution of organic particulates from wastewater depends upon the percentage of flows from this source in the total overflows, but usually it is comparatively small. The organic fraction in wastewaters originates from body wastes, food scraps and from numerous industrial operations which might be included in the system. Breweries, paper and pulp, and packinghouses are examples of industries that could contribute a sizable fraction of organic particulates.

The fact that it is the organic particulates which exert an oxygen demand is another reason why there is interest in identifying this fraction. The removal of organic particulates from storm generated discharges results in the removal of oxygen demanding constituents as well. The work of Hansen, Gupta and Agnew (17) in combined sewer overflow studies at two Wisconsin cities demonstrated that the contact stabilization process and a physical-chemical process were effective in removing BOD because in both cases approximately 70% of the organic pollutants were of a particulate nature.

Variation in Particulate Concentration

One of the important features of particulate concentrations associated with storm flows is the tremendous variation in possible values, even at one outfall site. There are a number of reasons for this, among the most important of which are:

1. Intensity and duration of the rainfall. High intensity rains result in higher rates of overland flow with an associated increase in scour. If the velocity is sufficiently high in the conduit, the scoured particulates will be conveyed to an outlet point. If not, the particulates settle to the bottom of the conduit. A number of studies with storm flows have shown rather conclusively that the particulate concentration conveyed is directly proportional to rate of discharge, that is, peak concentrations occurred during the peak discharge period (7)(9)(67)(68). This relationship may be partly the result of conduit scour. The velocity of flow in a circular conduit increases with each incremental increase in discharge; the former increasing at a faster rate. These high velocities cause the scour of heavy particulates. Only a few of these particulates in a sample can influence the resulting concentration value greatly.

2. Duration between rainfall events. Each day a certain amount of dirt, dust, particulates, litter and debris of all types accumulates on the land surface of urban areas. Rainfall and thaws "wash" this material into separate storm and combined sewers. Naturally, the longer the time between runoff events, the greater will be the amount of particulates removed from the surface. The higher "first flush" particulate concentrations reported by some investigators (7)(17)(69) is no doubt the result of the initial scour of the lighter fraction of this accumulated debris as well as the same material deposited in combined sewers during dry-weather periods.

3. Characteristics of the drainage area. Land runoff from industrial yards, material storage areas, produce storage and industrial centers, railroad yards, truck depots, erosion from construction sites, etc. would be expected to convey more particulate debris than from well kept residential areas and parks. Grass areas and other vegetated regions tend to retard flow, increase infiltration and consequently reduce scour. Central city areas which include mostly paved areas and roof tops can also be the origin of much particulate matter. General community cleanliness including municipal street sweeping practices has a significant effect on the amount of particulates which will eventually end up in a storm generated discharge.

For the above reasons, it is difficult to predict the concentrations of particulate matter which one can expect in combined sewer overflows and storm runoff. Peak concentrations in the 10,000 to 20,000 mg/l range are not unusual. After several hours of rainfall, concentrations of 100 to 200 mg/l are commonly reported. The work of Burm et al (8) is particularly interesting in this regard since they compared storm runoff concentrations with combined sewer overflow concentrations in the Detroit area for a number of constituents. In the case of particulate concentrations they reported the following:

	Storm System	Combined Sewer System
Suspended Solids (mg/l)		
Maximum	11,900	804
Annual Mean	2,080	274
Settleable Solids (mg/l)		
Maximum	11,100	656
Annual Mean	1,590	238

Weibel et al (69) found that particulate concentrations from a separate storm sewer area in Cincinnati exhibited the greatest variation of all parameters evaluated, as well as the only parameter which exceeded the loading from a separate sanitary sewer area. They obtained the following summary results:

	Range	Mean
Turbidity, (JTU)	30-1000	170
Suspended Solids (mg/l)	5-1200	210

The values reported by Weston, Germain and Fiore (70) for the Washington, D.C. area are interesting when the particulate concentration for domestic raw wastewater, combined sewer overflows and storm runoff are compared. The fact that the BOD of the latter two flows is very low compared to the suspended solids indicates that a large fraction of the particulates are inorganic, or if organic, resistant to microbial degradation.

	Raw Domestic	Combined Sewer* Overflow	Storm Runoff
Biochemical Oxygen Demand (mg/l)	250	71	19
Suspended Solids (mg/l)	220	622	1697

*Average of 18 storms

Finally, the results obtained at the Hawley Road combined sewer overflow in Milwaukee (17) are interesting in that the particulate concentrations obtained during "first flushes" are compared to those obtained during "extended overflows". In the case of the former, a mean suspended solids value of 522 ± 150 mg/l (95% confidence level) was obtained for 12 overflow events, whereas in the case of the latter the value was 166 ± 26 mg/l (95% confidence level) for the case of 44 overflow events. It is noted the first flush concentrations are more inherently variable than the extended overflow concentrations which is to be extpected.

Possible Particulate Analytical Procedures

There are a number of different analytical procedures which can be used to quantitate the concentration of particulate matter in combined sewer overflows and storm runoff. No one procedure satisfies all the requirements desired for the determination in question. One procedure favors the lighter fraction of the particulates whereas another favors the heavier fraction. The procedure that is most desirable for evaluating a particular treatment process is not necessarily the best for assessing the impact of a particular discharge on a receiving water body. The advantages and disadvantages of five possible procedures follow.

Total Residue - One possible measure of particulate matter is to determine the total residue in a sample following evaporation of a known aliquot. The advantages of this procedure are that it is a measure of the total residue present in the sample, both undissolved or particulate and dissolved, and that the laboratory procedure is basically a very simple one. The disadvantages are that one large particulate particle such as a pebble has a disproportionately large effect on the final results, and that generally, the dissolved fraction is of minor interest in most combined sewer overflow and storm runoff applications. Treatment devices and systems which have been applied to these discharges have for the most part been directed toward the removal of as large a fraction of the particulates as possible. Including the dissolved fraction in the analysis procedure tends to reduce the sensitivity of this parameter for such applications. It is true that the dissolved fraction of residue in storm flows is generally low in comparison with the undissolved fraction, but at times it can be quite high. Examples of the latter are during the early thaw period in northern communities when deicing chemical concentrations are high, or in the case of the effluent of treatment devices which are effective in removing the particulate fraction.

It is common practice when a total residue analysis is made to determine the fractions of the total which are volatile and fixed. The total volatile residue in the sample is of particular interest since it consists primarily of organic matter. In fact some investigators have used the total volatile residue determination as an indirect measure of the amount of oxygen demanding matter in a sample, in lieu of or in addition to the BOD or the COD. The use of the total volatile residue determination as an oxygen demand parameter is reasonable as long as the amount of inorganic salt decomposition during the high temeprature analysis step is minimal. This is presumed to be the case for the type of total residue found in most storm flow samples.

Settleable Residue - This analytical procedure is particularly useful for those applications where gravity separation is used to remove particulates from storm generated discharges. It also provides a more sensitive parameter to estimate the extent of potential bottom deposits below an outflow point. It is a cumbersome test to run in comparison to other particulate analytical procedures, since a large sample must be settled in the laboratory for a period of one hour or more. The test is not a particularly sensitive one for those situations where physical treatment methods such as straining, filtration or flotation are employed. The settleable solids concentration to these treatment units will naturally be quite high, particularly during the "first flush" period. The effluent concentration, on the other hand, would be close to zero, and yet these processes are designed to remove solids in the size distribution smaller than what is included in the settleable fraction. Again, the use of this analytical procedure is meaningful where the treatment device involves gravity separation.

Flotable Residues - Particulates with a specific gravity less than that of water represent a special class of particulates in storm generated discharges. All such flows include some particulates within this category. These generally include the organic substances such as grease globules, twigs, leaf and grain parts, fibers and related materials. The amount of these flotables depends greatly on the characteristics of the drainage area and the rainfall pattern. In terms of oxygen demand it it possible that this fraction might be more significant in some areas than the settleable fraction. Usually from a weight standpoint, the settleable fraction is still considerably greater, but from the standpoint of impact on the environment, it can be less important than the lighter flotable fraction.

The main objections to the use of the flotable particulate fraction are the difficulty in getting a representative sample and in conducting the analysis itself. A two step operation must be used; first a quiescent storage step to allow the flotables to accumulate on the liquid surface followed by a separation and weighing step.

Turbidity - The principal advantage of using turbidity as a measure of particulate concentration is that this parameter is amenable to continuous automatic monitoring. Stegmaier (9) showed that the turbidity value of storm runoff correlated well with fixed residue and total residue values in a number of time series studies conducted in the City of Baltimore. In spite of this, the turbidity measurement is not a sensitive parameter for evaluating the efficiencies of treatment processes which would normally be involved. For this reason this parameter has never gained favor in the wastewater treatment field as well. The particulate fraction associated with turbidity is a very small percentage of the total particulate fraction of most storm flows, and thus this parameter is of little interest in most situations where impact on receiving water is a major concern. It is conceivable, however, that a situation might arise where it is necessary to treat storm generated discharges to a point where low turbidities are desirable, as for example, discharges into certain recreational areas or fish stocking ponds.

Suspended Residue - The suspended or nonfilterable residue has been one of the most common parameters used for determining the fraction of particulate matter in wastewaters. As discussed earlier, it has also been used extensively for storm flow applications. The particulates which are included in this fraction depend upon the filter selected for use in the analysis. It is correct to assume, however, that regardless of the filtering medium, all the settleable and flotable solids are included. In addition a large percentage of finely suspended matter that would take many hours to settle by gravity is also retained on the filter. On the other hand, all the dissolved solids as well as the very finely suspended and colloidal solids which cause turbidity in water do not contribute to the suspended residue fraction.

The principal advantage of using the suspended residue as the particulate parameter is that it does include the total fraction of the residue that is within this classification. Particulate residue and nonfilterable residue characterize the same fraction of suspended residue. This same desirable feature can become a definite disadvantage in certain applications, particularly where specific treatment processes are involved.

As in the case of the total residue, it is common practice to determine the volatile fraction of the total suspended residue whenever the analysis is made. The assumption is made that this fraction consists primarily of organic matter and is the fraction which will exert a demand for dissolved oxygen when discharged into the aquatic environment. Also it is the volatile suspended residue which contributes to the benthic layer or bottom muds of a receiving water body, or which makes up the organic fraction of sludges produced in the treatment of storm flows.

Recommended Particulate Concentration Analyses

With full consideration to the preceding discussion plus the experiences of the authors of this report and others who have worked with storm generated discharges, it is recommended that the suspended residue be employed as the measure of particulate concentration. In most applications the removal of the entire suspended residue fraction from combined sewer overflows and storm runoff would be considered an ideal achievement or goal. Anything less than this total would be a partial success which can be effectively evaluated by making the appropriate suspended residue analyses. The analysis itself is considered routine and not as time consuming and cumbersome as some of the other particulate analyses. Only a small sample aliquot is needed in most cases. With a few additional steps it is possible to determine both the fixed and volatile portion of the suspended residue, an additional useful piece of information in many instances.

In addition to the suspended residue concentration, it is recommended that the settleable residue be determined for those applications where gravity or inertial separation is involved, or where an assessment must be made of bottom deposit buildup directly below or surrounding an outfall. For these applications the use of the suspended residue concentration alone could result in a distorted evaluation of the situation, primarily because of the heavy inert fraction of residues generally associated with storm generated discharges. Also, this determination may point out the need for grit removal facilities if treatment is being contemplated.

Conducting total residue, flotable residue and turbidity analyses on combined sewer overflows and storm runoff generally do not add much additional information, and for this reason, the routine use of these analyses is not recommended.

Recommended Laboratory Procedures

For the most part the procedures recommended in Standard Methods (39) and the 1971 EPA manual (40) can be successfully employed for the determination of suspended residue and settleable solids of combined sewer overflow and storm runoff samples. This statement applies particularly to such recommendations as drying and volatization times and temperatures, type of equipment, weighing procedure, and filter medium handling and preparation. However, the peculiar characteristics of the samples involved do suggest a number of modifications and additions which are disucssed below. Preservation method for solids determination is limited to refrigeration until the samples can be analyzed. Therefore as little delay as possible is best to avoid dissolution of certain materials.

Suspended Residue Determination - The value of the suspended residue of any sample depends primarily on the filter medium selected for the analysis. One of the first media used consisted of an asbestos mat formed at the bottom of a "Gooch" curcible. Because of the variability in the mat characteristics and time required in its preparation, this medium has limited use today. Other media which have been employed for this analysis are cellulose acetate membranes with a pore opening of 0.45 microns, glass fiber filters with an approximate pore opening of 0.8 to 1.0 microns, and conventional filter paper. The first two have been used rather extensively for wastewaters, combined sewer overflows, storm runoff and related water samples. Filter paper, for a number of reasons, has had limited use and will no longer be considered in this discussion.

Engelbrecht and McKinney (71) deomonstrated the superiority of the cellulose acetate filter over the gooch crucible and aluminum dish methods for determining the suspended residue of activated sludge mixed liquor. They also presented similar evidence for the case of raw wastewater suspended residue analyses. They felt that cost of the filter was the principal deterrent to its routine use. The authors have had extensive experience with the use of these filters in the analysis of samples from storm flows. There is no question of the cost disadvantage; the cellulose acetate filters cost almost five times as much as the glass fiber filters. Other disadvantages are that the cellulose acetate filters are more difficult to handle, having tendency to adhere to surfaces or to wrinkle easily. More handling is required for volatile residue determinations since the weighed filters must be transferred to tared porcelain crucibles following the total residue determination. Also, because of the small pore size the filters tend to plug up quickly thus limiting the amount of sample which can be filtered and decreasing the accuracy of the determination because of the small buildup of residue on the filter. Principal advantages of the cellulose acetate filter are that prewashing with distilled water is not required and the filter is completely destroyed in the volatile solids determination.

The glass fiber filter is highly recommended for the analysis in question. Wyckoff (72) demonstrated the superiority of this medium over the cellulose acetate filter for the total and volatile residue analysis of raw wastewater, activated sludge effluent and mixed liquor. The author as well as others (8)(33)(35) has used glass fiber filters on storm flow samples with much success. In addition to being economical, the filters are easy to handle, can accumulate a sizable residue load before plugging and can be fired to 550°C without being altered. One disadvantage is that the filter must be pre-washed to remove fines prior to use. The glass fiber filters are available in a number of sizes depending on the filtering assembly employed. The 4.7 cm size is recommended because it provides a sufficient area to obtain a good buildup of residue, and because it is the size used on the filtering apparatus for cellulose acetate filters, which is currently readily available in most water and wastewater analysis laboratories. The 2.2 cm size can be placed in the same gooch crucibles which formerly were used for the asbestos mats. Though the smaller filters have been successfully employed in the past, the larger ones are recommended for the reasons cited above.

The characteristics of storm flow samples require that a few special handling and preparation steps be employed. It is not uncommon to find large floating debris such as leaf parts, twigs, stems, cigarette filters, pieces of paper, etc. on the surface of the sample to be analyzed. Generally the laboratory analyst must exercise judgment as to whether or not he removes the particles from the sample. If it appears that the particle is of large enough size to significantly influence the total weight of residue removed on the filtering medium, it should normally be removed. Or if the particle is of such a size that it causes a difference in determinations of duplicate samples amounting to approximately 20% or more, it should be removed. With experience, most analysts can become fairly consistent in exercising this judgment. If a sufficient amount of this debris makes it cumbersome to remove the individual pieces by hand, it is recommended that the sample be passed through a No. 6 sieve (3.36 mm opening) prior to analysis. The analyst should indicate that this operation was applied to the sample in any final recording of the laboratory results.

The likelihood of an appreciable amount of sand and grit in the samples in question precludes the use of pipettes in transferring an aliquot to the filter assembly. It is recommended that 200 to 300 ml of sample first be transferred to a 500 ml beaker while at the same time the sample is shaken vigorously. The sample should then be transferred to a graduated cylinder while it is being stirred with a glass rod. The total aliquot measured in the cylinder should be passed through the glass fiber filter. As a general rule, a maximum of 10 minutes filtering time under vacuum should be employed. Values considerably below this amount indicate that more sample should be passed through the filter to obtain an accurate result. Greater values indicate that the residue concentration (or characteristics) was such that a smaller aliquot could have been used.

Generally with some experience analyzing combined sewer overflow and storm runoff samples, the analyst will gain proficiency in selecting the most suitable aliquot.

Vigorous shaking and stirring as described above is all that can be done with samples containing oil and grease. Any quantity of these materials which remains with the residue on the filter following drying becomes part of the total suspended residue value.

It is considered good practice to run duplicate analyses, particularly considering the properties of the samples in question. Variation of duplicate analyses within 10% or less would be considered an acceptable precision for samples of this type.

While it is not recommended that the volatile fraction of the total suspended residue be determined in each case, as stated previously, this added analysis can provide some additional useful information in certain situations. When running the volatile fraction it is important that a large enough sample be passed through the glass filter to insure that a measurable amount of weight loss is obtained following ignition at 550°C for 20 minutes. Temperature control is critical since higher temperatures can result in the partial decomposition of inorganic salts as well. Because the volatile fraction of some samples can be quite small, special precautions should be taken that the usual gravimetric analysis steps such as desiccation times, filter handling and transport, weighing technique, etc. are carefully done.

Settleable Residue Determination - The most common method of determining settleable residue in wastewater samples in past years was by the Imhoff cone method. The experience of this author with this method applied to combined sewer overflow and storm runoff samples has not been too favorable. Because of the nature of the solids, bridging generally occurs in the bottom portion of the cone; particularly when a twig or similar particle becomes wedged horizontally in the settling matter. Also numerous particles tend to adhere to the side walls of the cone.

The "weight" method described in Standard Methods (39) is felt to be superior in spite of the fact that it is more time consuming than the cone method. Basically the procedure involves making a total suspended residue determination on a well mixed sample as described previously, allowing a sufficiently large sample to stand quiescent for the period of time desired, and siphoning an aliquot for a second suspended residue determination from the center of the quiescent sample. The concentration of settleable matter is the difference between the two determinations. An excellent technique for obtaining the quiescent sample is to use a 200 ml broken-tip volumetric pipette with the mouth end immersed in the sample and the tip end connected by rubber tubing to a water trap and vacuum source. The rate of sample withdrawal is conveniently controlled by pinching the rubber tubing.

Other Solids Analyses - Though the routine use of total residue, flotable residue and turbidity analyses as measures of particulate concentration in storm flow samples has not been recommended, there may be instances where it is useful to conduct one or all of these tests. In general the same precautions noted in the case of the suspended residue determination, particulatly with regard to sample handling and obtaining a truly representative sample aliquot, apply to the above anlayses as well. The Standard Methods (39) procedure for conducting total residue and total volatile residue appears to be suitable for most storm generated flow samples. Samples that include the runoff from industrial yards and truck loading areas may include grease and other petroleum products that would begin to volatilize at the 103-105°C temperature range used for the total residue determination. Care should be exercised in the interpretation of the results of such analyses.

There is no "standard" procedure for determination of flotable residue. In those situations where this parameter may be useful, the following procedure is recommended. First allow one liter of the sample to reamin quiescent for one hour. Decant the upper 800 ml quickly into a second beaker, discard the lower portion, and allow the decanted portion to remain quiescent a second hour. With the inlet at the bottom of the container, carefully siphon from this container until only 70 to 80 mg/l of sample remains. Pour the remainder into a tared evaporating dish, rinse the container with a small amount of distilled water, and pour into the same evaporating dish. Determine the total residue by the procedure described above. During the final stages of the siphoning procedure, set aside an aliquot of the siphoned liquid and determine the total residue.

Subtract the total residue found in the siphoned liquid from the value determined in the last 70-80 ml to obtain an estimate of the total flotable residue.

The main problem with the turbidity analysis is obtaining an aliquot of sample which does not include the flotable and settleable solids. These solids do not add significantly to the turbidity of the sample, but can cause annoying problems in any type of turbidity measurements. It is recommended that the turbidity measurements be conducted on the internatant aliquot siphoned from a quiescent sample as described under the settleable residue determination. The use of one of the proprietary devices for turbidity measurement would be much more practical than the use of the Jackson candle turbidimeter for analysis of storm flow samples.

Although no analysis other than the suspended solids analysis has been recommended for standard use (settleable solids may be needed in some cases), Section V - Monitoring Instrumentation contains a discussion of some of the available in-situ monitoring equipment. This includes instruments for both the measurement of suspended solids and turbidity.

RECOMMENDED CHOICE OF PATHOGENIC INDICATOR

A quality parameter of particular concern in storm flows is the quantity and types of microorganisms present, since this parameter is related to the health and safety of humans and other animals. Complete water resources management near urban areas requires knowledge of the quantity and type of disease causing microorganisms which enter the aquatic environment from combined sewer overflows and storm runoff sources. It has been demonstrated historically from experiences gained in water supply and water pollution control applications, that the use of an indicator organism or organisms is the only practical way of making an overall health assessment. It does not necessarily follow that the same indicator system used in the past is directly applicable to the combined sewer overflow and storm runoff situation. Thus, it is the purpose of this portion of the report to examine the literature critically in this regard, and on the basis of this information plus experience gained from field surveys and studies, suggest an indicator system for pathogens that would serve best for the applications noted above.

It should be also noted that there are other applications for use of a suitable indicator system in addition to assessing receiving water quality. The possible use of treatment processes and storage for the control of combined sewer overflows and storm runoff will require the use of a number of parameters for evaluation of treatment and storage effectiveness. Degree of microbial destruction will no doubt be employed as one of the parameters. However, it does not necessarily follow that the same indicator system should be used for both receiving water and treatment applications.

Pathogens Associated with Storm Generated Discharges

The most important pathogens associated with the aquatic environment originate in the feces of humans and other animals. Because a combined sewer overflow generally includes both domestic wastewater and storm runoff, the likelihood that some pathogens are present in this discharge is high. The same is not as apparent in the case of storm runoff.

However, the runoff from an urban area can contain fecal matter from dogs, cats, rodents, and other animals and in some instances even humans, and thus this flow can also contain some disease-causing microorganisms. Also, illegal sanitary sewer connections to storm sewers can be a source of pathogens. Based on current knowledge, the pathogens of greatest concern in these flows are the bacteria, and to a lesser extent, the viruses and a few other types of microorganisms.

Bacteria - Bacteria are single celled microorganisms in the 1 to 10 micron size which can be present in waters in either the vegetative or spore state. The most common bacterial pathogens associated with fecal discharges are: Salmonella sp, the causative agents of typhoid and paratyphoid fever, and gastroenteritis; Shigella, the causative agent of bacillary dysentery; Vibrio the causative agent of cholera; Leptospira, the causative agent of leptospirosis; enteropathogenic Escherichia, the causative agent of intestinal disorders; and Streptococci sp which can cause a number of diseases in both man and animals. To a lesser extent Mycobacterium and Franciselia, the causative agents of tuberculosis and tularemia respectively, and Staphylococcus aureus and Pseudomonas aeruginosa the pathogens involved in most of the eye, ear nose and skin-type infections, have also been isolated from the fecal discharges of warm blooded animals.

Viruses - Viruses are ultramicroscopic obligate intracellular parasites processing either DNA or RNA. They are considerably smaller than the bacteria and thus not visible in a conventional light microscope. The viruses generally associated with fecal discharges are the causative agents of infectious hepatitus, poliomyelitis, and a number of other respiratary and gastrointestinal diseases. Enteric viruses, or the so-called "Enteroviruses", which are a subgroup of the major group, "Picornaviruses", include the Polioviruses, coxsackie viruses, ECHO viruses, the virus(es) of infectious hepatitis, and adenoviruses, and the reoviruses (73).

Others - A number of other types of organisms present in feces can cuase diseases. E. histolytica, the causative agent of amoebic dysentery, is a protozoan, the group containing the smallest form of animal life. The hookworm diseases are caused by a very thin worm about 1.3 cm (0.5 in) long which resides in the intestines of infected persons. The eggs produced by the female worm are discharged in the feces of humans and other animals and are the means of producing subsequent infections in healthy hosts. In addition to the two organisms above, a few other minor parasites which are found in feces can also cause diseases.

Water-Borne Diseases

The primary reason for interest in the presence of pathogens in combined sewer overflows and storm runoff is the fact that these pathogens can enter private water supplies or open finished water reservoirs used for potable water, or surface water bodies used for recreation by people and water sources by animals and thus result in the transmission of a disease. Though most water-borne diseases have been brought under control in this country, the threat always remains if pathogens are present and safeguards break down. An excellent review of water-borne diseases which includes an extensive literature search was prepared by Geldreich (74). According to a study conducted in England, cholera and typhoid are diseases most frequently associated with water supplies (75). A summary of the water-borne disease outbreaks in the United States for the 1946-1960 period is presented below (76).

Disease	Outbreaks
Gastroenteritis	126
Typhoid	39
Infectious hepatitis	23
Diarrhea	16
Shigellosis	11
Salmonellosis	4
Amebiasis	2
Other	7
Total......	228

All the above diseases can be contracted by people engaged in swimming and other water contact sports in the event that some water containing pathogens is swallowed while partaking in these activities. The likelihood of such an event occurring is rather remote, at least in the case of the serious water-borne diseases. However, such waters can serve as the media for the transmission of eye, ear, nose, throat and skin infections as a result of pathogens which originate from combined sewer discharges and storm runoff.

Possible Pathogenic Indicators

It is apparent that in applications dealing with combined sewer overflows and storm runoff, there is need for an analytical procedure to establish whether pathogens are present or absent. Because of the nature and origin of these discharges, the analytical procedure employed is not necessarily the one that works best for water supplies, raw wastewaters and receiving waters.

Two types of procedures are possible when it comes to establishing the presence or absence of pathogens in water. The first would involve techniques for the detection of the pathogens themselves or some by-products traceable to specific pathogens. The second would involve the use of an indicator system in which the presence of pathogens is inferred by virtue of the presence of related microorganisms or by their by-products. The first type provides direct proof of pathogen presence, the second type provides only indirect proof of the same situation. It would appear that the first type is superior for most applications, however, as will be discussed below, there are many factors which preclude the use of this approach for routine work.

Specific Pathogens Themselves

Ideally the most satisfactory indicator of the presence of pathogenic organisms in waters is to find the specific pathogens themselves. In practice, however, this could never be a suitable approach because of the variety of pathogens involved and the fact that the laboratory procedures are complex, time consuming, and for the most part rather insensitive (77)(78). Also, because of the comparatively low numbers of pathogens, very large water samples are needed for the detection procedure. Except possibly for some recent work (79) which demonstrated that a quantitative procedure is possible for the isolation of Salmonella sp. the prospect of using specific pathogens in combined sewer overflows and stormwater runoff as indicators of unsanitary conditions is remote at the present time, and probably for some years into the future. Thus reliance must be placed on some other group of microorganisms.

Total Coliforms - Since the latter part of the nineteenth century when the coliform group was first isolated from human feces by Escherich, this group of microorganisms has been the most important indicator of unsanitary or possible disease producing conditions in waters (80). According to Standard Methods (39), the coliform group comprises all of the aerobic and facultative anaerobic, gram-negative, non-spore-forming, rod-shaped bacteria which ferment lactose with gas formation within 48 hours at 35°C. This group has been used as an indicator group through the years because of the belief that it compares in many respects to the common enteric pathogens. According to Kabler (77), "This comparison is suggested because it has been repeatedly observed that the coliform group and the pathogenic enteric bacteria have survival rates in the same order of magnitude under similar environmental conditons of temperature, pH, disinfection, or extended exposures to soil or to fresh, polluted or salt waters." Another reason why the coliform organism has served as an indicator group all these years is the tremendous numbers discharged in human feces, estimated at 1.95 billion per person per day as an average (81). Thus, it has become common practice that the presence of any members of the coliform group in treated "potable" water is not acceptable regardless of the source (80). Recent reviews of the use and limitations of coliforms in the water quality standards and other applications have been written by Wolf (82) and Bott (83).

One of the principal problems in using the coliform group for applications other than potable water is that in addition to being found in the feces of warm blooded animals, coliforms can also be isolated from the gut of cold-blooded animals, soils and many palnts. It must be recognized, as demonstrated by many investigators, that there are both coliforms of fecal origin and non-fecal origin in virtually all natural waters (80)(84)(85). Many investigators have demonstrated the presence of large coliform counts in combined sewer overflow, urban runoff and natural water bodies (86)(87)(88)(89). The questions are, in spite of these high counts, do these waters in actuality represent a health hazard to those who come into contact with them? What is the seriousness of the health hazard? Is it possible to have relatively high coliform counts and yet negligible health hazards? When applied to potable water supplies, the coliform standard provides a safety factor which is highly desirable for obvious reasons. When applied to other applications, like combined sewer overflows and urban runoff, the same standard can result in confusion and erroneous interpretations of conditions.

Fecal Coliforms - There has been interest in distinguishing the fecal from the non-fecal coliforms for many years. In 1904 Eijkman first proposed an elevated temperature test for this purpose (81). The so-called IMViC procedure described in *Standard Methods* (39) for differentiation of the coliform group into *Escherichia coli*, *Aerobacter aerogenes* and *Escherichia freundii* (intermediates) has been in various stages of development for a large number of years. The primary reason for the strong interest in the fecal group is the conviction held by most observers that these organisms represent a more sensitive measure of health hazard because of their definite origin in the feces of warm blooded animals (39)(84)(90)(91). Geldreich (92) found that the fecal coliform group as an indicator system has an excellent positive correlation with warm blooded animal fecal contamination. He reported the following correlation percentages in the feces of various warm blooded animals.

Sources of feces	% Positive Correlation
Humans	96.4
Livestock	98.7
Poultry	93.0
Cats, dogs and rodents	95.3

Geldreich went on to state that, "The fecal coliform test is the most accurate bacteriological measurement now available for detecting warm blooded animal feces in polluted water". Other work by Geldreich *et al* (93) showed that very few coliforms traceable to the gut of warm blooded animals are associated with plants and insects, which lends further support to the usefulness of this indicator group investigations and surface water quality evaluations.

One important characteristic of the fecal coliform as an indicator group is that the behavior of these organisms is very similar to that of common enteric bacterial pathogens. According to Van Donsel *et al* (94), for example, there is a close relationship between the growth and survival of fecal coliforms and the pathogens, *Salmonella* and *Shigella*. This is one of the most important features of a good indicator system, especially when it is not possible to use the pathogens themselves. Also, the fact that the fecal coliform analysis does not distinguish between fecal coliforms of human origin and fecal coliforms of other warm blooded animals is more of an advantage than disadvantage. The literature provides evidence that human pathogens can be present in the feces of poultry, livestock, cats, dogs and wild animals (92).

Fecal Streptococci - The fecal streptococcus group, sometimes referred to as the "enterococcus group", has been under consideration as an indicator of fecal pollution for about 25 years. The primary interest in this group is related to the fact that the normal habitat of the bacteria included is the intestine of man and warm blooded animals. However, studies have shown that there is considerable variation in types and numbers of fecal streptococci between various animals, even between animals of the same species (95)(96). One often cited advantage of the fecal streptococcus group as an indicator is that certain species predominate in human feces and other species predominate in animal feces (97). For example *S. faecalis* strains are part of the former group and *S. bovis* part of the latter group. Another advantage is that streptococci normally persist longer in surface waters than bacteria in the coliform group, and apparently they do not multiply in surface waters (98). Though streptococcus survival rates in natural waters may not correlate with those of known pathogens, this situation provides a safety feature for this indicator system.

The principal disadvantage of the fecal streptococci is that some members of the group are indigenous to insects, vegetation, agricultural soils and the feces of fresh water fish (99). *S. faecalis* var. *liquifaciens* is an example of such a strain not limited to animal feces. Obviously there is little sanitary significance to the group of streptococci which do not originate in animal feces. It is possible that the use of this group alone as a pollutional indicator in certain situations may yield misleading results.

Salmonella Group - The reason for the interest in the salmonella group of bacteria as a possible indicator of pollution is obvious when one considers that the causative agents of typhoid and paratyphoid fever, and salmonellosis belong to this important group. Though there has been consideration given to this group for a number of years (77), it has only been recently that a fairly reliable quantitative method for its detection has been developed (79). According to Geldreich and Van Donsel (100) there are several hundred strains of Salmonella known to be pathogenic and the presence of any one of these strains in water should be considered a serious health hazard.

The major problem with the use of the salmonella group is that the occurrence of this population in polluted waters is highly variable. It has been found, for example, that salmonella infection rates are higher in animals than in human population (101). Even 13 percent of clinically healthy cattle were found to be infected with Salmonella in one study (101). Thus the population of Salmonella in polluted waters can be quite varied and the counts are considerably below those of some of the other indicator groups. The summary results of some work conducted in the Saline and Huron rivers tributary to Lake Erie demonstrate this point (102).

	Counts per 100 ml relative to Salmonella			
River	Salmonella	Coliforms	Fecal Coliforms	Fecal Streptococci
Saline River	1	1472	227	367
Huron River	1	274	24	109

Dutka and Bell (103) concur that the introduction of salmonellae into natural waters is intermittent and therefore natural dilution results in low concentrations. For this reason the above investigators recommend a 50 gallon sampling technique. The undesirability of using such a sampling technique for routine application is obvious.

Other Possible Indicator Systems - Several other indicator systems have been suggested through the years, namely the total plate count, the enteric viruses, the upper respiratory tract bacteria, and Adenosine tri-phosphate (ATP) measurements. The total plate count is simply a gross count of the bacteria present in a water sample. Since many of the bacteria are indigenous to natural waters, the count is not by any means a sensitive indicator for the presence of enteric pathogens. Some indication of the degree of domestic sewage pollution can be obtained by comparing the total counts which result from 35°C and 20°C incubation temperatures.

There is much interest in the enteric viruses since there are some that are known to be the causative agents of water-borne diseases. The major problem with the use of this group as a pathogen indicator is that detection and enumeration techniques are considerably more difficult than the case of bacterial indicators. Investigators are still searching for a suitable technique that laboratory technicians could use routinely for the detection of small amounts of viruses in large volumes of water (104). A recent American Water Works Association committee report (73) stressed that since the ratio of coliforms to viruses is approximately 92,000 to 1 in the case of raw sewage and 50,000 to 1 in the case of polluted waters, the coliform indicator is superior to a virus indicator. This same observation is made in Standard Methods (39), that is, if viruses are to be used as indicators, the major problem in analysis is to concentrate sufficient viruses for detection with the result that large volumes of water must be processed to achieve a reasonable degree of precision. Smith and McVey (105) investigated the use of chlorine dioxide for inactivation of viruses in synthetic combined sewer overflow samples. The results of limited studies indicated that a small animal-type bacteriophage (virus) would not be as good an indicator as the fecal streptococci or total coliforms, but that a poliovirus potentially could be a better indicator than these bacterial indicators. The authors felt that disinfection treatment to achieve a 5 log reduction in virus titer would probably result in the destruction of all viable viruses for most situations relative to combined sewer overflows.

In those cases where combined sewer overflow and surface runoff may influence the quality of waters used for swimming and other water contact sports, indicator organisms that originate from the gastro-intestinal tract may not be a sensitive parameter of potential health hazard from diseases of the skin and upper respiratory tract. In this situation, bacteria traceable to the upper respiratory tract or the skin of humans may be better since these are the ones involved in eye, nose, and throat infections. S. aureus and P. aeruginosa are bacteria which have been suggested for this purpose (39); however, a limited history of past usage plus difficulty of routine analysis preclude the use of these organisms at this point in time.

Moffa et al (106) used a luminesence biometer to analyze for ATP extracted from synthetic combined sewer overflow samples as a means of monitoring the effectiveness of various chlorine and chlorine dioxide schemes for disinfection purposes. They obtained good correlations between ATP reductions and both total coliform and fecal coliform reductions following disinfection operations, which prompted the authors to concluded that, "...ATP represents a promising possibility for more accurate and precise control of disinfection".

Use of Indicator Count Ratios - In recent years, a very interesting and useful analytical tool has been developed for the interpretation of bacteriological data obtained from wastewaters and polluted receiving waters. The tool is simply to determine the ratio of counts of bacterial groups used for pollution indicators. The ratios which have been employed are: total coliform (TC) to fecal streptococci (FS) and fecal coliform (FC) to fecal streptococci. However, because of the wide distribution of total coliforms in nature, only the latter ratio is considered to be of any real practical value. The case study reported by Geldreich (78) in which he employed FC/FS ratios to establish the effect of heavy runoff on a small lake, is a good example of how these ratios can be helpful in assessing pollutional loadings.

The usefulness of the FC/FS ratio is based on the fact that fecal coliform counts are considerably higher in human feces than fecal streptococcus counts. The converse is true for most animal feces. The FC/FS ratios reported for a number of different animal feces are as follows (107): Rat - 0.04, chipmunk - 0.03, rabbit - 0.0004, cat - 0.29, dog - 0.02, and man - 4.4. Thus, the FC/FS ratios for domestic sewage would be expected to be considerably higher than for storm runoff. The ratios for combined sewer overflows would be somewhat in between the two extremes above, depending upon the amount of storm runoff which is diluting the raw domestic wastewater or the re-entry of the pollutional discharge. Geldreich and Kenner (99) have investigated seven wastewater sources and found that the FC/FS ratios varied from 4.0 to 27.9, and three stormwater sources obtained had ratios from 0.04 to 0.26. Following a review of the literature, a leading manufacturer of membrane filters (108) accepted the basic findings of Geldreich and Kenner (99) and suggested that when the FC/FS ratio is equal to or greater than 4.0, it is highly probable that the pollution is from human origin. On the other hand, when the ratio is equal to or less than 0.7, it is highly probable the pollution source is animal feces, such as livestock, poultry and household pets. Undoubtedly, the low ratios usually found in urban runoff are due to high fecal streptococcus counts which originate from the feces of household pets, rodents and bird droppings.

Selection of a Pathogenic Indicator for Combined Sewer Overflow and Stormwater Runoff

The selection of a certain group of microorganisms as an indicator system for pathogens should take into account the following traits or characteristics:

1. The microorganisms should be present in large numbers in the feces of humans and animals.

2. The microorganisms should always be present when various types of enteric pathogens are also present.

3. The growth and die-off characteristics of the microorganisms in waters and wastewaters should be as close to those of key pathogens as possible. Ideally the indicator organisms should persist in nature a little lònger than all enteric pathogens.

4. The absence of the indicator microorganisms should mean that all enteric pathogen are also not present.

5. The laboratory detection procedure should be as routine, economical and reliable as possible.

It is obvious that what is described above is an ideal indicator system. The variable characteristics of wastewaters, combined sewer overflow and storm runoff make it impossible to achieve completely all of the traits listed. The selection process is one of meeting them as closely as possible.

Peculiar Characteristics of Combined Sewer Overflows and Storm Runoff - In contrast to wastewater flows, storm runoff only occurs during periods of precipitation and thaws. Even in well-watered regions, this type of discharge occurs only 3 to 5 percent of the total time. The characteristics of urban runoff, including its bacterial constituents depend on numerous factors such as intensity and duration of rainfall, time from preceding rainfall, watershed characteristics, etc. Usually the "first slug" of urban runoff contains the highest microorganism densities. Numerous studies have been reported in which total coliforms, fecal coliforms and fecal streptococci have been found in urban runoff (69)(87)(109)(110)(111)(112). The population of total coliforms is generally highest, followed by fecal streptococci and fecal coliforms. Though the numbers vary considerably, it can be expected that the total coliform counts per 100 ml are usually in the range of hundreds of thousands, the fecal streptococci in the tens of thousands, and the fecal coliform usually less than ten thousand.

The microbiological characteristics of combined sewer overflows are even more variable than storm runoff since the added variable of degree of mixture with raw sewage is involved. Depending upon the hydraulics and design of the sewer system, direct overflow from a combined sewer system may not occur with the same frequency as urban storm runoff. As expected, numerous studies have also demonstrated the presence of total coliforms, fecal coliforms and fecal streptococci in combined sewer overflows, but the counts were greater than urban storm runoff in all categories (7)(17)(113)(114)(115)(116). A study by Benzie and Courchaine (114) for example, showed that the total coliform, fecal coliform and fecal streptococci counts in combined sewer overflows were 8, 33 and 4 times as great as those normally found in storm runoff respectively. Burns and Vaughan (113) showed that the fecal streptococcus densities were about the same in combined sewer overflows and stormwater runoff. The biggest bacteriological difference between combined sewer overflow and storm runoff was found to be in the fecal coliform category, with the higher densities in the former discharge as expected.

Indicator System Selected - All the evidence available in the literature and actual experience acquired in working with combined sewer overflows and storm runoff, strongly suggest that the fecal coliform indicator system is the superior one at the present time for assessing the sanitary quality of these flows. The fecal coliform test comes closest to meeting all the traits of an ideal indicator system listed previously. As stated by Geldreich (92), "The fecal coliform test is the most accurate bacteriological measurement now available for detecting warm blooded animal feces in polluted water". Man and other animal feces can contain the caustive agents of all the important water-borne diseases. Until a better indicator system becomes available, the assumption can be made that if fecal coliforms are absent so are the pathogens of all water-borne diseases, including viruses. Likewise, if fecal coliforms are present, the likelihood of some microbial pathogens being present is high, particularly bacteria of the salmonella group. The major exception to the above statements is the cysts of E. histolytica which are resistant to common water disinfection procedures, and thus do not behave as the common enteric bacteria.

For some applications it may be very useful to also include the fecal streptococcus analysis as well and express the bacterial data in the form of the ratio of fecal coliforms to fecal streptococci (FC/FS). Use of this ratio would be helpful in assessing the pollutional impact of combined sewer and storm runoff flows directly at the outfalls. As indicated previously, ratios in excess of approximately 4.0 indicate pollution of a human origin, whereas ratios less than 0.7 indicate pollution of animal origin. These ratios should be established only at the outfalls or immediately downstream of an outfall. Because of variable die-off characteristics, it would be highly questionable to apply the same reasoning to samples obtained after residence times of one day or more in receiving waters or from other locations.

The use of the fecal coliform analysis is sufficient for characterizing the effectiveness of pathogen destruction of any treatment process applied to either combined sewer overflows or stormwater runoff. Little, if any, additional information is gained by the use of the FC/FS ratio in applications such as these, except possibly where packinghouse wastewaters or feedlot runoff are involved.

Recommended Laboratory Procedure

A clear distinction should be made at the outset between conducting bacteriological analyses on raw wastewaters, storm runoff and combined sewer overflows on the one hand, and potable waters and other high quality waters on the other. In the case of the former the counts are generally very high, frequently in the range of hundreds of thousands to millions per 100 ml of sample. A serial dilution must be conducted in the laboratory in order to conduct these counts. While careful laboratory techniques should be used in any case, it is apparent that with such high counts, high precision work of the type used in research studies is simply not required, and for that matter, an unnecessary expense.

In the case of storm generated discharges, gross counts of a relative nature are generally of primary interest. It may be of interest to know, for example, the difference in fecal coliform counts between influent and effluent of a treatment process; the variation in fecal coliform counts with time of overflow at a specific discharge point, the difference in fecal coliform counts for one land use type versus another type within the same community; or a comparison of counts in combined sewer overflows at a number of different communities. In all the above situations the relative differences are of greater importance than the absolute numbers. Thus it is more important that the procedure employed be convenient to run, be economical, and be one in which results are obtained as quickly as possible, rather than one where maximum accuracy is the main criterion.

In the case of raw or potable water supplies, such laboratory analysis features as convenience and economy are subservient to accuracy and precision. Values in the order of one to several fecal coliforms per 100 ml are of significance. It is possible that under certain conditions this level of accuracy is desirable even in the case of storm flows. A good example is an impounded area used for recreational purposes, even to the extent of water contact activity and fishing, to which storm runoff is directed. It is also possible that well treated combined sewer overflows are discharged to the same water bodies, in which case the most sensitive pathogenic indicator analysis available is not only desirable but necessary.

Sampling Procedure - The most suitable way of obtaining a sample for bacteriological analysis is to collect a discrete or grab sample in a sterile bottle and return the sample under iced conditions to the laboratory for immediate analysis. When chlorinated effluents are being sampled, it will be necessary to dechlorinate as described on page 491 of Standard Methods (39). It is best practice to collect bacteriological samples in separate bottles containing the appropriate concentration of thiosulfate solution. These samples should not be used for other analyses except possibly certain select analyses where interferences are known to be minimal. If non-chlorinated discharges are involved, the samples collected for bacteriological analyses can be used for other analyses upon completion of the initial work.

As a general rule bacteriological samples should not be composited. Frequently, however, where storm generated discharges are involved, it is only possible or economically practical to obtain composited samples for such analyses. Though admittedly this is not an ideal situation, it is often the only sample source for analysis, and the results must be employed or interpreted with full cognizance given to this practice.

It is usually very difficult to achieve ideal sampling conditions in most storm generated discharge applications, since automatic samplers are generally used to obtain the necessary samples. Samplers that have individual suction lines leading to separate sample bottles are obviously the most suitable. In this case, sterile sample bottles and tubing should be used.

Autoclaving the bottles is the best way of insuring that sterile conditions are achieved. This may not always be the most practical way, considering the fact that, as stated previously, gross counts are usually of interest. Ancillary studies conducted by this author have demonstrated that washing the bottles in an automatic laboratory dishwasher, using a good quality detergent, effective rinsing, and water temperatures of the 80°C to 90°C range, while not achieving strict sterile conditions, will destroy vegetative cells. The automatic sampler head and individual sample lines have to be disinfected as well. This can be done using a chlorine solution with approximately 50 mg/l of free available chlorine to flush out the lines, and to clean the head and other parts. It is imperative that these surfaces be well rinsed with hot water to insure that no trace of chlorine remains. The sample bottles should be attached to the sampling lines using aseptic techniques, perferably in the laboratory rather than the field.

Many of the automatic samplers in use have a single sampling line which directs the samples into one bottle or into a series of bottles. In both cases, the sample bottles should be washed as described previously. Naturally, once the first sample is drawn, the line is contaminated and will effect all subsequent samples. Automatic samplers which provide a thorough pre-flushing sequence with the new sample water prior to introduction of the sample into the bottle, reduce somewhat the problem of carry-over contamination of the intake line. However there is no convenient way of completely eliminating this sampling problem, and thus it should simply be accepted as one of the normal features of conducting bacterial analyses on storm generated discharge samples using single line automatic samplers.

Because of the number of organisms involved and the fact that relative counts are usually of primary interest, the error introduced by this sampling technique is normally not considered to be significant. This situation should not preclude the use of acceptable sample handling and setup procedures after the sample is collected. Care should still be exercised in cleaning the sampling lines and bottles as described previously, as well as the use of other aseptic techniques common in bacteriological-type analyses.

Analysis Procedure - Once fecal coliforms and other enteric organisms are discharged from the ideal habitat of the intestines of warm blooded animals to the more hostile aquatic environment, they begin to die-off. Work by Hendricks (117) and Klock (118) among others have shown that the rate of die-off is retarded at lower temperatures. Thus, for best results, the samples should be chilled (iced if possible)to 10°C or below during sample collection, storage and transit to the laboratory. Freezing of the sample should be avoided since this will cause a destruction of microorganisms. As stated in Standard Methods (39) samples for bacteriological analysis should be refrigerated upon receipt in the laboratory and processed within two hours. When samples are being composited over a 24 hour period, it is obvious that the first sample obtained of the series will have been stored 24 hours before it is possible to transport the composite to the laboratory. This once again is one of the unavoidable features of working with samples of this type. Die-off of microorganisms can be kept to a minimum by proper cooling of the sample during the entire time the composite is stored in the sampler. Relative gross counts will be meaningful as long as all samples are handled in a similar fashion.

Fecal coliform counts can be made using either the multiple tube fermentation procedure in which results are expressed in a form of a statistical number called the most probable number (MPN), or the membrane filter technique (MF), in which a direct count is made of colonies which form on the filter pad. In both cases it is imperative that the incubation temperature be rigidly controlled; 44.5 ± 0.2°C being the specification generally recommended. In recent years there has been a definite trend away from the MPN procedure in preference to the membrane filter procedure. The primary reasons for this trend are the latter technique is easier to set up, requires less time for results, causes fewer logistical problems in the laboratory, results in a direct count rather than a statistical count, and on the whole is more economical to run per analysis. The two enumeration procedures, however, do not yield the same results. The work of Little et al (119) on total and fecal coliform removals in nine oxidation ponds in the southern United States showed, for example, that the MPN values were generally higher than the MF values. They found that the MF value fell within the MPN 95% confidence interval approximately 80 percent of the time. For most of the applications associated with storm generated discharges, this disparity is inconsequential, compared to the many other favorable aspects of the MF procedure. In any case, because of the high counts involved, sampling problems and dilutions required during analysis, either enumeration procedure results in an estimate of the "true" count.

Standard Methods (39) discourages the use of the MF procedure for chlorinated samples because of the lower recovery as contrasted to the multiple tube procedure. Though the precise reasons are not given, presumably it may be because the shorter MF incubation does not allow sufficient time for the "aftergrowth" of fecal coliforms protected within solids from the action of the chlorine, or that the liquid medium of the MPN technique provides a greater "buffering" effect in stimulating the growth of semi-viable or stressed organisms, or that the membrane medium tends to plug up since larger aliquots of debris laden sample must be processed to obtain reliable counts. Bordner (120) of U.S. EPA in Cincinnati is working on a pre-incubation enrichment step which possibly could be applied to chlorinated samples in order to minimize the erratic results which apparently can occur with the standard single-step MF technique. It is apparent that it is only a matter of time before the MF procedure will be modified to compensate for the problems noted above.

It is recommended that the MF technique be employed for conducting fecal coliform and fecal streptococcus analyses on all samples associated with combined sewer overflow and storm runoff applications. The experiences of this author clearly indicate that the numerous advantages of the MF technique far outweigh the MPN technique, even for the case of chlorinated samples. The MF technique is sufficiently sensitive considering the high counts normally encountered and the less than ideal sampling procedure which by necessity must be employed. In certain instances where high quality waters are involved it may be advisable to use the MPN technique, especially on chlorinated samples, or to establish correlations between the MF and MPN results. Decisions of this type can only be made by the particular investigator in each case.

Standard Methods (39) or the membrane manufactuer's brochures (108) should be consulted for the most suitable growth media and techniques to be employed. Sodium thiosulfate solution must be added to the bottles used to collect or store sample with chlorine residuals. Because of the random nature of storm flow samples, it is generally best practice to make up the medium fresh for each sampling program or to purchase pre-made sterile medium in convenient sized ampoules. All pre-dilutions must be made with sterile-buffered dilution water. It is not necessary to use a new sterile membrane holder and funnel for each new sample. A thorough wash with sterile water will suffice to remove bacteria on the funnel and include these organisms in the sample aliquot being filtered. It is good practice to run the samples in the order of lowest estimated density to highest density to minimize carry-over from one sample to the next. Floating debris and heavy grit often associated with storm flows are normally not a problem if the sample is mixed well and the aliquot for analysis is pipetted from the mid-height of the container. Also the necessity for sample dilution tends to minimize the effect of particulates in the original sample. Some investigators have suggested that use of short term blending of turbid stormwater samples prior to analysis by the MF procedure to minimize the effects of particulates, however experience of the author with storm generated discharge samples have not proven this step to be necessary.

RECOMMENDED MEASUREMENT OF EUTROPHICATION POTENTIAL

There has probably been more attention given to the problem of eutrophication during the last fifteen years than to any other water resources problem. As stated in the National Academy of Sciences publication (121) Eutrophication: Causes, Consequences, Correctives, "The term 'eutrophic' means well-nourished; thus 'eutrophication' results from the proliferation of plant life in water bodies as a result of the additon of plant nutrients." Algae are the category of plant life primarily involved in most water bodies, though in some cases rooted aquatic plants are also a manifestation of a eutrophic condition, particularly its advanced stages. Eutrophication conditions are generally associated with fresh water lakes, but it is possible for rivers and estuaries to exhibit some form of eutrophic behavior under the proper set of environmental conditions. The nutrients which are required to stimulate plant growth can originate from numerous sources, namely, domestic and industrial wastewaters, urban and rural runoff, combined sewer overflows, underground flow, and rainfall. Thus these sources are the result of both natural and man-originated activities. The sources of primary interest in this report are those associated with storm flows to water bodies.

It should be kept in mind that eutrophication is a natural process which takes place in all water bodies. The activities of man can greatly increase the rate of this natural activity to the point where undesirable results can occur. Accelerated eutrophication or "cultural" eutrophication can cause changes or shifts in the population of biota in a water body. It can also adversely influence the esthetics of a water body, impair its use for recreational and water supply purposes, and reduce the values of properties along the shoreline. Excessive rooted vegetation, also a manifestation of accelerated eutrophication, fouls the air and uses up dissolved oxygen as a result of death and decomposition.

Possible Nutrients Contributing to the Eutrophication Problem

During photosynthesis sunlight provides the energy for the production of plant cellular materials from basic raw products including carbon dioxide, water, nitrates, phosphates, plus a number of other trace salts which include the elements potassium, iron, sulfur, calcium, magnesium and cobalt among others. Molecular oxygen is the major by-product of this growth activity. A chemical assay of plant material will show that the dry wight will consist primarily of carbon, oxygen, hydrogen, nitrogen, and phosphorus, plus a very small weight fraction of numerous trace elements.

It is obvious that in order to have plant growth all the above elements must be present. In agriculture when plant production is of primary concern, it is common practice to carefully examine the soil environment to determine if any key element or nutrient is present in a low concentration or lacking, since it will be this particular element that will eventually limit plant growth. This particular element would be considered the "limiting" one since at some point in the plant production cycle it will begin to control growth. Obviously, at this point, fortifying the soil with the element will result in the resumption of the plant growth. In the case of eutrophication it is the opposite approach which is employed; that is, to attempt to limit plant growth by controlling one of the most critical plant nutrients. One of the principal eutrophication research objectives through the years has been directed toward determining which is the most effective nutrient to control. Because trace nutrients are available in most natural waters to support algal growth, very limited success has been achieved in attempting to control eutrophication by limiting such elements as potassium, iron, calcium, silicon and magnesium. Most efforts have centered around the control of various forms of carbon, nitrogen, and phosphorus.

Carbon - The largest fraction of plant cellular material consists of the element carbon. The source of carbon in plant growth is carbon dioxide which is obtained directly from the atmosphere in the case of terrestrial plants, and from that dissolved in water in the case of aquatic plants like algae. In the case of the latter, bound carbon dioxide in the form of bicarbonates and carbonates can also serve as carbon sources, but this availability is tied into other chemical properties of water such as pH and dissociation kinetics. Gaseous carbon dioxide can also be introduced into water bodies as a result of the aerobic degradation of organic matter directly in the receiving water body. Carbon dioxide is one of the main end products of this degradation. Several years ago Kuentzel (122) suggested that in most situations biologically produced carbon dioxide derived from organic matter is the limiting nutrient in the eutrophication process. This work instigated the carbon dioxide versus phosphorus limiting nutrient controversy which occurred during the early 1970's. Presently it is generally accepted that while carbon dioxide is necessary for plant growth, it is so readily available in all aquatic environments and thus very unlikely to be limiting to plant growth. As Fruh (123) noted, carbon dioxide may cause growth stimulation without being the limiting nutrient in the sense of "Liebig's Law of the Minimum".

It would appear that the use of any type of carbon measurement on storm flows would not provide a sensitive indicator or parameter of eutrophic potential. Maier and McConnell (124) felt that organic carbon type measurements, as for example the TOC, conducted on lake and river waters do provide an indication of the state of productivity of these waters. Water bodies in a eutrophic state as a rule exhibit high rates of organic matter production usually expressed in grams of carbon per year per square meter of water surface area. Conducting TOC analyses on storm flows, on the other hand, will yield little information regarding the contribution of these flows to a specific eutrophication problem.

Nitrogen - Approximately 6 to 8 percent of the total dry weight of plant cellular material consists of nitrogen, and for this reason is considered one of the key nutrients of plant growth. Nitrogen quantities are always considered whenever nutrient loadings or nutrient budgets are conducted on water bodies (125)(126). Aquatic plants can utilize nitrogen in either the nitrate or ammonium ion forms, both of which can be present in surface runoff and combined sewer overflows. There are some blue-green algae which have the ability of utilizing gaseous nitrogen as their sole nitrogen source in the event inorganic forms are not available. For this reason Fruh (123) felt that to try to control eutrophication by limiting the supply of combined nitrogen alone is an exercise in futility. He added further that because nitrogen fixing algae are not indigenous to high saline waters, it is possible and likely that nitrogen can be the limiting nutrient in coastal water eutrophication problems. Though nitrogen may not be the limiting nutrient in all situations, it is still considered one of the key nutrients, and the availability of large amounts of inorganic nitrogen will no doubt intensify the problem greatly.

Conversely its unavailability will limit algae growth in fresh waters to the nitrogen fixing varieties which in itself is a form of eutrophication limitations.

Phosphorus - Algal cells contain anywhere from 1 to 3 percent phosphorus on a dry weight basis. By far, the greatest amount of attention has been given to this element as the key nutrient in the eutrophication process. Phosphorus is available to plant life in the phosphate ion form only, and unlike nitrogen, it is never available to plants or present in nature in the elemental form. For this reason many researchers in the eutrophication area agree with Fruh (123) that since the distribution of phosphorus in nature is largely influenced by the activities of man, and since this element is an indispensable building material in all living matter, its control is the single most efficient means of limiting eutrophication in fresh waters.

Others - As stated previously, in addition to the key elements of carbon, nitrogen and phosphorus, aquatic plants require a large number of other elements for optional growth. Some of these elements, even though required in extremely low concentrations, are absolutely essential for growth. Iron, for example, is required for key enzymes involved in cellular energy transformations. If it were possible to totally eliminate iron from the aquatic environment, presumably algae growth would cease. Given the wide distribution of iron in nature, the prospect of such a situation occurring in a body of water simply does not exist. Thus even though iron theoretically can be a limiting nutrient, its use as a eutrophication parameter in any type of discharge would be completely worthless.

In addition to iron, Stewart and Rohlich (127) have listed a number of other elements that researchers have considered as possible eutrophication parameters. These include magnesium, calcium, silicon, sulfur, manganese, sodium, potassium and cobalt. Some attention has also been given to certain vitamins and micronutrients. At the present time, none of these would be considered seriously as a sensitive measure of eutrophication potential.

Selection of the Best Eutrophication Parameters

From the evidence available at the present time, analyses for nitrogen and phosphorus in storm generated discharges will provide the most suitable parameters of the eutrophication potential of such discharges.

Nitrogen - Nitrogen occurs in nature in five forms, namely, elemental nitrogen, organic nitrogen, ammonia nitrogen, nitrite nitrogen and nitrate nitrogen. Analyzing water samples for elemental nitrogen is of little value. Of the remaining forms, the reduced forms of nitrogen, organic and ammonia, are found in all municipal wastewaters, and to some extent in surface runoff. The oxidized forms of nitrogen, nitrite and nitrate, are usually present in the effluents of biological treatment plants and surface runoff. These forms are normally not present in raw municipal wastewaters. The concentration of nitrate is much higher than nitrite in most water samples, and for this reason the nitrite analysis is often eliminated in the nitrogen series. From the standpoint of impact on a receiving water body, it is the total nitrogen being added that is of primary interest, since all four forms are eventually available to plant life following transformations in the receiving water body. Unfortunately, a single analytical procedure is not available to include all the nitrogen forms.

It is recommended that basically two nitrogen analyses be conducted on storm flows. The first would be for the total oxidized forms of nitrogen, that is, the sum of the nitrite and nitrate forms. This can be done by oxidizing all the nitrite nitrogen to the nitrate form and conducting one analysis on the latter ion. Or it is possible to reduce all the nitrate nitrogen to the nitrite form and just run the nitrite analysis. Both of the most popular nitrite and nitrate analyses are colorimetric procedures, but of the two, the nitrite analysis is considered to be superior. The nitrate nitrogen analysis is not as sensitive a procedure as the nitrite analysis, and it is subject to more serious interferences, especially the chloride ion (128). Chloride is commonly found in storm generated discharges, especially in cities along coastal areas and during the early spring in northern cities where salt is used for deicing roads. Thus it is recommended that the nitrite analysis be used for quantitating the total oxidized nitrogen in storm generated discharges.

The second nitrogen analysis would be for the reduced forms of nitrogen, namely the total of ammonia and organic nitrogen. It is recommended that the Kjeldahl procedure be used for this purpose. This procedure includes all nitrogen in the amine ($-NH_2$) form. This form of nitrogen is a desirable plant nutrient, especially when present as ammonia. Organic nitrogen undergoes a biochemical process in all natural waters called ammonification, in which the amine radical is released from complex organics as ammonia.

It is recommended that both the oxidized and reduced nitorgen analyses be expressed in terms of the weight of nitrogen rather than the individual ions. In this way the two nitrogen values can be added to arrive at the total nitrogen content. In many storm flow applications, only this one value is actually needed. In some applications it may be necessary to know in what forms the nitrogen is present, as for example, when certain wastewater treatment processes are involved. A good example is chlorination. Chlorine combines with organic and ammonia nitrogen to form chloramines. These compounds of chlorine and nitrogen which still exert biocidal action in receiving waters, are not derived from the oxidized nitrogen forms. Knowledge of the amount of Kjeldahl nitrogen is also advantageous since a stoichiometric estimate of the nitrogenous oxygen demand (which usually does not appear in the BOD_5 test) can be made.

Phosphorus - All phosphorus in nature is present as in the form of $PO_4^{=}$, its highest oxidized form. The phosphate ion can occur in a variety of soluble and insoluble inorganic compounds, including orthophosphates and polyphosphates or complex phosphates. In addition, the phosphate ion can occur in both living and dead organic matter. According to Barth (129) it is possible to obtain fourteen different phosphorus fractions depending upon the sample processing technique and analytical procedure involved. Because of these possibilities, Barth recommends that the total phosphorus analysis be conducted for situations involving the evaluation of treatment processes. The same can also be said where impact on a receiving water body is of concern.

It is recommended that the total phosphorus analysis be conducted on storm generated discharge samples, as the nutrient parameter for phosphorus. Since the phosphate ion tends to combine readily with a number of metalics like iron, calcium and aluminum to form insoluble compounds, in certain treatment processes for storm generated discharges it may be very helpful to run both the total soluble phosphate and the total phosphate. This can be accomplished by passing a sample through the same filtering medium recommended for suspended residue analysis, and conducting the total phosphorus analysis on both the original sample prior to filtration and on the filtrate.

Nitrogen and Phosphorus Concentrations Associated with Storm Generated Discharges

A number of studies have been conducted in recent years which already demonstrate that storm generated discharges can contribute sizable amounts of nutrients to receiving water bodies. Weidner et al (88) examined the surface runoff quality from six different rural sites around Coshocton, Ohio and showed that the kg/ha (lbs/acre) of total solids, BOD, COD, phosphate and total nitrogen varied considerably for various types of agricultural crops and practices. For example, on one particular plot the phosphate loading varied from 2.3 to 310.2 kg/ha (1.1 to 27.7 lbs/acre) and the total nitrogen varied from 123.3 to 2654 kg/ha (11 to 237 lbs/acre). They concluded that runoff is a factor in stream pollution and that it must be considered when one evaluates the quality of any stream or receiving water.

Hetling and Sykes (130) conducted an extensive study of a nutrient balance on Candarago Lake in New York. Under nutrients they included total and soluble phosphorus, the full nitrogen series, magnesium, potassium and chlorides. They felt that none of the latter three elements were algae limiting in the study lake. An interesting finding of their study was that two-thirds of the nitrogen in streams tributary to the lake was either in the nitrite or nitrate form.

Two investigations concentrated on the quality of urban runoff. An often quoted study by Weibel et al (69) conducted on a 10.8 ha (27 acre) site in Cincinnati over a 13 month period, resulted in the following nutrient loadings:

Nutrient	Range, mg/l	Mean, mg/l
NO_2 - N	0.02 - 0.2	0.05
NO_3 - N	0.1 - 1.5	0.40
NH_3 - N	0.1 - 1.9	0.60
Org - N	0.2 - 4.8	1.70
Total S01. PO_4	0.07 - 4.3	0.80

It is particularly noteworthy that the nitrite nitrogen concentration is insignificant compared to the other nitrogen forms and that approximately 15 percent of the total nitrogen loading is in the oxidized form. Sartor et al (131) analyzed the street surface runoff from 12 cities in the U.S. and concluded that storm runoff is a more serious source of pollutant in many areas than municipal wastes. They estimated that the kg/curb m (lbs/curb mile) of phosphates, nitrates, and Kjeldahl nitrogen were 0.30 (1.1), 0.027 (0.094) and 0.62 (2.2) respectively, and that the largest percentage of the nutrient loading was associated with the fine solids (less than 246µ) fraction of the street surface contaminants. It should be noted that the nitrite ion concentration was not included in this study and that the largest share of the nitrogen loading is in the amine form rather than the oxidized form.

Several studies have been conducted in which pollutional loadings from separate storm sewers were compared to those from combined sewer overflows The study conducted in the Detroit-Ann Arbor area was very extensive and included a comparison of nutrient loadings, the salient features of which are summarized in Table VI-7 (8)(15). As noted, analyzing for the soluble phosphate alone can result in an erroneously low conclusion. Also, the nitrate fraction of the total nitrogen loading can be significant; especially for a separate storm sewer or unsewered discharge. Similar comparison studies were also conducted in Washington, D.C. (7)(70), in which it was concluded that the average nutrient concentrations in separated storm sewer runoff were approximately one-third of those in combined sewer discharges. Selected nutrient loading data are presented in Table VI-8 for a six month period of testing. These data demonstrate the preference of running the total phosphate analysis over that of one of the other fractions.

Nutrient analyses were also conducted during combined overflow studies at two cities in Wisconsin (17). The mean Kjeldahl nitrogen concentration at the 95% confidence level was 17.6 ± 3.1 mg/l for 12 "first flush" events and 5.5 ± 0.8 mg/l for 44 extended combined overflow events, at an overflow site in Milwaukee. At Kenosha, the mean Kjeldahl nitrogen and PO_4 as P concentration of 23 overflow events were 12.9 and 5.1 mg/l, respectively.

Table VI-7. COMPARISON OF NUTRIENT LOADINGS FROM SEPARATE STORM AND COMBINED SEWERS, DETROIT - ANN ARBOR AREA

	Separate system				Combined system			
	Conc., mg/l[b]		Loading[a]		Conc., mg/l[b]		Loading[a]	
	Max	Mean	kg/ha	lbs/acre	max	mean	kg/ha	lbs/acre
NH_3 - N	2.0	1.0	7.8	0.7	134	12.6	69.4	6.2
Org - N	4.0	1.0	4.5	0.4	38	3.7	17.9	1.6
NO_3 - N	3.6	1.5	9.0	0.8	2.8	0.5	1.7	0.15
Soluble PO_4	3.4	0.8	10.0	0.9	21.2	7.7	62.7	5.6
Total PO_4	16.4	5.0	31.4	2.8	43.2	14.6	123.2	11.0

a. During three month summer period.
b. Annual values

Table VI-8. COMPARISON OF NUTRIENT LOADINGS FROM SEPARATE STORM AND COMBINED SEWERS, WASHINGTON, D.C. AREA[a]

	Separate system, mg/l		Combined system, mg/l	
	Range	Mean	Range	Mean
NH_3 - N			0- 4.7	1.5
Total - N	0.5-6.5	2.1	1.0-16.5	3.5
Ortho - PO_4			0.1- 5.0	2.0
Total - PO_4	0.2-4.5	1.3	0.8- 9.4	3.0

a. Six month spring and summer period.

Two recent studies on urban runoff quality shed new light on nutrient loadings from this source. The first was conducted by Kluesener and Lee (132) on a 50 ha (123 acre) residential area site in Madison, Wisconsin. They estimated that 27 percent of the area is impervious (streets, walks, roofs, etc.). Thirty-four storms were monitored. The results of their study compared to those of others are summarized in Table VI-9.

Table VI-9. COMPARISON OF AVERAGE ANNUAL NUTRIENT CONCENTRATIONS IN URBAN RUNOFF

Source of data[a]	Nitrogen as N, mg/l			Phosphorus as P, mg/l	
	NH_3	NO_3	Org	Dissolved	Total
Sawyer	0.28	--	--	0.22	0.56
Sylvester	--	0.53	2.0	--	0.15
Weibel	0.60	0.40	1.7	0.26	--
Bryan	--	--	--	0.14	0.19
AVCO	--	--	0.8	0.22	--
Kluesener & Lee	0.45	0.60	3.5	0.57	0.98

a. Refer to Reference 19, p. 931.

As noted, the nitrate concentration exceeds the ammonia concentration. They found that the concentration of all parameters was highest during the first flush. Extrapolating the results of the study to the entire Lake Winona basin, they estimated that approximately 80 percent of the total phosphorus and 35 to 40 percent of the total nitrogen arise from urban runoff. The second study conducted by Whipple et al (133) evaluated the urban runoff from a 13.5 sq m (5.2 sq mi) mainly residential area with a population of 11,700. The nitrate and phosphate contributions were 59 and 32 kg/day (130 and 70 lbs/day), respectively over a 4 day low rainfall period and 154 and 263 kg/day (340 and 580 lbs/day), respectively over a 7 day heavy rainfall period. The authors concluded that for rivers with high loadings of nutrients emanating from urban runoff, it would be entirely unrealistic to attempt to control algae blooms by treatment of dry-weather flow only.

Recommended Analyses for Nitrogen and Phosphorus

As noted previously, two analyses are recommended for establishing the nitrogen content of storm flow samples, namely, total Kjeldahl nitrogen and total oxidized nitrogen. The total phosphorus analysis is recommended for quantitating the second nutrient of interest. Salient features of the analysis procedures recommended for these nutrients follow.

Nitrogen - The total Kjeldahl analysis as described in Standard Methods (39) or the 1971 EPA Manual (40) is recommended for the determination of total nitrogen in the reduced form. This procedure can be applied to most combined sewer overflow and storm runoff samples without much difficulty. If the analysis is conducted within 1 or 2 days of the time of collection, storage under refrigeration would be advisable. During this period little, if any at all, microbial nitrification would be expected to take place. The same would be true in the case of ammonification, but even if some does occur, it would not affect the final results since the analysis includes all reduced nitrogen forms. If longer storage is anticipated it would be advisable to add mercuric chloride as a preservative to arrest bacterial activity. This will insure that the proportion of nitrogen in the reduced and oxidized forms will remain as collected, and that nitrogen will not be lost through the microbial process of denitrification.

When it is necessary to run the ammonia nitrogen analysis it is recommended that the distillation procedure be employed. Experience with the use of this procedure on combined sewer overflow samples indicates that the borate buffer recommended in the 1971 EPA Manual (40) is preferred to the phosphate buffer recommended in Standard Methods (39). The latter buffer solution may result in the formation of precipitates if a high concentration of hardness-causing cations is present in the sample.

The procedure which is recommended for total oxidized nitrogen is the cadmium reduction method presented by Strickland and Parsons (42) and in Standard Methods (39). For most storm flow applications there is no need to distinguish between the nitrite and nitrate ion forms, therefore an aliquot of sample can be passed directly through the reduction column and, as recommended, analyzed for the nitrite concentration. The colorimetric analysis procedure for nitrite is a very sensitive one and not subject to many interferences. It is important that a control be passed through the reduction column each time a new series of samples is analyzed, to make certain that the reduction properties of the cadmium surface are intact. The life of the column can be prolonged by passing only clarified samples on the cadmium surface. Samples heavily laden with organic and inorganic particulates should be clarified by first allowing the heavier particles to settle and passing the upper clarified portion through filter paper. For highly turbid samples, the use of zinc sulfate flocculent would be helpful for the clarification process.

Phosphorus - Two basic analysis steps are involved in the total phosphorus analysis. The first involves a rigorous digestion step in which all phosphorus in the sample is released from organic matter and hydrolyzed to the ortho-phosphate form, and the second involves a colorimetric analysis step where the ortho-phosphate ion is complexed with ammonium molybdate to form a blue colored solution. Standard Methods (39) suggests three possible digestion procedures. The most rigorous of the three, and the one used successfully by the Milwaukee Sewerage Commission (134) in a very extensive study on removing phosphorus from municipal wastewaters, is the perchloric acid digestion method. A major disadvantage of this technique is the explosion hazard of the perchloric acid mixture. Of the remaining two methods, namely, the sulfuric acid-nitric acid digestion and the persulfate digestion, the latter is much more convenient to run though it may not be as rigorous a digestion procedure as the former. Zanoni (135) compared the persulfate digestion method to the ashing method and found the results to be comparable for most liquid samples. The ashing method is considered to be an excellent control method, but it is far too time consuming to use for routine analysis. Therefore, it is recommended that the persulfate digestion method be employed for the routine analysis of combined sewer overflow and storm runoff samples. In select cases wehre heavy sludges or samples containing much organic debris are involved, the ashing method is recommended.

Three different colorimetric methods are suggested in Standard Methods (39) for ortho-phosphate determination, any one of which could be applied to storm flow samples. The authors have a preference for the ascorbic acid method or the single reagent method of the 1971 U.S. EPA Manual (40) which also includes the use of ascorbic acid as a reducing agent.

RECOMMENDED CHOICE OF METAL ANALYSES

The analysis of metals has been somewhat ignored in most storm generated discharge projects. However, the potential toxic effect of some metals on the biological community merits more attention. Since metals in storm generated dishcarges could exist in relatively high concentrations, depending upon the industrial discharges (including those into the air), metallic corrosion and the vehicular traffic in the area, periodic analysis is necessary. If a certain constituent has a high concentration, more frequent tests may be necessary.

With the development and improvements in atomic absorption, the analysis of various metals has been simplified and the accuracy improved. Atomic absorption spectroscopy works on the principle that a sample is aspirated and then atomized in a flame. The amount of light absorbed by a certain element is proportional to the concentration of the element in the sample. Calibration curves are used and the method is relatively rapid and free of interferences.

In practice however, special care must be taken prior to actual analysis. The first important aspect is in the sampling procedure. The bottles must be absolutely clean and inert to the metallic compound being determined so there is no leaching into or from the sides of the container. Secondly, all glassware must be scrupulously clean for all samples and standards and extreme care must be taken in standard preparation due to the minute quantities being measured. Finally, the digestion procedure must be followed carefully to insure that there is no loss of metal in this step. All of these are critical due to the fact that the metals may be found in concentrations as low as the μg/l (ppb) range and a slight error in analysis can result in a large error in sample concentration determinations.

Heavy Metals

Heavy metals analyses were performed in only two of thirty-eight studies of storm flow characterization and treatment of (1)(37). It appears that the concentrations of heavy metals have been considered relatively unimportant compared to potential oxygen demand and particulate concentration. Several of the studies, however, indicate that problems with BOD results may have been due to the presence of toxic heavy metals (11)(131)(136). Heavy metals may enter the storm or combined sewer system from various sources. Runoff from streets and highways may contain lead, zinc and copper and to a lesser extent, chromium, mercury and nickel. The average amount of these metals along certain streets of six cities studied by Sartor and Boyd (2) are listed in Table VI-10. Another possible source of toxic metals in storm generated discharges may be metallic corrosion (i.e. Cu, Cr, Zn). Drainage of industrial areas may contain any of the metals used in that industry.

When studying the quality of storm flows or when operating a stormwater treatment system, 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. Also, based on the concentrations found in the discharges going to treatment, the sludge resulting from this treatment should be analyzed accordingly. This is especially important if the possibility exists that the sludge may be discharged to a subsequent process sensitive to heavy metal toxicity.

Table VI-11 has been constructed for nine heavy metals indicating possible sources, effects, preservation and storage, and pretreatment methods, and the analytical method. In cases where chromium concentrations are high, it may be desirable to know whether the chromium is present in the

Table VI-10. HEAVY METALS LOADING INTENSITIES

	lb/curb mile (kg/curb km)											
	Zinc		Copper		Lead		Nickel		Mercury		Chromium	
San Jose-I	1.40	(0.39)	0.49	(0.13)	1.85	(0.51)	0.19	(0.05)	0.200	(0.05)	0.100	(0.03)
San Jose-II	0.28	(0.08	0.020	(0.005)	0.90	(0.25)	0.085	(0.024)	0.085	(0.024)	0.140	(0.04)
Phoenix-II	0.36	(0.10)	0.058	(0.016)	0.12	(0.034)	0.038	(0.01)	0.022	(0.006)	0.029	(0.008)
Milwaukee	2.10	(0.59)	0.59	(0.16)	1.51	(0.42)	0.032	(0.009)	--	--	0.047	(0.013)
Baltimore	1.30	(0.36)	0.33	(0.09)	0.47	(0.13)	0.077	(0.02)	--	--	0.450	(0.13)
Atlanta	0.11	(0.03)	0.066	(0.018)	0.077	(0.04)	0.021	(0.006)	0.023	(0.006)	0.011	(0.003)
Seattle	0.37	(0.103)	0.075	(0.021)	0.50	(0.14)	0.028	(0.008)	0.034	(0.009)	0.081	(0.023)
Arithmetic means	0.75	(0.21)	0.21	(0.06)	0.68	(0.19)	0.060	(0.017)	0.080	(0.02)	0.12	(0.034)

Taken from reference 131

Table VI-11. INFORMATION SURVEY FOR VARIOUS HEAVY METALS

Metal	Source	Effects	Preservation	Storage time	Pretreatment	Analysis
Copper	industry corrosion of pipe water system	not much large doses cause liver damage	acidify to less than pH 3.0 with HNO_3	no limit	digestion procedure outlined for AA	AA
Chromium (see below)	industry corrosion	carcinogenic toxic	acidify to less than pH 3.0 with HNO_3	no limit	digestion with HNO_3-HCl	AA
Lead	industry/mining smelter/plumbing	cumulative bone poison	acidify to less than pH 3.0	no limit	digestion with HNO_3-HCl	AA
Mercury	industry sea water	poison (respiratory)	acidify to less than pH 3.0 with HNO_3	as soon as possible	digestion with HNO_3 only	flameless AA
Nickel	industry	dermatitis	acidify to less than pH 3.0 with HNO_3	no limit	digestion with HNO_3-HCl	AA
Arsenic	industry insecticides	poison carcinogenic	acidify to less than pH 3.0 with HNO_3	no limit	digestion with H_2SO_4-HNO_3	colorimetric
Tin	industry plating	no effect	acidify to less than pH 3.0 with HNO_3	as soon as possible	digestion with HNO_3	AA
Cadmium	industry galvanized pipe	toxic/feed poisoning	acidify to less than pH 3.0 with HNO_3	no limit	digestion with HNO_3-HCl	AA
Zinc	industry deteriorated galvanized pipe	taste	acidify to less than pH 3.0 with HNO_3	no limit	digestion with HNO_3-HCl	AA
Chromium, hexavalent	industry	carcinogenic toxic	none	<24 hours	remove solids by centrifuge	colorimetric (diphenyl carbazide)

trivalent or the more toxic hexavalent form. In this case a portion of the sample should be separated before addition of HNO_3 preservative and analyzed for hexavalent chromium by the diphenylcarbazide method within 24 hours.

Other Metals

Metals which are not toxic to biological life or which are not commonly expected to be present need not be routinely analyzed. In certain circumstances, however, analysis for some of these metals may be desirable. Certain industies contribute metals of a specific type and street salting in northern climates can contribute sodium, calcium and iron in various concentrations. The amount of material present will indicate the frequency of analysis needed.

Ferrous iron is more soluble than ferric acid and may not be removed by most storm generated discharge treatment processes. However, oxidation at a later time may cause formation of an unsightly ferric precipitate in the treatment process effluent as in the receiving water.

Recommended Laboratory Procedures

Heavy Metals - Analysis of samples for heavy metals should always include the total amount of metal present. Additional analyses for the soluble or insoluble portions are optional and may be useful in certain instances for evaluating the performance of some treatment units. Evaluation of the potential effect of toxic metals on the receiving water, however, requires that the total amount be measured. Therefore, because of the large amount of organics generally present, samples should be digested prior to analyses.

It is recommended that the following procedures be used for digestion of the samples and for analyses. Reagent blanks should be run with each set of samples from the digestion step on. Samples should be analyzed in duplicate starting with the digestion step. Samples for metal determination should be split off, preserved with nitric acid to pH less than 2.0, and refrigerated until digestion. They may be stored in this manner up to 6 months. The container used will depend upon the analysis to be run and samples should be acidified soon after sampling to minimize adsorption on the contrainer walls. Polyethylene containers are recommended for most metals other than mercury.

Listed below are the recommended digestion procedures for various heavy metals.

1. Lead, zinc, copper, chromium, cadmium, and nickel - The nitric acid-hydrochloric acid procedure (described later) should be used.

2. Mercury and Tin - Mercury pretreatment will depend on the type of sample involved. Effluent samples of good quality or any other sample that has little solid material can be analyzed directly without digestion. However, samples from storm generated discharges and the resultant sludges from the treatment of these discharges must be digested according to the nitric acid procedure (described later).

   Tin seems to cause problems due to volatility, especially of $SnCl_2$ and organotin compounds. Normal digestion procedures will cause the loss of tin. Therefore, consideration should be given to using the nitric acid digestion procedure that is used for mercury for tin also.

3. Arsenic - The sulfuric acid-nitric acid procedure described on page 420 of Standard Methods (39) should be used. Care should be taken to maintain oxidizing conditions during digestion to prevent formation of arsine and loss of arsenic (137). After digestion, all the nitric acid must be removed to prevent subsequent interference with arsine evolution. To insure the absence of nitric acid, ammonium oxalate solution may be added and heat applied until SO_3 fumes are evolved.

   The recommended anlaytical procedures are as follows:

   1. After digestion, analysis for lead, zinc, copper, chromium, cadmium, nickel, and tin should be performed using atomic absorption spectrophotometry. The instrument should be operated according to the manufacturers instructions.

   2. After digestion, the analysis for mercury should be performed by flameless atomic absorption methods as described on page 121 of WQO Methods 1971 (40).

   3. Analysis for arsenic should be performed using the method by which arsenic is reduced to arsine and reacted with silver diethyldithiocarbamate (SDDC). This method is described on page 62 of Standard Methods (39).

When analyzing for hexavalent chromium the sample should not be digested. The sample should be analyzed as soon as possible after sampling to minimize losses due to adsorption on container walls (use of new bottles is recommended). Analysis should be performed by the diphenylcarbazide method described on page 156 of Standard Methods (39).

Other Metals - For the analysis of aluminum, calcium, iron, magnesium, manganese, potassium, silver, sodium, antimony, barium, beryllium, molybdenum, selenium, thallium, titanium, and vanadium, digestion using the nitric acid-hydrochloric acid procedure is recommended. Special care should be given to prevent possible loss due to volatilization when digesting samples for Fe, Mg, Mn, Mo and V analysis. The digestates are then analyzed by atomic absorption spectroscopy. Boron is analyzed using the curcumin method outlined in Standard Methods p. 69, Method 107A (39). Care must be taken to store the sample in polyethylene or boron free glassware and to have thoroughly clean glassware throughout the analysis. Samples for analysis of ferrous ion must be specially prepared immediately ater sampling. The pH should be adjusted to > 6 to precipitate ferric iron and filtered as soon as possible to avoid oxidation. The filtrate pH should be reduced to < 3 and analyzed for iron by atomic absorption.

Nitric acid-hydrochloric acid digestion procedure - Choose a volume of sample that will yield the appropriate value of metals. Place this aliquot of well mixed sample into a beaker and add 3 ml of concentrated nitric acid. Place the beaker on a hot plate and evaporate to dryness making certain the sample does not boil. Cool the beaker and add another 3 ml portion of concnetrated HNO_3. Cover the beaker with a watch glass and return to the hot plate. Increase the temperature of the hot plate so a gentle reflux action occurs. Continue heating, adding additional acid as necessary until the degestion is complete, generally indicated by a light colored residue. Add sufficient distilled 1:1 HCl and again warm the beaker to dissolve the residue. Wash down the beaker walls and wash glass with distilled water and filter sample to remove silicates and other insoluble material that could clog the atomizer. Adjust the volume to a predetermined value based on expected metal concentrations. This will yield values of the total metal concentration.

Nitric acid digestion procedure - A sample of suitable volume is placed in a 250 ml round bottom flask and 10 ml of concentrated nitric acid added. The flask is then connected to a reflux condensor (about 60 cm in length) and heated with a heating mantle causing the acid to reflux gently. Continue heating for 2 hours and cool the mixture. Wash down the column with about 60-70 ml of distilled water. Filter the sample through Whatman No. 42 paper to remove insoluble material and make filtrate up to 100 ml with distilled water. Take a suitable aliquot and analyze.

PESTICIDES AND POLYCHLORINATED BIPHENYLS

The controversy over the use of pesticides continues as the pros and cons of pesticide effects are debated in courts and agencies. However, their use is widespread and does merit special attention. Pesticides can be classified into several types of which the organochlorine compounds are most dangerous due in part to their extremely long half life. This fact has caused many pesticide users to change to less objectionable types of materials, such as organophosphates, in their present applications. However, it is still necessary to analyze for the organochlorines since they are very persistent and the toxic effects are important.

Although polychlorinated biphenyls (PCB's) are not pesticides they react similarly to pesticides and have the same type of persistence. These chemicals accumulate in the fatty tissues of animals and have been found in all parts of the earth. PCB's have a wide range of applications from plasticizers to hydraulic brake fluid and the amount of these in the environment can be quite large. Therefore analysis for these materials is also critical.

Pesticide and PCB analyses can be broken into three parts:

1. Extraction
2. Cleanup
3. Measurement

The extraction is done with a hexane-acetone mixture and all hexane soluble materials are removed. The cleanup steps remove materials that may interfere with the final analysis or cause questionable results. The measurement is done with electron capture gas chromatography and this step is very sensitive to minute quantities of interfering compounds. Pesticide determination on storm flows is complicated due to the wide range of materials present in the sample and the large percentage of organic solids. The general analytical procedures are outlined below. Due to the nature of storm generated discharges, a special procedure has been developed and a brief discussion of the modifications is presented here. The specific procedure is outlined later.

The extraction step is basically the same as a routine analysis, however, the large amount of organic solids usually prevent the separate handling of the solids and liquid portion. The solid material is separated by centrifugation. The solids are dried with anhydrous sodium sulfate to avoid codistillation with water that occurs with these organic compounds during air drying. They are extracted from a glass thimble using a Soxhlet extraction apparatus. The liquid portion is extracted in a separate funnel to insure good contact between the phases.

The cleanup is divided into several steps due to the difficulty in removing the interfering substances from the sample. Because of the high concentration of these interferences in storm generated discharges the four cleanup steps are recommended. Special care is taken so the elements are pure and that the concentrations are accurate. The micro-scale alkali cleanup/confirming procedure is a destructive step, so only portions of the sample are treated in this manner. If sulfur interference is indicated, treatment with elemental copper is recommended, however, alkali treatment also removes the sulfur.

Finally, the analysis is done on two gas chromatograph columns of different polarity to allow cross checks. The peak postions are compared to peaks produced by known materials for identification. The peak area is used to determine the quantity of material measured.

Recommended Analyses

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.

For evaluating a treatment process, the same procedures should be used as for evaluating a discharge. In addition, if it is found that pesticides are present in the treatment process, then the residual sludges arising from these processes should also be analyzed.

Recommended Analytical Procedures

Scope and Application - This method describes the extraction and isolation of organochlorine pesticides and certain PCB mixtures from storm sewer discharges and combined sewer overflows, influents and discharges from treatment processes. The cleanup procedures permit the analyst to eliminate those interferences which may be encountered and allows for separation of analogs of Arochlor #1254, #1260, and #1262 from organochlorine pesticides.

PCB's and organochlorine pesticides are coextracted either by liquid-liquid extraction or for samples of high solids by mixing with anhydrous sodium sulfate and soxhlet extration. A combination of the standard Florisil column cleanup and silicic acid column chromatography are employed to separate PCB's from organochlorine pesticides (138). Identification is made with a gas chromatograph equipped with an electron capture detector through the use of two or more unlike columns. Further configuration by chemical modification using a micro scale alkali treatment (139) is recommended.

Sampling Preservation Volume and Container - As with all analyses, the more quickly the test can be performed, the more accurate the results. Pesticide samples must be taken in glass containers and preserved by refrigeration at 4°C. Sludge samples may also be preserved by freezing.

Interferences - All glassware, solvents, reagents, and sampling hardware must be demonstrated to be free of interferences under the conditions of analysis. It is recommended that all glassware be fired at 230°C as described by Lamberton et al (140). Organochlorine pesticides and PCB's are mutually interfering. The silicic acid column will not separate Arochlor #1221, #1242, and #1248 completely from DDT and its analogs. (Early eluting peaks from the Aroclors may occur in the polar eluate.) For this reason, the use of the chemical modification confirmation technique is recommended.

The sensitivity of this procedure is predicated on the size of the aliquot extracted, the organochlorine's response on the EC detector and the background interferences. The cleanup procedure will eliminate most of the background interferences, however, great care should be exercised to minimize organochlorine loss during cleanup. Spiked samples are recommended as a quality control check of organochlorine recovery. As a general rule, a 100 ml sample should yield quantifiable results for most organochlorine pesticides with a sensitivity of 1 µg/l.

Apparatus -

1. Gas chromatograph equipped with recorder.
2. Detector, electron capture.
3. Gas chromatograph columns - two glass columns packed with nonpolar and semipolar adsorbents suitable for pesticide analysis. Recommended column dimensions are 0.63 cm x 1.83 m (0.25 in. x 6 ft). Suitable packings are 1.5% OV-17 and 1.95% OF-1 on 80-100 mesh Anakrom ABC (polar column) and 5% OV-210 on 80-100 mesh Anakrom (semipolar columns).
4. 500 ml Kuderna-Danish glassware (Kontes K-570000).
5. Chromatographic column 400 x 22 mm (Kontes K-420550, C-4) with adapter, hose connector type (Kontes K-185030).
6. Separating funnel 250 ml (Kontes K-633030).
7. Evaporative concentrator (Kontes K-569250).
8. Concentrator tube (Kontes K-570050) graduated in 0.1 ml to 1 ml.
9. Separatory funnels (125 ml, 1000 ml with teflon stopcocks).

10. Volumetric flask, 250 ml.

11. Florisil-PR Grade (60-100 mesh) prepared after the method of Hall (141).

12. Silicic acid, Mallinckrodt 100 mesh "Especially Prepared for Chromatograph analysis by the Method of Ramsey and Patterson", see sample preparation later.

13. Glass wool - hexane extracted.

14. Centrifuge tubes, 40 ml Pyrex.

15. Soxhlet extractor, 250 ml.

16. Magnetic stirrer with teflon control bar, hexane extracted.

17. 4 liter (1 gal) sample bottles, with teflon caps.

18. Transfer pipette, 10 ml.

19. Celite 545, acid washed.

20. Air regulator.

Reagents, Solvents, and Standards

1. Sodium chloride, ACS, saturated solution.

2. Sodium sulfate, ACS, granular anhydrous, conditioned for four hours at 400°C.

3. Diethyl ether - nanograde.

4. Hexane, acetonitrile, methanol, methylene chloride, petroleum ether (BP 30-60°C) - pesticide grade.

5. Standards - appropriate organochlorine and arochlors for elements in question.

Calibration - Gas chromatograph conditions are considered acceptable when response to heptachlor epoxide is 50% of full scale for $\leq$ 1 ng injection (full scale - 1×10^{-9} amp). Detector response for quantitative work must be in the demonstrated linear range. Standards are injected frequently as a check on detector and column stability. For quantitation, noise should not exceed 2% of full scale.

Sample Preparation - Adjust pH to near neutral. If the solids content of the sample is high (as with sludges and some influent samples) liquid-liquid partition is not possible due to emulsion formation. Under these conditions the sample aliquot is centrifuged and the supernatant treated as described below. The solids are combined with anhydrous sodium sulfate and extracted as described below also.

Extraction - Two methods of extraction may be employed depending on the nature of the sample. Unless the sample appears to be low in solids and organics (a well treated effluent sample for example) it will be necessary to separate the solids from the liquid and extract each separately. The extracts may then be combined and concentrated as a single extract.

Liquid-liquid extraction is employed for samples of low solids and organic content. Place an aliquot of the sample in a one liter separatory funnel and make the volume up to 500 ml using distilled water. Add 30 ml of 15% methylene chloride in hexane (V:V) and shake vigorously for two minutes. Allow the phases to separate and drain the water layer into a clean Erlenmeyer flask. Pass the organic layer through a 7.6-10.2 cm (3-4") column of anhydrous sodium sulfate and collect in a 500 ml flask. Return the water phase to the separatory funnel and rinse the Erlenmeyer with a second 30 ml volume of solvent. Add the solvent to the separatory funnel and complete the extraction procedure. The water phase should be extracted with three 30 ml aliquots of solvent. Concentrate the extract on a water bath to 5 ml. Note that if an emulsion is formed between the water and solvent phases it will be necessary to remove the solids as follows.

Samples of high solids content should be centrifuged in clean, hexane washed glass centrifuge tubes. Decant the supernatant into a 1 liter funnel and extract the pesticides as outlined above. Remove as much of the centrifuge cake as possible with a glass rod and combine it with hexane washed anhydrous sodium sulfate in a large mortar and pestle. Work the sample to free flowing dry state by continuously adding small amounts of anhydrous sodium sulfate. Add a small amount of sodium sulfate to the centrifuge tube to dry any remaining sample and aid in removing it. Combine all the dried sample and pour it into a glass Soxhlet extraction thimble. Place the filled thimble in a Soxhlet apparatus and wash the mortar and pestle and centrifuge tube with three washings of 1:1 hexane, acetone. Carefully add the washings to the extraction apparatus by pouring them through the filled extraction thimble. Extract the sample for 6 to 8 hours. Take the extract just to dryness on a water bath in a Kuderna-Danish assembly, cool and wash the Kuderna-Danish assembly with hexane and adjust sample volume to 5 ml.

Inject the concentrate in the gas chromatograph and determine:

1. If only organochlorine pesticides are present.
2. If only PCB's are present.
3. Combination of 1 and 2.
4. If elemental sulfur is present.
5. If response it too complex to determine 1, 2, or 3.
6. If 1, determine organochlorine pesticides according to Reference 142.
7. If 2, determine PCB's according to Reference 143, Section IIff.

8. If 3, compare peaks obtained to standard Arochlors and determine which Arochlors are present. If Arochlor peaks are analogs of #1254 and #1260, the PCB's may be separated from DDT and its analogs by the combination of Florisil column and silicic acid column technique described later. If other Arochlor analogs are present further confirmation with the microalkali technique in Appendix III of Reference 143 should be employed.

9. If 4, remove sulfur according to the procedure discussed later.

10. If 5, see the discussion below. The selection of the various cleanup techniques can be simplified if a background knowledge of the storm generated discharge sample is available.

Cleanup and Separation Procedures -

Acetonitrile partition for removal of fats and oils - (Note: Not all pesticides are quantitatively recovered by this procedure. Efficiency of partitioning for pesticides of interest should be demonstrated.) Transfer the concentrated extract to a 125 ml separatory funnel using hexane rinses to ensure complete transfer. Final volume should be 15 ml. Extract the sample with four 30 ml portions of hexane saturated acetonitrile by shaking vigorously for one minute. Combine and transfer the acetonitrile phases to a one liter separatory funnel and add 650 ml of distilled water. Add 40 ml of saturated sodium chloride solution, mix thoroughly and extract with two 100 ml portions of hexane. Combine the hexane extracts in a one liter separatory funnel and wash with two 100 ml portions of water. Discard the water layer, pass the hexane layer through a 7.6 to 10.2 cm (3-4 in.) anhydrous sodium sulfate column into a Kuderna-Danish flask and rinse the funnel and column with three 10 ml portions of hexane. Concentrate the hexane extracts to 6-10 ml and analyze by gas chromatography if further cleanup is not required.

Sulfur interference - Elemental sulfur is encountered in most sediment samples, marine algae and some industrial wastes. The solubility of sulfur in various solvents is very similar to the organochlorine and organophosphate pesticides; therefore, the sulfur interference follows along with the pesticides through the normal extraction and cleanup techniques. The sulfur will be quite evident in gas chromatograms obtained from electron capture detectors, flame photometric detectors operated in the sulfur or phosphorus mode, and Coulson electrolytic conductivity detectors. If the gas chromatograph is operated at the normal conditions for pesticide analysis, the sulfur interference can completely mask the region from the solvent peak through pp'DDE.

This technique eliminates sulfur by the formation of copper sulfide on the surface of the copper. There are two critical steps that must be followed to remove all the sulfur: 1) the copper must be highly reactive; all oxides must be removed so that the copper has a shiny, bright appearance; and 2) the sample extract must be vigorously agitated with the reactive copper for at least one minute.

It will probably be necessary to treat both the 6% and 15% Florisil eluates with copper if sulfur crystallizes out upon concentration of the 6% eluate.

Certain pesticides will also be degraded by this technique, such as the organophosphates, chlorobenzilate and heptachlor, as shown in Table VI-12.

Table VI-12. EFFECT OF EXPOSURE OF PESTICIDES TO MERCURY AND COPPER

Compound	Percentage recovery based on mean of duplicate tests: Mercury	Copper
BHC	81.2	98.1
Lindane	75.7	94.8
Heptachlor	39.8	5.4
Aldrin	95.5	83.3
Hept. Epoxide	69.1	96.6
p,p'-DDE	92.1	102.9
Dieldrin	79.1	94.9
Endrin	90.8	89.3
DDT	79.8	85.1
Chlorobenzilate	7.1	0
Arochlor 1254	97.1	104.3
Malathion, diazinon Parathion, Ethion Trithion	0	0

Note: If the microalkali dehydrochlorination procedure is used, elemental sulfur is removed (from Reference 139).

However, these pesticides are not likely to be found in routine sediment or sludge samples because they are readily degraded in the aquatic environment.

If the presence of sulfur is indicated by an exploratory injection from the final extract concentrate (usually 5 ml) into the gas chromatograph, proceed with removal as follows:

1. Under a nitrogen stream at ambient temperature, concentrate the extract in the concentrator tube to exactly 1.0 ml.

2. If the sulfur concentration is such that crystallization occurs, carefully transfer, by syringe, 500 µl of the supernatant extract (or a lesser volume if sulfur deposit is too heavy) into a glass-stoppered, 12 ml graduated, conical centrifuge tube. Add 500 µl of iso-octane.

3. Add about 2 mg of <u>bright</u> copper powder, stopper and mix vigorously 1 minute on a Vortex mixer. (<u>NOTE</u>: The copper powder as received from the supplier must be treated for removal of surface oxides with 6$\underline{N}$ HNO_3. After about 30 seconds of exposure, decant off acid, rinse several times with distilled water and finally with acetone. Dry under a nitrogen stream.)

4. Carefully transfer 500 µl of the supernatant-treated extract into a 10 ml graduated evaporator concentrator tube. An exploratory injection into the gas chromatograph at this point will provide information as to whether further quantitative dilution of the extract is required. <u>NOTE</u>: If the volume transfers given above are followed, a final extract volume of 1.0 ml will be of equal sample concentration to a 4 ml concentrate of the Florisil cleanup fraction.

<u>Florisil column cleanup</u> - Place a charge of activated Florisil (the weight of the charge is determined by its Lauric Acid Value - see Reference 141) in the Chromaflex column and settle by gentle tapping. Add a 1 cm layer of anhydrous sodium sulfate and pass 50-60 ml of petroleum ether through the column. When the petroleum ether is about 5 mm from the sodium sulfate surface, transfer the sample extract by a long stem funnel with petroleum ether washings to the column and elute with the following mixed ethers at 5 ml/minute. (<u>NOTE</u>: For both column chromatography procedures the elution rate is important. To quickly adjust this rate the lower part of a broken 25 ml burette equipped with teflon stopcock placed between the chromaflex column and the receiving vessel is most useful in making repetitive flow adjustments without losing eluate. See Figure VI-4). Collect each eluate in a 500 ml Kuderna-Danish flask and concentrate to 5 ml.

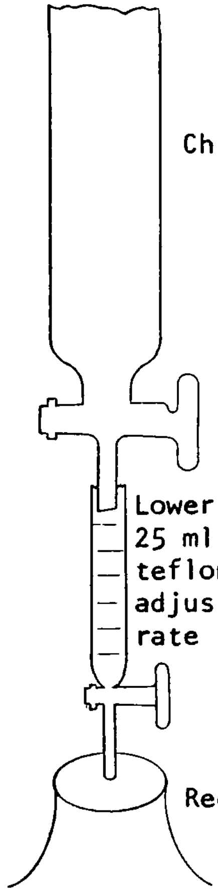


Figure VI-4. Drawing of a recommended procedure for obtaining proper elution rates

First elution (6% eluate) add 200 ml of 6% ethyl ether in petroleum ether (V/V). Second elution (15% eluate): Add 200 ml of 15% ethyl ether in petroleum ether. Most pesticides of interest will be in these eluates. Refer to Reference 142 for more details. The pesticides that may be expected in each of the eluates are listed below:

<u>6% Eluate</u>

Aldrin	Heptachlor	Strobane
BHC	Heptachlor epoxide	Toxaphene
Chlordane	Lindane	Trifluralin

DDD	Methoxychlor	PCB's
DDE	Mirex	
DDT	Pentachloronitrobenzene	

15% Eluate

Endosulfan I	Dichloran
Endrin	Phtholate
Dieldrin	esters

Concentrate the eluates and analyze by GLC.

Silicic Acid Column separation procedure -

1. Silicic Acid Preparation: Celite 545 must be oven dried and free of electron capturing substances (acid washed). Silicic acid: oven dry for a minimum of seven hours at 130°C to remove water. Cool the silicic acid, weigh into a glass stoppered bottle and add 3% water. Stopper bottle and shake well. Allow 15 hours for equilibrium to occur. Determine separation achieved as described below by loading 40 µg of Arochlor #1254 and pp'DDE in hexane on the column. Inadequate separation will mean readjustment of the water content of the silicic acid in recommended increments of 0.5%. More water is required when the PCB elutes in the polar solvent with pp'DDE; less water when pp'DDE elutes in the petroleum ether portion. Standardization is required for each new lot of silicic acid purchased. Once a batch of silicic acid is hydrated activity remains for about 5 days.

2. Column Preparation: Weigh 5 g of Celite and 20 g of silicic acid and combine in a 250 ml beaker. Immediately slurry with 80 ml of petroleum ether. Transfer the slurry to the chromatographic column, keeping the stopcock open. Stir the slurry in the column to remove air bubbles, then apply air pressure to force the petroleum ether through the column. Do not allow the column to crack or go dry and close the stopcock when air pressure is not being applied. Stop the flow when the petroleum ether level is 3 mm above the surface of the silicic acid. The absorbant at this point should be firm and not change shape if tapped.

3. Elution Patterns: Large amounts of PCB's or pesticides placed on the column will result in incomplete separation. The extracted sample placed on the column should contain no polar solvents and be $\leq$ 5 ml in volume. Place a 250 ml volumetric flask beneath the column and carefully add a suitable aliquot of the 6% Florisil eluate, taking care not to distrub the surface of the silicic acid. A long stem funnel is useful for this purpose. Apply slight air pressure until the solvent level is about 3 mm from the surface of the silicic acid. Carefully position the 250 ml separatory funnel containing 250 ml of petroleum ether on the column and allow the petroleum ether to run down the sides of the column until the space above the silicic acid is one half full. Apply air pressure and adjust the flow rate to 5 ml/minute. When exactly 250 ml are collected replace the volumetric flush with 500 ml Kuderna-Danish flask and elute at 5 ml/minute with 200 ml of methylene chloride, hexane and acetonitrile (90:19:1, V/V) to recover the pesticides. Quantitatively transfer the petroleum ether eluate containing the PCB's to a 500 ml K-D and concentrate both eluates to 5 ml. Analyze by gas chromatography. NOTE: The separation between the PCB's and pp'DDE is very narrow; great care should be exercised in adjusting the elution flow rate and volume of the petroleum ether portion.

Petroleum Ether Eluate

Aldrin		
Arochlors	#1248[a]	#1252[a]
	#1221[a]	#1254[a]
	#1252[a]	#1260[a]
	#1258[a]	#1262[a]
Hexachlorabenzene		

Polar Eluate (Acetonitrile, Methylene Chlroide, Hexane)

Arochlors	#1221[a]	Endrin
	#1242[a]	Heptachlor
	#1248[a]	Heptachlor epoxide
BHC		Lindane
pp'DDE		Toxaphene
pp'DDT		
pp'DDD		

a. These Arochlors divide between the two eluates. The earliest evaluating GLC peaks may occur in the polar eluate.

Confirmation Techniques

Qualitative confirmation - By comparing relative retention times of the constituents on two or more unlike columns as a minimum criteria for identification after appropriate cleanup and column chromatography, it is felt that satisfactory qualitative confirmation can be performed.

If an Arochlor analog which does not completely occur in the petroleum ether eluate is suspected, the alkali-dechlorination procedure is strongly recommended (see Young et al (139)). In any event such confirmation techniques add greatly to the reliability of the residue analysis in the absence of more sophisticated mass spectroscopy instrumentation.

Quantitative Determination - For organochlorine pesticides, use Reference 142, Section II. For PCB's use Reference 143, Section II. Report results in micrograms/l without correction for recovery data. For sludge samples it may be necessary to adjust for a density factor.

RECOMMENDATION OF OTHER CHARACTERISTICS

Storm generated discharges may contain a number of contaminants that are not often measured in most domestic wastewaters, but may be important in the characterization and treatment of storm generated discharges. Many of these characteristics have been indicated in the literature (7)(30)(144)(145). A recent review of possible combined sewer overflow contaminants has been made by Field and Tafuri (146). Table VI-13 shows some of the contaminants that can be expected in storm generated discharges.

Surveys have been conducted to determine how ordinances and street cleaning practices can best minimize the contaminants that build up in streets between rainfalls (2)(145). Street surface contaminants have been characterized and quantified in different areas of the country (2). The largest portion of street surface contaminants consisted of dust and dirt (fine solids), however, litter and other contaminants were found from a number of other sources. Many of these contaminants were subjective in nature and are not easily quantified by available testing procedures. The proper characterization of the subjective waste contaminants can be handled by use of a check off sheet with general categories as shown in the tables in Figure VI-5. Also, entries should be made periodically in a log book to describe these characteristics in the operator's own manner as he observes it.

The general appearance of storm generated discharges will often be very useful in determining treatment plant problems. Changes in wastewater color and extensive foaming may indicate the presence of large quantities of soaps, detergents or other materials that reduce the surface tension. These types of materials can cause significant problems in the physical and chemical treatment of combined sewer overflows by inhibiting settling and chemical coagulation. An increase in soluble and total phosphorus may also occur which will increase the nutrient load to the receiving body of water. Gasoline, solvents, and other industrial chemicals that

Table VI-13. POLLUTANT CHARACTERISTICS OF URBAN RUNOFF

1. Color causing materials
2. Turbidity
3. Foam causing materials
4. Floating material
5. Street litter debris
6. Material from street or pavement surface
7. Debris from vacant lands
8. Ice control chemicals
9. Pest control chemicals
10. Fertilizers
11. Droppings from animal or bird sources
12. Lawn or garden litter
13. Household or commercial refuse
14. Air deposited materials from precipitation
15. Twigs and leaves
16. Paper
17. Plastic materials
18. Tire and vehicular exhaust residue
19. Heavy metals
20. Hazardous material spills
21. Other large, heavy items

COLOR CHARACTERIZATION

Time	Normal	Blackish	Whiteish	Reddish	Foaming	Other

ODOR CHARACTERIZATION

Time	Normal	Septic	Rotten Egg H_2S	Hydrocarbon Gasoline, Solvents	Other

DEBRIS CHARACTERIZATION

Time	Construction material, lumber, bricks, etc.	Rags	Other

Figure VI-5. Subjective check-off sheet for characterizing various contaminants can cause fires or explosions in enclosed areas usually produce strong distinctive odors that are readily detected by treatment plant operating personnel. Debris can plug inlets and damage treatment facilities. Materials toxic to humans, fish, or aquatic flora and fauna may be present in thes discharges. A discussion of physical and other unusual parameters that are important in characterizing storm generated discharges or in the treatment of these waters follows.

Potential Physical Parameters in Storm Flow Characterization

Asbestos - The importance of asbestos in storm generated discharges has not been defined. The primary potential source of asbestos is street and highway runoff where deposits may be caused by asbestos brake shoes of vehicles. In some areas of the country industries using asbestos as raw products may contribute to the presence of asbestos in storm generated discharges.

The analysis and detection of asbestos in storm flow are in the formative stages of development. Many studies from manufacturing plants producing asbestos products use the suspended solids test described in Standard Methods (39) in characterizing their wastewaters. The suspended solids test is easily determined but it does not differentiate between asbestos or other fibers and suspended material that can be present in a storm generated flow; hence it is inadequate for this purpose. A dispersion staining technique that relies on microscopic observation of fibers deposited on a filter has been developed (147). It was possible to differentiate between asbestos and other fibers by suspending the nonfilterable particles from the filter in a liquid with a refraction index that matches that of the asbestos fiber at a wavelength of 550 nanometers. In the same reference a procedure for determining the total fibers present in a water sample by counting fibers by a phase-contrast microscope was described. It was suggested that to determine the total number of asbestos-like fibers present in the water sample, a microscope with a device for switching objectives could be employed. Thus, the same field of view could be observed using alternately the dispersion staining and then the phase-constrast objectives. In other studies identification and quantification has been accomplished with an electron microscope (148)(149)(150), using the electron microscope for measurement of asbestos fibers. It was reported that despite variations in geographical origin, asbestos (chrysotiles) fibers have a narrow size distribution. Ultrasonic treatment was used to separate the asbestos material into individual fibers (150).

Since there are a large number of different types of suspended materials in storm flows there are many interferences to asbestos identification analytical techniques. Ashing at 450°C has been used to destroy organic materials such as plant and bacterial debris that would interfere (148). It was shown that the addition of dibutylphthalate to the suspended solids sample prior to ashing would reduce loss of asbestos due to explosive combustion of the membrane filters (150). After ashing, the samples were homogenized using an ultrasonic water bath to resuspend the remaining materials and to separate the asbestos into individual fibers.

X-ray diffraction has also been used for identification and quantitative determination of different types of asbestos (151). Fifty to 100 µg/l of asbestos could be detected even when interferences were present. The amount of asbestos in the filter must remain small in order to reduce errors due to specimen thickening. Studies with air samples have shown the x-ray diffraction technique capable of detecting 0.1 $\mu g/m^3$ of asbestos; the electron microscopic method can detect 0.1 ng/m^3. Thus the electron microscopic technique is about 1000 times more sensitive. Other methods of detecting asbestos include infrared spectrometry and elemental analysis (149).

Five hours are required for the analysis of each sample using the electron microscopic technique. However, actual time required is longer because of extensive filtration and ultrasonic resuspension techniques required. The routine testing for asbestos is not recommended for storm flows. Periodic testing for asbestos in storm flows should be conducted in municipal areas where there are asbestos factories or industries machining asbestos products. In most cases it will be necessary to send the samples to a regional laboratory where x-ray diffraction or an electron microscope is available.

Asphalt and Road Materials - Street surfaces have been found to be a source of potential contaminants in storm generated discharges (152). Included in these materials are asphalts and portland cement, their various decomposition products and aggregate materials. There may also be some contribution of small amounts of road marking paints, crack fillers and expansion joint compounds. All asphalt streets and those streets with poor surface conditions were found to have a substantially higher amount of loose particulate materials that could end up in storm generated discharges than all concrete streets and streets in good condition (2). Climate also was a major factor in the presence of contaminants from streets due to freeze-thaw cycling and the use of studded tires. Leaks and spills of fuels or oils hastened the degradation of asphaltic pavement and resulted in a higher amount of pollutants appearing in storm generated discharges.

Specific identification of asphalt is complicated by its complex makeup and the fact that many asphaltic functional groups form intermolecular complexes. Infrared spectrometry has been used to identify key asphaltic functional groups that have been isolated using selective chemical reagents and solvents (151). However, no analytical procedure has been developed for detection of asphalt from different areas of the country. In stormwater studies the presence of asphalt will be included in other more general analytical tests. Small particulate materials from road surfaces may enter a large bore pipet and be measured in the suspended solids determination. In some cases the presence of larger particles from road and other sources will cause large variations and erratic results in the suspended solids analysis. These variations are caused by the nonuniform presence of heavy particles and the difficulty of obtaining a representative sampling of these types of materials.

Asphaltic materials will also be measured to some extent where solvent extractions are made to determine grease and oil. While the specific determination of asphaltic and other road materials will not be determined by the above tests, the general pollutional nature will be determined when suspended solids, grease and oil, and to some extent when oxygen demand tests are conducted. Since specific tests for all types of asphaltic materials are not readily available and since the asphaltic materials are probably quantified by the other analyses, the routine analysis for asphalt is not recommended.

Color - Natural color in storm generated discharges will cause these wastewaters to exhibit different colors in different areas of the country. Natural color can be due to tannins, humic acid, humates from the decomposition of lignin (48), iron, colloidal clay and other inorganic materials. Weeds, vegetable materials and industrial wastes may also contribute to the color of a wastewater. Descriptions of materials collected on screens in sewers have included brownish pulp appearance, pinkish-gray appearance and light brown appearance (30). Intentional and accidental industrial waste spills can have significant effects on storm generated discharge characteristics. Paint spills have colored wastewaters and material from screening operations have brilliant colors. Oil dumps have occurred that produced a black color in storm generated discharges (27). The normal color of storm generated discharges in the midwest has been found by the authors to vary throughout a storm and to depend, to some extent, on antecedent rainfall. The first flush is usually black and gradually changes to a yellow-brown color as the storm progresses. After an extended period, the water may become relatively clear with very little color. Combined sewer overflows at Racine, Wisconsin have contained a white, milk-like color possibly due to soaps or detergents, milk products, or some other unknown contaminants (153). A gray cast to these discharges has also occurred at the same plant during the first flush. A milky-white combined sewer overflow at Kenosha, Wisconsin was traced to a local industry (154).

While the characterization of color in storm flow is often difficult and somehwat subjective, the presence of color may indicate a need to determine specific tests that are not normally conducted. Analyses such as calcium, oil and grease, or TOD may provide important information in characterizing the storm generated discharges, in evaluating their treatability, and the future treatment needs.

True color is designated as that color exhibited by a water sample after the turbidity has been removed. Apparent color is the color observed from the whole sample including the suspended materials. Two methods are described in Standard Methods (39) for accurately specifying the color of a wastewater. Color is not usually determined in the characterization of sewages but may be important where industrial wastes are a component of the wastewater. The determination of color as described in Standard Methods (39) is not recommended for storm flows. However, a qualitative description of storm flows can be useful and should be conducted by the operating personnel. Special analytical tests should be conducted when the color of storm flows continue to deviate from the normally expected color. Surveys of local industries may show possible problems with industrial waste controls that can be corrected.

Debris and Bulk Solids - No analytical laboratory test can be used for debris and bulk solids found in storm generated discharges. Usually, specific items in this category can be readily identified. Table VI-14 shows a list of different types of items that have been found in inlets to storm generated discharge treatment plants. Many of the larger debris have caused damage to protective cages of submersible pumps (7) or eventually stopped flow to the treatment plant as rags and other smaller items collected around the larger bulk items (153). Many of these items listed in Table VI-14 are from highway or sewer construction. However, in some cases intentional disposal of wastes from street and lawn maintenance have occurred as individual home owners use the street and nearby catch basins for disposal. Many reports on storm generated discharge studies have not found debris or other large items to be a problem; however, most of these studies are pilot scale where combined sewer overflows or storm sewer discharges are pumped or drawn from an existing sewer in such a manner as to screen out the larger objects. Where wetwells, sumps or the entire waste has been treated, debris and large items similar to those in Table VI-14 have been ecountered.

It is expected that bar screens will be an important design consideration in stormwater treatment systems because of these large objects. A log book should be maintained to record the presence of all debris and large objects found in storm flows. The log should include a description of the effects of the objects and any damage they may have caused. Attempts should be made in the surrounding community to minimize the loss of these items to the sewer where possible.

Density/Specific Gravity - Very little meaningful information can be obtained from density measurements of storm flow as a whole because of the extremely high percentage of water contents. Although the specific gravity of the particles in a wastewater is the most significant variable in the treatability of these materials, direct determination is not necessary. Instead, the settleability (or flotability) of the solids in a storm generated discharge is better qualified by the routine bench scale settling and flotation tests conducted in the laboratory. However, the density of the solids themselves has been discussed and may be important in solids handling and disposal (155).

Table VI-14. DEBRIS AND BULK SOLIDS FOUND IN STORMWATER

Item	Reference
1. Droppings from animals, birds or humans	30
2. Lawn or garden litter	30
3. Remnants from household or commercial refuse	30
4. Twigs	144
5. Cloth and rags	144
6. Plastic material	144
7. String	144
8. Tires	145
9. Concrete slabs	145
10. Steel drums	145
11. Mattresses	145
12. Automobile radiator	145
13. Chains	145
14. Wheelborrow	153
15. 24'' x 10' PVC pipe	153
16. 4'' x 50' long fine hose	153
17. Building bricks, cement	153
18. Logs, 18'' x 5'	153
19. Street barricade with flashers	153
20. Rodents	153

The density of clay is about 0.96 kg/l (60 lb/cu ft) and for sand, about 1.77 kg/l (110 lb/cu ft); a single measurement of combined sewer overflow solids measured 13.6 kg/l (85 lb/cu ft). The sludge volume index (SVI) defined in Standard Methods (39) gives the volume of settled sludge (ml) occupied by one gram of solids after settling for 30 minutes. This is the inverse specific gravity which is equal in magnitude to density in the metric system of units. Hence the density of activated sludge would be 1/(SVI) x 1 g/cc (62.4 lb/cu ft). A commonly accepted SVI value for well settling sludge is 100 ml/gm which is equal to a sludge density of 0.1 g/cc (6.24 lb/cu ft). The parameter, sludge density index (SDI) has been defined in Standard Methods (39) as SDI = 100 x 1/(SVI), thus SDI measurements would be equivalent to 100 x the density of the solids. SVI or SDI measurements are usually made for biological treatment systems and would be useful in characterizing biological plants treating storm generated discharges such as the contact stabilization plant at Kenosha, Wisconsin (17). Where biological treatment systems are used to treat storm wastewaters one of the above tests should be used. However, no other density parameters are recommended for routine analyses.

Oils and Grease - Oils and grease are commonly found in storm flows as seen in Table VI-15.

Table VI-15. OILS AND GREASE IN STORM GENERATED WASTEWATERS

Concentration in inlet to treatment plant, mg/l		
Range	Mean	Reference
2 - 99	--	29
1.3 - 54.4	12.3	30
10.9 - 48.4	27.6	35
31 - 140[a]	81	156
--	40	157
33 - 95	--	157

a. Pressure sewer system

Oils and grease may be introduced into storm flows by overflow from municipal treatment plants, by various industrial sources, by individual home owners and of course by roadway runoff. Filling stations have disposed of used crank case oil in floor drains and in catch basins (19). Laundries, car wash operations, packing houses, and refineries can be expected to contribute significant amounts of oils and grease to the wastewaters when they are treated by combined municipal-industrial plants.

It is not necessary to routinely measure oils and grease in most areas of the country. However, oils and grease should be determined once at the beginning of every storm generated discharge study. Where oils and grease are likely to be present in storm discharges, as discussed above, analyses should be made for both dry-weather flows and for each storm event analyzed. Oils and grease are defined based on the method used for analysis; hence the method used should always be specified with these data. The soxhlet extraction method described in Standard Methods (39) Section 209A, page 409 should be used for investigating the presence of oils and grease or where high solids are present in a wastewater sample. If light oil or soluble oils are possible constituents of a sample the liquid-liquid extraction procedure described in Section 137, page 254 of Standard Methods should be used.

Odor - Although a tentative test exists for determining odor intensity in wastewater samples (39), odor should be considered a qualitative parameter only. Storm generated discharges may smell of gasoline, oil, chemical solvents, fertilizer, herbicides, insecticides, mustiness, hydrogen sulfide, septicity or not at all. Strong odors of herbicides, insecticides, and oil or gasoline have been detected in operating combined sewer overflow treatment plants (153). The odor should be recorded in the operating log for the plant and specific analytical tests should be considered depending on the odor. When strong solvent or gasoline odors are detected, safety precautions should be taken and the source identified if possible. No specific threshold odor tests used in water quality analyses are recommended for storm generated discharges (39).

Particle Size Distribution - Particle size is important in several treatment processes used in treating storm generated discharges. Although the density of particles also plays a large role in solids removal, the particle size will affect the settleability or floatability of different solids. Thus, settling tanks, air flotation, screening, and filtration may be affected by particle size. Suspended solids removal by screening is dependent on the particle size distribution as shown in Figure VI-6 and Table VI-16. These data are from combined sewer overflow studies and show a significant improvement in removal where small opening screens were used, thus indicating the presence of a large amount of smaller particle sizes. A wet sieve analysis developed by Envirex Inc. has been used to characterize two storm generated discharges as shown in Table VI-17. In the discharge at Hawley Road (Milwaukee, Wisconsin) 94% of the solids were smaller than 84 μ and at Racine, Wisconsin about 72% were smaller than 74 μ. Over 90% (by weight) of the solids at Hawley Road were smaller than 37 μ. While 10% of the solids at Hawley Road were larger than 37 μ, 22% (by weight) suspended solids removal was achieved with 63 μ screens (159). Increased solids removal was achieved because of the buildup of solids on the screen which made the effective pore size smaller.

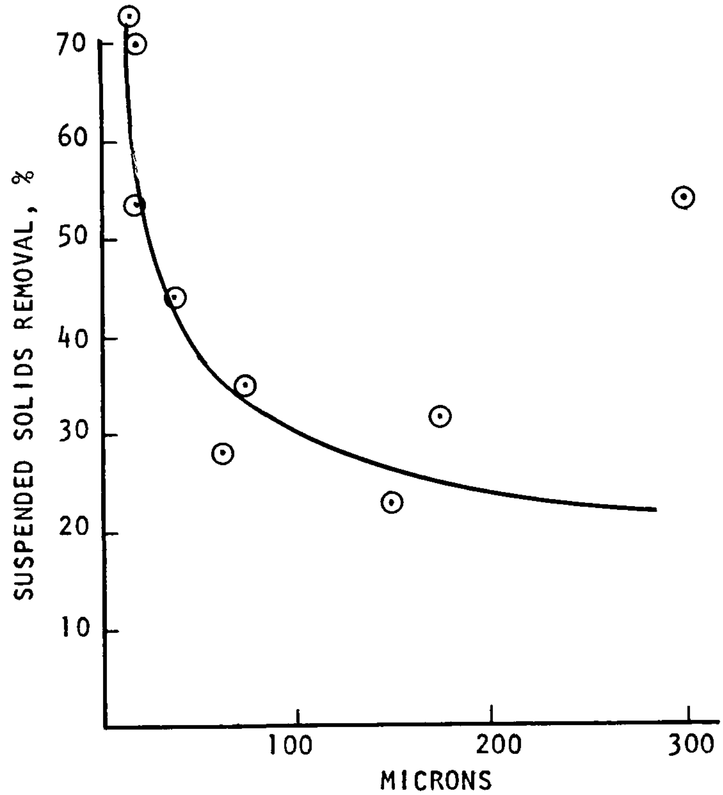


Figure VI-6. Suspended solids removal for different size screens from storm generated discharge projects

Table VI-16. SCREENING REMOVAL EFFICIENCIES FROM LITERATURE

	Screen size, μ	SS removal, percent	References
Philadelphia	23	72	158
Milwaukee,			
Hawley Road	23	70	26
Hawley Road	23	54	26
Philadelphia	35	44	158
Milwaukee			
Hawley Road	63	28	26
Hawley Road	63	32	26
Hawley Road	63	25	26
Portland	73	35	48
Milwaukee			
Hawley Road	149	22	26
Portland	167	31	48
Milwaukee			
Hawley Road	841	8	26
San Francisco	3175	2[a]	19

a. Solids removal based on total solids.

Table VI-17. WET SIEVE ANALYSIS RESULTS FROM TWO COMBINED SEWER OVERFLOWS[a]

Hawley Road combined sewer overflow	
Screen opening, μ	% retained, by weight
841	2.0
149	2.6
84	1.0
37	4.3
<37	90.1

Racine combined sewer overflow	
Screen opening, μ	% retained, by weight
2380	1.2
841	2.8
297	6.7
149	10.6
74	1.4
<74	72.3

a. Reference 159

Table VI-18 shows the particle size distribution of solids from street surfaces for several cities. These data indicate that the potential solids sizes from street surfaces are greater than the sizes found using the dry sieve analysis in Tables VI-16 and VI-17. A large fraction of the solids in Table VI-18 is due to sand. These particles are usually heavy and may settle out either in the sewers or somewhere near the head end of the treatment plant. Also, sand may be removed by street washing operations. The data in Table VI-18 were taken using the dry sieving particle size distribution technique which may also be the cause of the difference in average particle size as compared with Table VI-17.

Particle size distribution studies are not recommended except for general evaluation of storm generated discharges unless screening is to be used as a means of treatment or the efficiency of street cleaning is being studied. A minimum of three particle size distribution analyses evenly spaced throughout the project should be made for these treatment plant designs. In some cases more analyses will be required. The wet sieve method has been found by the authors to provide the most realistic values with a minimum of interference; hence it is recommended.

pH - The pH of a wastewater sample is a measure of the hydrogen ion activity and is used to determine if a water is acidic, $pH < 7$, or basic, $pH > 7$. pH is defined mathematically as the $\log 1/(H^+)$, thus as the hydrogen ion concentration (or activity) increases, the pH decreases. Water with a pH of 7.0 is designated a neutral solution. pH is a measure of the instantaneous hydrogen activity in contrast to alkalinity and acidity measurements which measure the capacity of a liquid sample to resist a change in pH. The parameter pH is important in all environmental projects because of its effects on treatment plant operations, corrosion to pipes and equipment, disinfection, water softening and receiving water quality.

The pH of natural waters is usually between 4 to 9; most waters will have a pH slightly greater than 7 (slightly basic) because of the presence of bicarbonate and carbonate alkalinity. In most storm generated discharges, the pH is also slightly basic. However, the pH may differ significantly from either very low or very high values when stormwaters come in contact with industrial wastes. Where stormwater runoff passes over acid mine drainage areas and other industrial waste disposal sites, pH may be a problem and should be monitored. Where biological treatment is to be used, the pH should be between 6 and 9.5. Chemical coagulation of natural waters is usually optimum at pH values between 5.0 and 6.5 (152). However, the optimum pH for coagulation will usually vary depending on the alkalinity, hardness, and other water quality characteristics. Chlorination is also affected by pH because the type of chlorine residual existing in a water is highly dependent on the pH of the solution (48). At pH values below 7.5 hypochlorous acid predominates and greater bacterial killing power tends to exist than at pH levels above 7.5 where the hypochlorite ion predominates.

Table VI-18. PARTICLE SIZE DISTRIBUTION OF SOLIDS[a], SELECTED CITY COMPOSITES

Size range, μ	Milwaukee, %	Bucyrus, %	Baltimore, %	Atlanta, %	Tulsa, %
<4,800					
2,000 - 4,800	12.1	10.1	4.6	14.8	37.1
840 - 2,000	40.8	7.3	6.0	6.6	9.4
246 - 840	20.4	20.9	22.3	30.9	16.7
104 - 246	5.5	15.5	20.3	29.5	17.1
43 - 104	1.3	20.3	11.5	10.1	12.0
30 - 43	4.2	13.3	10.1	5.1	3.7
14 - 30	2.0	7.9	4.4	1.8	3.0
4 - 14	1.2	4.7	2.6	0.9	0.9
<4	0.5	--	0.9	0.3	0.1
Sand, % 43 - 4,800	92.1	74.1	82.1	91.9	92.3
Silt, %, 4 - 43	7.4	25.9	17.1	7.8	7.6
Clay, %, <4	0.5	--	0.9	0.3	0.1
kg sand/curb km (lb/mi)	700 (2480)	287.5 (1020)	238.2 (845)	11.1 (394)	89.5 (300)
kg silt/curb km lb/mi)	56.4 (200)	100.3 (356)	49.6 (176)	9.4 (33.5)	8.4 (30)
kg clay/curb km lb/mi)	3.8 (13.5)	-- --	2.6 (9.3)	0.37 (1.3)	0.08 (0.3)

a. Dry sieving method used; Reference 2.

Currently pH is seldom adjusted in combined sewer and stormwater treatment plants; however, because of the effects described above, pH should be measured regularly throughout discharge. In cases where industry or other factors cause the pH to vary greatly outside the range of 6.0 - 9.5, pH control will usually be necessary. As the treatment of storm generated discharges becomes more sophisticated, pH adjustment may frequently improve treatment efficiencies and reduce chemical dosages. Recommended pH procedures are described in Section 144, page 276 of Standard Methods (39).

Rubber - Potential presence of rubber in storm generated discharges exists from the wear of vehicle tires which can be washed from streets. Rubber is of concern as a pollutant because of its high BOD, taste, and odor. Rubber found in modern day tires is usually made up of a variety of polymeric materials and presents a unique problem in analysis. Different procedures such as thin layer chromatography, pyrolyses-gas chromatography, nuclear magnetic resonance spectroscopy, infrared and other physical and chemical techniques for analysis of rubber have been recently reviewed (160). Reproducibility of results between laboratories has been a major problem and it is usually necessary to run standards for each analysis. Quantitative evaluation of natural rubber, styrene-butadiene rubber, and ethylene-propylene-terpolymer rubber has been achieved using pyrolyses-gas chromatography to eliminate interferences of carbon black and other similar materials (161). Analytical techniques usually used are based on the analysis of a single component of the specific rubber or one of its pyrolysis products, there is no general analytical test for identification or quantifying the different types of rubber into a single classification which can be called "rubber". As has been pointed out, the major monomer units of rubber are ethene and propene which are produced on the pyrolysis of almost all rubbers (161). Hence it is possible that analysis based on the evaluation of ethene or propene from the pyrolysis of samples containing rubber could be used to group all types of rubber into a single test. Additional research needs to be conducted in this area before analyses of rubber can be considered for storm generated discharges.

Specific Conductance - Specific conductance measurements are often used in water and wastewater characterization to obtain an estimate of the amount of dissolved solids in solution. This measurement determines the ability of a water sample to carry an electrical current. The dissolved solids value can be determined by multiplying an empirical factor times the specific conductance of that sample. It is important to note, however, that only ionized material will contribute to the specific conductance measurement. Partially ionized organic acids (the fraction that is not ionized) and nonionized materials, such as glucose and benzene, will not be detected by specific conductance measurements. On the other hand, specific conductance measurements are easily made and continuous monitoring is possible. High salt content in stormwater runoff from ice control can be detected by specific conductance measurements.

However, because of the lack of ability to consistently measure the dissolved solids content of a sample, interpretation of specific conductance data is very difficult and it is not recommended for routine analyses in storm generated discharge studies. In specific cases where it is possible to correlate specific conductance with chloride content or other ice control materials, it may be useful. When specific conductance is used the technique described in Standard Methods (39) Section 154, page 323, should be followed.

Sulfates - Sulfate concentrations in storm generated discharges are of interest primarily from the receiving stream water quality standpoint. U.S. Public Health Service Standards recommend an upper concentration of 250 mg/l in any water to be used for human consumption. Also, sulfates are detrimental because of the odors produced when anaerobic conditions exist. In the absence of oxygen, sulfates are reduced by anaerobic bacteria to hydrogen sulfide with the resulting objectionable odor. In some cases the hydrogen sulfide that is produced under anaerobic conditions can be oxidized by a special group of bacteria in another part of the sewer, usually the crown, and produce sulfuric acid (48). When sulfuric acid comes in contact with the cement in concrete sewers, corrosion of the sewer results. High sulfate concentrations could also result in a digester going sour.

In most surface waters sulfate is not a problem. For example, Lake Michigan has a sulfate concentration less than 20 mg/l and Lake Superior is about 3 mg/l (162). Hence the addition of storm generated discharges to surface waters will not increase the sulfate concentrations to levels of concern in most cases.

The methods for the analysis of sulfates have been presented in Standard Methods (39) and discussed as to their relative merits. Routine analysis of sulfate is not recommended. However, in the special case where sulfate is known to be a problem or potential problem, the Gravimetric Method with Ignition of Residue is suggested as described in Standard Methods, Section 156A, page 331 (39).

Temperature - Temperature is important in both biological and chemical reactions in that the higher the temperature, within a given range, the the faster the rate of reaction will be, and the lower the temperature the slower the rate of reaction. The solubility of chemicals in chemical treatment processes and of oxygen in water are also affected by temperature Solubility of oxygen at 10°C is given as 11.3 mg/l when no chloride is present in the sample compared to 4.5 mg/l at 50°C (39). The temperature in most storm generated discharges will range somewhere between that of the air and the ground surrounding the sewer lines. Temperature measurements are not recommended in storm generated discharge studies because of their relatively constant temperature and the impracticality of making any major changes in these temperatures. However, in some cases where disinfection of storm flows is being performed temperature monitoring may be important.

Trace Organics- Trace organics in storm generated discharges may come from natural substances, pesticides, insecticides, fertilizers, herbicides and industrial or other sources. Some of these materials are very resistant to biological activity and may remain in the water for long periods of time even after treatment.

Pesticides, polychlorinated biphenyls and phthalic acid esters have been found to be widely distributed in the environment (163). Using computerized gas chromatography-mass spectrometry, plasticizers and dye carries were identified in two New England rivers at levels from 0.1 to 30 ppb (parts per billion). In another study a column of polystyrene macroreticular resin was used to isolate hydrocarbons in well water (164). The hydrocarbons apparently originated from a coal tar pit used in the 1920's for disposal.

Organic materials are of particular concern when they are carcinogenic in nature, or when they tend to build up to toxic levels in cellular material of man and animals. Very small quantities of some of these materials may be very significant and it is necessary to be able to detect a few micrograms per liter or parts per billion concentration. Very few compounds can be detected at these low levels hence concentration steps are necessary. During the concentration of wastewater samples the concentration of many other organics and inorganics will also be increased and these will often interfere with analyses. Hence, isolation techniques may also be necessary.

Standard Methods (39), Section 139, page 259, describes procedures that may be used to obtain a measurement of organic contaminants. Two procedures described use activated carbon to adsorb the trace organics from large quantities of wastewater followed by solvent extraction to remove these materials. The solvent is finally evaporated and the weight of the residue determined. Three basic steps have been used in more specific analysis of organics in air and water samples (165). These steps are:

1. Organics are concentrated and isolated from the matrix.
2. Constituents of interest are identified.
3. Amounts of the identified compounds are measured.

Gas chromatography is used in the second step of identification. Two primary objections to the use of activated carbon are presented. The recovery of organic materials from the activated carbon is usually incomplete and variable, and changes in the characteristics of the sample may occur due to the carbon acting as a catalyst. It should be recognized that the procedure of evaporating the sample to dryness will usually eliminate the lower boiling compounds. Also, activated carbon may only recover a low percentage of organic substances from the water (164).

An excellent review of different concentrating procedures was recently made (166). These techniques included a) activated carbon, b) liquid-liquid partition, c) carbowax 4,000 d) silicones chemically bonded to diatomaceous earth, e) aromatic and alkyl chlorosilanes or celite, f) porous polyurethane plugs, g) macroreticulated resins and several solvent extraction procedures. In another report three techniques were described for sample concentration: liquid-liquid extraction, head space sampling and a column packed with porous polymer heads (164). Methylene chloride was used as the solvent in the liquid to liquid extraction with an increase in trace organic concentration acheived using 15 ml methylene chloride in 500 ml of the water sample and removing a 10 ml portion for analyses.

The headspace procedure is achieved by withdrawing gases in the region above a water sample through a collection column containing porous polymer head packing. The volatile organics in the sample are retained by the packing, but water is not. The sample cell described is shown in Figure VI-7 (165).

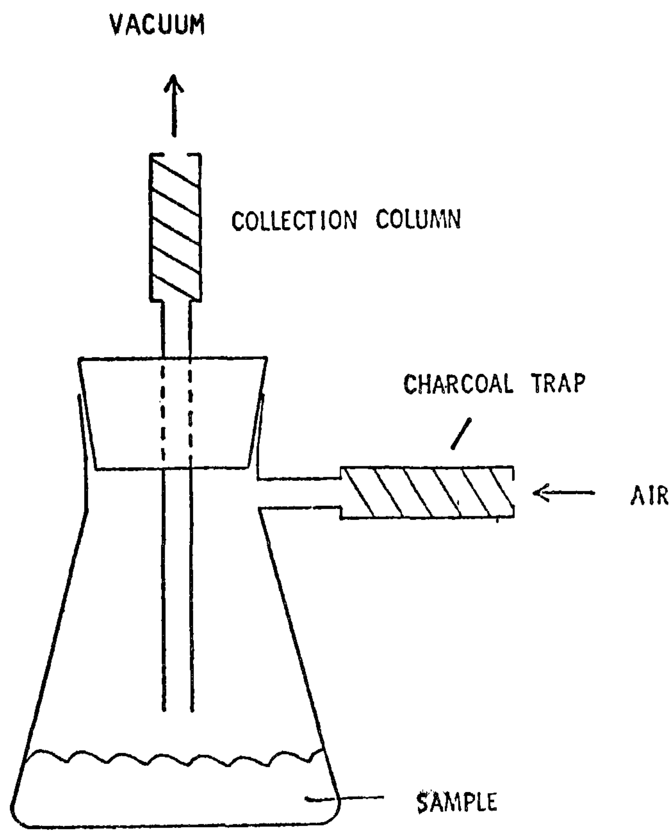


Figure VI-7. Schematic diagram of a cell used to collect headspace vapors from solids and liquids

From Reference 165

Advantages of headspace techniques for trace organic concentration were given as:

1. Since no measurements are made on the water itself, many types of handling problems such as filtering of particulates or emulsion formation are not encountered.

2. This type of measurement would be readily automated for semi-continuous monitoring.

3. This method is ideally suited to low-level determination of very volatile compounds. These are usually masked in a gas chromatogram when using common extraction solvents.

However, organics that are insoluble, complexed or adsorbed on solid material will not be efficiently concentrated. Surface film may produce higher than expected concentrations.

The third concentration method described the use of a packed column with porous polymer beads through which a water sample was passed. The adsorbed organic was then forced into a gas chromatograph which was temperature programmed. Low molecular weight molecules did not show a high recovery efficiency but larger molecules that tend to be less soluble in water exhibited a high recovery, as shown in Table VI-19.

Table VI-19. RECOVERY OF ORGANICS FROM WATER USING POROUS POLYMER PACKINGS

Component	Concentration, ppm	Percent Recovered (one pass)
Methanol	0.79	<5
	6.30	<5
Acetone	0.79	21
	6.30	42
Chloroform	1.50	93
	12.00	85
Benzene	0.88	100
	7.00	100
Pyridine	0.98	46
	7.80	79
Phenol	0.22	25
	1.90	61
Methyl Isobutyl Ketone	2.70	100
m-Cresol	0.15	75
o-Ethylphenol	0.06	97
p-Ethylphenol	0.35	89

Reference 165.

When liquid-liquid extractions are used, solvents may be either heavier or ligher than water. Extraction vessels have been described to utilize either type of solvent (166). Figure VI-8 shows the extractor used for solvents ligher than water. The operation of this is as follows:

> The extractor design is a two-cycle system. The water cycle is continuous flow. Water enters at A and exits at B. In so doing it passes through chamber C which is half-filled with solvent. A stopcock, D, can be provided to regulate the water flow rate.
>
> The second cycle is a solvent cycle. This system is closed in that the solvent cycles exclusively in the extractor. The 500-ml bulb E contains pure, nonmiscible, organic solvent. This solvent is gently boiled and vapor rises in area F up through the upper extractor tube G into reflux condensor H. At this point it is liquified and falls off of drip tang I into funnel J. The long funnel stem sets up a hydraulic head sufficient to drive the solvent through a porous glass frit at K. The frit homogenizes the solvent resulting in fine beadlike particles which form as an emulsion as they rise through the water in chamber C. This emulsion extracts organic solutes during the period of water-solvent contact. The emulsion separates in the extractor's lower neck L and the solvent-solute mixture spills over connection tube F into boiling flask E.
>
> The closed solvent system cycles fresh solvent from the boiling flask into the extractor. After extracting the organic solutes, the "loaded" solvent is returned to the boiling flask thus collecting and concentrating the extracted solutes in flask E but always supplying fresh solvent to the extraction chamber at C. (167).

For solvents heavier than water the extractor shown in Figure VI-9 was used. It operated as follows:

> Water enters at M and exits at N. The stopcock O (optional) regulates flow rate. While in the lower nick of the extractor P, the water flows through the extraction solvent.
>
> The solvent cycle, which is closed to the extractor, starts by the solvent being vaporized in bulb Q. The vapor rises in arm R to condensor S where the vapor liquifies and drops from drip tang T to funnel U. The solvent under a hydraulic head is forced through the upper extractor nick W. Extraction of the water takes place at the interface between the emulsified solvent and the water. A stirring bar at X (optional) stirs the solvent-water mix. The solvent separates in the lower half of the extractor and flows through tube Y into bulb Q.

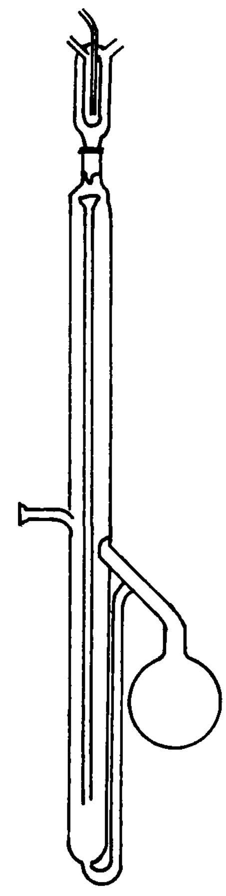


Figure VI-8. Extractor design for solvent lighter than water

From Reference 167

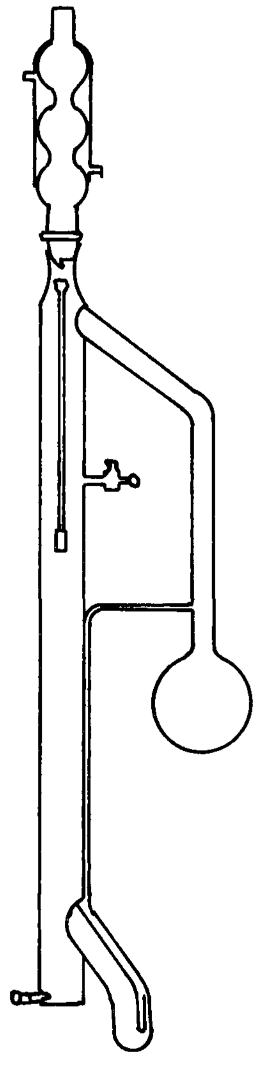


Figure VI-9. Extractor design for solvent heavier than water

From Reference 167

Organic solutes extracted from water then concentrate in bulb Q (164).

After the trace organics were removed from the water phase by concentration in the solvent, they were concentrated further by distilling the solvent. Freeze concentration and freeze drying were also considered for the removal of excess solvent (166).

The above discussion of concentration and analysis of trace organics will provide guidelines for analyzing these materials in storm generated discharges when these analyses are necessary. The routine determination of trace organics in storm generated discharges is not recommended unless there is a good possibility that these waters contain industrial contaminants or agricultural and other materials from land runoff. The optimum techniques for analyzing a given class of trace organics will vary depending on their characteristics. Other methods for trace organic analyses are described in the section on pesticides.

Recommended Analyses

Many of the parameters discussed above may be important for specific storm flow studies. For example, storm generated discharges may be contaminated from industrial wastes that will greatly affect the wastewater characteristics. The best method to determine the proper analytical program will include a careful assessment of the surrounding industries and their potential contamination. Some industries may have process overflow connnections to sewer lines and surface runoff from industrial areas may be diverted to sanitary, combined or storm sewers. Parameters such as oils and grease, asbestos, residual organics, or pH may become the critical analytical parameter. However, for routine analytical programs in storm flow studies most of the tests discussed in the previous section will not be required.

The observations of unusual items by operating personnel at stormwater treatment plants should be recorded in a log book. The parameters to be entered in the log book will include such items as odor, color, presence of foaming, presence of large debris, etc. The use of tables similar to those in Figure VI-5 is recommended and will facilitate the operator in his log entries.

pH is the only parameter in the "other" category that should be regularly monitored in storm flow studies. This test will provide an indication of periods when chemical treatment can be expected to be inefficient as previously discussed. Unusually low or high pH wastewaters greatly inhibit the formation of floc particles in chemical coagulation. The pH of a wastewater also determines, to a large extent, the form of chlorine present and the oxidizing power for a given chlorination dose. This can control the necessary contact time for adequate bacterial kill or chemical oxidation.

pH should be measured as described in Section 144, page 276 of Standard Methods (39). Great care should be taken that the electrodes are maintained in a clean condition, free of grease, oil, or other surface materials. pH samples should be taken in situ if at all possible. When in situ pH measurements are made the probes or electrodes must be protected from breakage due to debris in the wastewater. When in situ sampling is not possible the pH of individual or composite samples should be made as soon as possible after the samples have been taken. pH measurements should always be conducted prior to addition of acid or other chemicals used for sample preservation. pH data from permanently installed units should be periodically checked, preferably with a carefully calibrated portable unit.

Other tests described above may be important in specific storm flows and may become routine tests for these studies. This discussion will serve as an introduction to the analyst when he is required to test for unusual contaminants.

ANALYSIS OF SLUDGES

Most, if not all, stormwater treatment processes produce a secondary flow containing the solids removed from the sewer discharge. Although this secondary flow may vary in suspended solids concentration from 1200 mg/l to 110,000 mg/l, it is usually referred to as sludge. At the present time, it is common practice to collect the sludge in a holding tank and pump it back into the sewerage system when the storm is over. It is probable, however, that disposal in this manner may not be the best method of sludge disposal in all cases. Research is presently being conducted on alternate methods of sludge treatment and disposal. Because of the dilute nature of the sludge, thickening is usually necessary before ultimate disposal. Possible alternate forms of final disposal include incineration and burial in a landfill site.

The analytical parameters to be measured depend, of course, on the subsequent sludge treatment process and the method of final disposal. In all cases, however, the sludge solids concentrations should be measured. For dilute sludges, suspended solids should be measured. Thick sludges should be analyzed for total solids. Sludges discharged to a minicipal sewerage system might also be analyzed for heavy metals, oxygen demand and nutrient analyses to indicate the effect on the sewage treatment process. Sludges which are incinerated might be analyzed for heat value. Sludges transported to a landfill site might be analyzed for pH and heavy metals.

Sludge thickening processes produce a clarified flow that must be discharged. If this flow is discharged to a receiving stream, the same analyses should be performed as are done for the treated effluent. In addition, occassional samples (say 4 per year) might be analyzed for heavy metal concentrations. Since it is possible that the soluble contaminant concentration may make disposal to a receiving stream undesirable, this flow may have to be discharged elsewhere. The parameters to be analyzed will then depend on the conditions to be met for disposal.

The specific analytical procedures to be used in the analysis of the clarified flow from a thickening process are no different than the procedures to be used for analysis of the storm generated discharge. Procedures to be used in the analysis of sludges, however, may have to be modified. The parameters that might be measured along with recommended modifications for analysis of sludges are listed below:

Total Residue - This is the recommended method of residue analysis for thick sludges. The procedure described on page 280, of the EPA Manual (1971) should be used.

Suspended Residue - This is the recommended method of residue analysis for sludges that are low in solids content. The procedures recommended for storm discharge should be used (page 167).

Volatile Residue - (Optional) - The procedure described on page 282 of the EPA Manual (1971) should be used.

Total Phosphate - (Optional) - High solids sludges may require high dilution prior to digestion. Blending of the sample may facilitate getting a representative sample for dilution. The diluted sample should be digested and analyzed according to the procedure described on page 239 of the 1971 EPA Manual.

Kjeldahl Nitrogen - (Optional) - The procedure described on page 149 of the 1971 EPA Manual should be used. Sample size should be reduced if large amounts of organic material are present.

Oxidized Nitrogen - (Nitrate and Nitrite) (Optional) - Sludges must be clarified before the oxidized nitrogen analysis can be run. Centrifugation or filtration through a 0.45 μ membrane filter is usually sufficient. When large amounts of colloidal material remain, however, it may be necessary to add zinc sulfate and form a floc by raising the pH. The floc can then be removed by centrifuge. The clarified sample should then be analyzed by the cadmium reduction method described on page 458 of Standard Methods, 13th Edition.

pH - (Optional) - Because of chemicals used in the treatment process, some sludges may have a pH so low that storage in unprotected containers may cause problems. The method described on page 230 of the 1971 EPA Manual should be used.

BOD - (Optional) - Large dilutions are required when analyzing sludges containing high solids concentrations. After dilution the procedure described on page 144 of this report should be followed.

TOC, TOD or COD - (Optional) - Large dilutions are required when analyzing sludges containing high solids concentrations. Homogenization by mixing in a Waring Blender is recommended after dilution. Additional homogenization using a tissue grinder may be necessary for TOC and TOD analyses. The recommended procedures for analysis of the diluted samples are:

TOC - page 146, this report
TOD - page 143, this report
COD - page 146, this report

Heavy Metals - Zn, Pb, Cu, Ni, Cr - (Optional) - After dilution, most sludges can be digested by the nitric and hydrochloric acid procedure described on page 209 of this report. In special cases, perchloric acid digestion may be necessary. Analysis of the digestate by atomic absorption spectrophotometry is recommended (page 186 of this report).

Mercury - (Optional) - After dilution, the sample should be digested by the nitric acid reflux procedure described on page 188 of this report. Mercury analysis should be performed by the flameless atomic absorption method described on page 187 of this report.

Density - (Optional) - The density of thickened sludge may be needed to compute hauling costs. The recommended method of measuring density is by means of a wide mouth pycnometer such as the Hubbard - Carmick Specific Gravity Bottle (Corning #1620).

Heat Value - (Optional) - This parameter may be useful when final disposal of sludge is by incineration. The sludge should be air dried and pulverized by mortar and pestle. This material is then pellatized and the heat value measured with an adiabatic calorimeter. The instrument manufacturers instructions should be followed.

Pesticides and PCB's - (Optional) - The procedure described on page 189 has provision for the analysis of sludge samples and is recommended.

ANALYSIS OF ACCUMULATED ROADWAY MATERIAL

In all cases acceptable storage and analytical methods must be used when studying accumulated roadway materials. The samples should be stored under conditions as required for each specific analysis. The time between collection and analysis must be kept to a minimum. All samples should be kept in a refrigerated or ice cooled containers during and after sampling. This cooling will slow the biological reactions and prevent significant changes in the nature of the sample.

The only analysis that should be conducted at the test site are volumetric (measuring the volume of flushed material). Gravimetric analyses should be conducted under suitable controlled laboratory conditions (168). Refer to specified sample storage and analytical procedures for each pollutant that is to be analyzed.

Chemical tests can be determined either on wet and dry sample fractions separately, or the sample fractions may be combined proportionately by study area for analyses. Bacterial analyses, if required, should be conducted as soon after sample collection as possible. Portable membrane filter techniques using field incubators are recommended.

Classical BOD_5 analyses are not believed accurate for typical street surface contaminants. The reasons for this include the low dilution ratios needed and the toxic effects of associated pollutants on the organisms (168). One method that attempts to eliminate these problems is described by Colston (169). This method measures the COD of an aerated sample with time. The rate of COD reduction is assumed to be proportional to the BOD of the sample.

During the Washington, D.C. study (170) procedures in Standard Methods (39) were followed in most cases. However, numerous modifications were made as these procedures were intended primarily for use with liquid samples and no standard methods exist for the analysis of street surface contaminants. Investigators have used a diversity of methods, some of which need improvement and standardization so that results of different studies can be compared. Methods for grease and for characterization of grease into hydrocarbon and normal paraffin fractions were pieced together from a number of exisiting procedures. In some cases, no satisfactory methods existed prior to this project for measurement of the parameters of interest. Therefore, methods for the estimation of asbestos and rubber had to be developed for the analysis of roadway samples. Development of these analytical methods and their limitations are discussed in the following below.

Determination of Rubber

The technique of pyrolysis-gas chromatography was used to develop a method capable of detecting 0.005% rubber in roadway dust and dirt samples. Pyrolysis-gas chromatography was first applied to the identification of vehicle tire rubber in roadway dust by Thompson, et al in 1966 (171). More recently, this approach was used for the quantitative estimation of rubbers in compound cured stocks (172). Styrene-butadiene rubber (SBR) is converted to styrene and other low molecular weight compounds by pyrolysis in a nitrogen atmosphere. The styrene is then separated and measured via gas chromatography using a flame ionization detector. Briefly, the method entailed pyrolysis of 20 to 25 mg of extracted sample for 20 seconds at 640°C in an inert nitrogen atmosphere. Dust and dirt samples were first extracted with aqueous acid to remove soluble materials and carbonates and then with hexane to remove interferring organics. Next, the gaseous pyrolysis products were chromatographed and the styrene peak measured.

SBR is the most commonly used synthetic rubber for vehicle tires manufactured in the United States. Passenger car tires contain 70 to 80% SBR, small truck tires 60 to 70% and large truck tires only 10 to 20% SBR. Since the total traffic at the roadway sites consisted largely of passenger cars, estimation of SBR in dust and dirt will give a staisfactory estimate of tire material in roadway samples. The standard curve shown in Figure VI-10 was generated by measuring styrene produced upon pyrolysis of known amounts of passenger car tire rubber. No rubber was detedcted in several of the roadway samples initially examined because of large amounts of interfering compounds produced during pyrolysis. These compounds obscured the styrene peak. A preliminary extraction of the acidified dust and dirt samples with hexane reduced the background interferences to a satisfactory level.

Determination of Asbestos

The method for the determination of asbestos in dust and dirt and flush fractions of roadway samples was based upon an industrial hygiene procedure recommended for airborne asbestos by the National Institute for Occupational Safety and Health (NIOSH) (173). In this procedure the flush water or aqueous suspension of the dust and dirt was sonicated briefly to disperse particulates and then membrane filtered. The filters were rendered transparent by the action of a mixed organic solvent and the asbestos fibers enumerated using phase contrast optical microscopy. Only fibers between 5 and 100 microns in length and having an aspect ratio (length to breadth) of 3 or greater were counted.

During development of this procedure, a "standard" suspension containing 10 mg/l of chrysotile asbestos was prepared and analyzed repetitively for use in estimating precision and recovery levels. Chrysotile was selected as it is the variety of asbestos most commonly used in the United States. The "standard" suspension was found to contain 10.6×10^4 fibers/ml with a standard deviation of 2.8×10^4 fibers/ml. Recoveries of asbestos fibers added to three dust and dirt samples were 98%, 85%, and 65%, respectively.

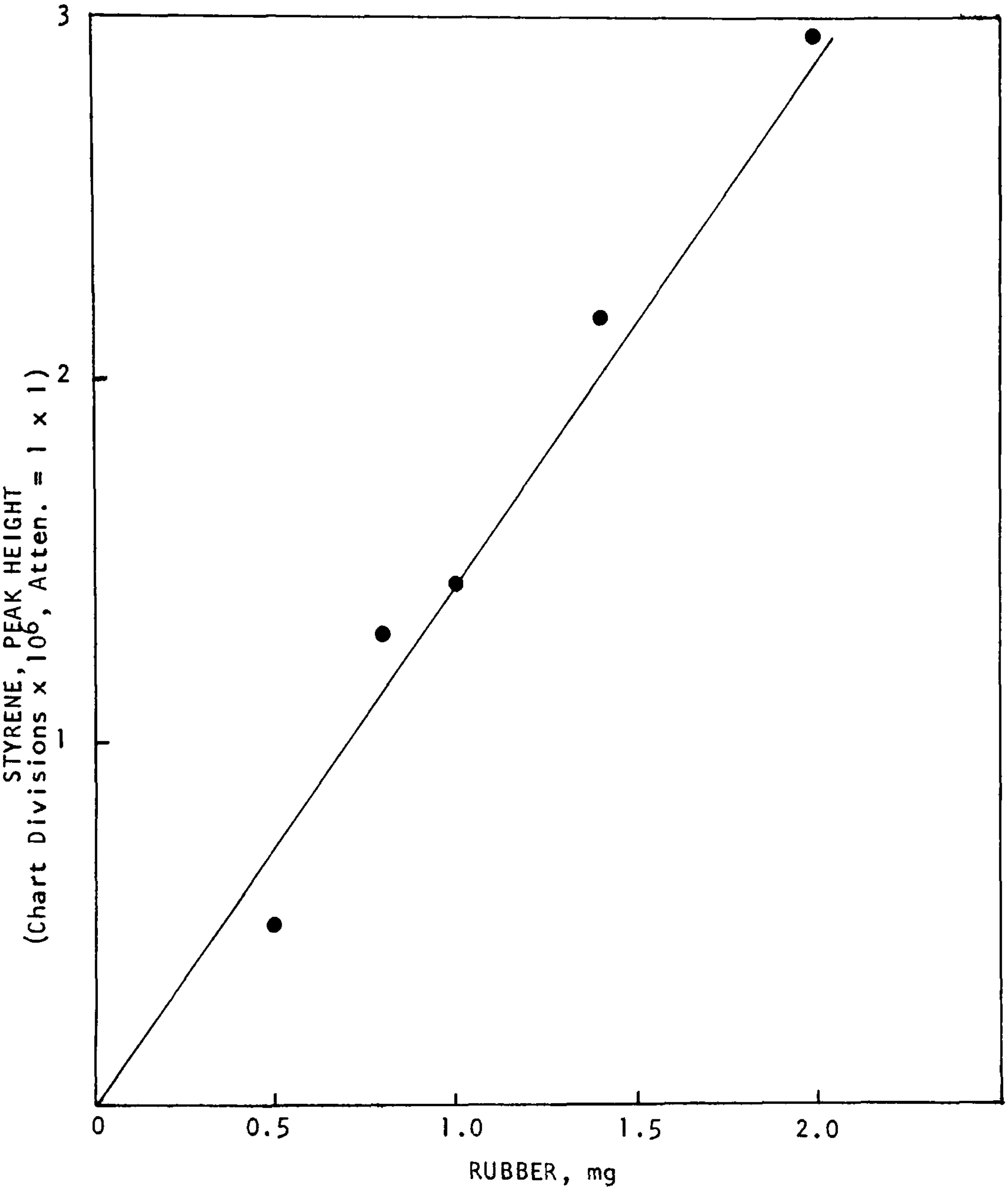


Figure VI-10. Standard curve - rubber in dust and dirt
From Reference 168

Increasing the sonication time from one minute to five minutes did not increase the yield from dust and dirt or from the asbestos "standard" suspension. This indicated that sonication was not fracturing fibers in the samples. Tap water was examined along with subsurface soil samples thought to contain no asbestos fibers in an attempt to check for naturally occurring inferences. No asbestos was found in the tap water (the detection limit in this analysis was about 10^3 fibers/l). Values of less than 3×10^5 fibers/g were found in the two soils examined. The levels found in the soils were at the limit of detection for these particular samples and represent less than one fiber from each soil in over 50 fields counted under the microscope. Detection limits on actual roadway samples were generally over one order of magnitude better than with soils.

The toxicology of asbestos fibers has not been well defined and the NIOSH method is based upon expediency and precedents set by earlier investigators. Further, it was not intended for environmental samples but rather for industrial hygiene purposes at mining operations or plant areas where asbestos products are fabricated. Presently, asbestos analytical methodology is trending toward the use of techniques requiring more sophisticated equipment and considerably more man hours per determination. Transmission and scanning electron microscopy are being used for the most critical analyses of environmental samples to measure fibers below the range of optical methods. Particle size distribution and weight of asbestos found are frequently required in addition to numbers of fibers.

Review of Sampling and Analyzing Roadway Material

Listed below are salient points which summarize the procedures to be used when studying accumulated roadway material.

1. In order to ensure characteristic samples of street surface contaminants samples should be collected by the use of hand sweeping, dry vacuuming, and water flushing of the study area. If the data collection program is concerned with only the weight of solids accumulated, however, hand sweeping of the study area should be sufficient. Particle size distribution studies will require hand sweeping followed by dry vacuuming. Any pollutant considerations in addition to solids should include a water flush.

2. Each sample should 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 the 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 (greater than 3.35 mm in diameter). 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.

3. Sample site selection should consider the effects of area land use, average daily traffic, the roadway surface material and the condition of the roadway, and the speed limit and other traffic controls. Curb should be available at the sampling site for the collection of water flush samples. The safety of the area during sampling should also be considered. At a minimum, flagmen and traffic cones should be employed during all sampling operations.

4. For a typical secondary street a single test area should cover 93 sq m, 7.6 x 12.2 m (1000 ft^2)(25 x 40 ft^2). Larger paved surfaces can be better sampled by using smaller test areas, 0.9 sq m (10 ft^2), and averaging the results.

5. The frequency of sampling will be largely dependent on the objectives of individual sampling programs; however, any extended sampling program should be developed to cover seasonal variations and weekly variations (weekdays versus weekends) in the accumulation of street surface pollutants.

6. The following parameters have been used to characterize street surface pollutants:

Total solids	TKN
Total volatile solids	Chlorides
BOD	Asbestos
COD	Fecal coliform
Grease	Fecal strep
Petroleum	Lead
n-Paraffins	Chromium
Total phosphorus	Copper
Nitrite-nitrogen	Nickel
Nitrate-nitrogen	Zinc

Most of these parameters have been found to be mainly present in the dust and dirt fraction of samples; however, BOD, TKN, and microorganisms are largely present in the water flush fraction.

7. The BOD_5 is not recommended because it may not be accurate for typical street surface contaminants. The reasons include the low dilution ratios needed and the toxic effects of associated pollutants on the organisms. One method that may eliminate these problems has been described by Colston (169).

8. Development of standard methods for analyzing street surface contaminants are needed. During the Washington, D.C., study (170), numerous modifications of Standard Methods (39) procedures were occassioned as these procedures were intended primarily for use with liquid samples and no standard methods exist for the analysis of street surface contaminants. The procedures developed by this study can be used as the basis for uniform analysis of street surface contaminant samples.

SUMMARY

This section has included a discussion of the selection of those parameters to be analyzed routinely in storm generated discharge projects and the recommended analytical methods. The following analyses are recommended:

POTENTIAL OXYGEN DEMAND: TOD and BOD_5

PARTICULATE CONCENTRATION: Suspneded Solids

PATHOGENIC INDICATOR: Fecal Coliform

EUTROPHICATION POTENTIAL: Total Oxidized Nitrogen, Total Reduced Nitrogen (Kjeldahl) and Total Phosphorus

OTHER: pH

These parameters are to be analyzed routinely for the evaluation of storm flows and the evaluation of treatment processes treating such flows. In addition, periodic analyses for certain metals, pesticides and oil and grease along with a few other parameters that may be peculiar to a specific discharge are recommended. If, during these periodic analyses, significant concentrations are found, then a more routine analysis program for these other parameters should be instigated.

Preservation of the entire sample begins with refrigeration or ice cooling during the sampling period and during the transportation period back to the laboratory. When compositing is performed it may be done either on site or in the laboratory, whichever is more convenient. However, in most cases it will be necessary to have a record of the flow available when compositing is being performed. Once the sample has reached the laboratory it should immediately be broken into separate portions for each analysis. It is understood that if the laboratory is more than a maximum of 6 hours travel from the point of sampling, then sample splitting and preservation should be done at the point of sampling.

For BOD samples analysis must be started as soon as possible (limit 6-12 hours) with no preservation other than refrigeration. TOD samples should be homogenized and then preserved with sulfuric acid and refrigerated. This will allow sample storage for up to 7 days. Samples for fecal coliform analysis cannot be preserved and must be analyzed immediately. Chlorinated effluent must be dechlorinated at the site of sampling. The nitrite/nitrate samples should be preserved with 40 mg/l of $HgCl_2$ and refrigerated for up to seven days if they are not going to be analyzed immediately. Total Kjeldahl nitrogen can be preserved also by the additionof 40 mg/l of $HgCl_2$ and refrigerated at $4^{o}C$, however, analysis as soon as possible is recommended. Total phosphorus and suspended solids may be preserved by refrigeration for up to a week with no chemical addition.

Plastic sample containers can be used for all of the routinely analyzed parameters other than fecal coliform which should use separate glass containers when a high degree of accuracy is required for this analysis. It is estimated that a minimum volume of 2000 ml is needed to perform all the routine analyses.

In general, those analytical procedures as described in Standard Methods (39) are recommended.

The recommended method for the BOD analysis addresses the importance of insuring that a sample representative of the suspended solids present is withdrawn from the sample jar. Suspended solids analyses should be done with glass fiber filters, again due to the large particulate concentration Bacteria analysis by membrane filter technique is recommended for fecal coliform analysis unless extremely high quality waters are involved. Kjeldahl nitrogen and nitrate/nitrite analyses are the same as those recommended in Standard Methods (39). Phosphorus should be digested with persulfate and colorimetrically analyzed using ascorbic acid.

Table VI-20 contains a summary of the type of container, sample volume, preservation methods, holding times, and analytical techniques for the recommended quality characteristics.

Table VI-20. SUMMARY OF CRITERIA FOR ANALYZING THE RECOMMENDED CHARACTERISTICS

Recommended indicator	Container	Volume	Preservation	Holding time	Analytical technique
		Routine:			
BOD	plastic	600	Refrig. at 4°C	6 hr (24 max)	Standard Methods + mod.
TOD	plastic	100	H_2SO_4 add - Refrig. @ 4°C		Manuf. Instructions
SS	plastic	500	Refrig. @ 4°C	ASAP	Glass fiber filter
TKN	plastic	100	$HgCl_2$ and/or Refrig. @ 4°C	7 days	Standard Methods
Phosphorus (total)	plastic	200	Refrig. at 4°C	7 days	Persulfate Ascorbic acid
NO_2/NO_3	plastic	100	$HgCl_2$ and/or Refrig. @ 4°C	7 days	Standard Methods (Total reduced to NO_2)
Fecal coliform	glass (sterile)	100	None	ASAP	Membrane filter technique
		Periodic:			
Oils & grease	glass	1000	H_2SO_4 + Refrig. @ 4°C	24 hours	Standard Methods
Pesticides	glass	1000	Refrig. @ 4°C or freezing	ASAP	Soxhlet Extraction modification described
Metals	glass/plastic[a]	200	HNO_3 add to pH 3 + refrig.	6 months	Standard Methods

a. Depends on metal type.

SECTION VII - DESCRIBING STORM GENERATED FLOWS

The periodic nature and extreme variability of storm generated discharges requires somewhat different procedures for describing their effects and impacts. This section discusses the various methods of describing storm generated discharges as well as methods of constructing hyetographs, hydrographs and pollutographs.

EXPLANATION AND DISCUSSION OF TERMS AND UNITS

mg/l

Pollutant concentrations are conventionally measured and reported in units of mg/l. These units are a measure of the concentration of pollutants in weight per volume in the sample that was collected, regardless of the time interval over which the sample was collected or the method of compositing the sample.

mass/unit time

The most elementary method for reporting the mass of pollutants in a wastewater stream is to integrate the pollutant concentration and the flow rate. This unit of measure enables the quantification of the relative impact of discharges. The selection of a specific unit of time is a function of the variability of flows and pollutant concentration, the frequency and type of sampling and the availability of a continuous record of flow.

Dry-weather municipal wastewater treatment plants usually composite samples over a 24 hour period and calculate mass pollutants on a kg/day (lbs/day) basis. This is calculated according to the following relationship:

$$P = V \times C$$

where: P = kilograms per day of pollutant
V = hydraulic flow in cubic meters per day
C = concentration of a pollutant in mg/l

This parameter is useful for reporting the overall efficiency of a dry-weather wastewater treatment plant and is readily understandable by both technicians and laymen. Because of the equalizing capabilities of municipal sewerage systems, the variation in mass loadings (kg) is generally not greater than one to two times (perhaps more in smaller plants) the average. On the other hand, combined sewage overflow and stormwater runoff are extremely variable both in hydraulic flow rate and pollutant concentration. In addition, storm events do not occur regularly nor is the overflow necessarily 24 hours in duration. As such, the establishment of mass loading rates is a somewhat more difficult task.

To facilitate understanding of the importance of evaluating mass loading rate for storm generated discharges, a somewhat simplified example is presented in Figures VII-1 and VII-2. Twelve discrete samples (two hour composites) were collected over a twenty-four hour discharge period. Average flow rates for each two hour period were also determined. This discrete data was then plotted in continuous form in Figure VII-1.

The mean mass loading for the 24 hour period as well as the continuous mass loading rate for each two hour period is shown in Figure VII-2. It is important to note that the peak mass loading rate is approximately 15 times the minimum rate, a factor of extreme importance when considering treatment processes such as screening and filtration. Calculation of the mean mass loading does not consider the magnitude of these variations which occur during a storm event. In the case where treatment processes or quality models which are sensitive to variation in mass loading are being considered, it is necessary to evaluate loading rates over shorter time periods than 24 hours.

<u>kg/ha (lb/acre), kg/ha/day (lb/acre/day), kg/ha/year (lb/acre/year), kg/cm/ha (lb/in./acre)</u>

Once the total emissions from a storm generated discharge have been established, it is desirable to relate this to the drainage basin. A convenient relationship is kg/ha and can be established by dividing the kg discharged by the area of the drainage basin. The parameter kg/ha can be compared to the dry-weather sewage contribution on this basis.

Efforts have been made to relate unit emissions to some time scale by the parameters kg/ha/day and kg/ha/year. These parameters can be quite useful as "rule of thumb" numbers for comparing the magnitude of storm related discharges with dry-weather sewage and other sources of environmental pollutants. The shock impact of storm related discharges tends to be masked in this parameter since the many dry days each year have zero contributions. Pollutant loadings are also quite often

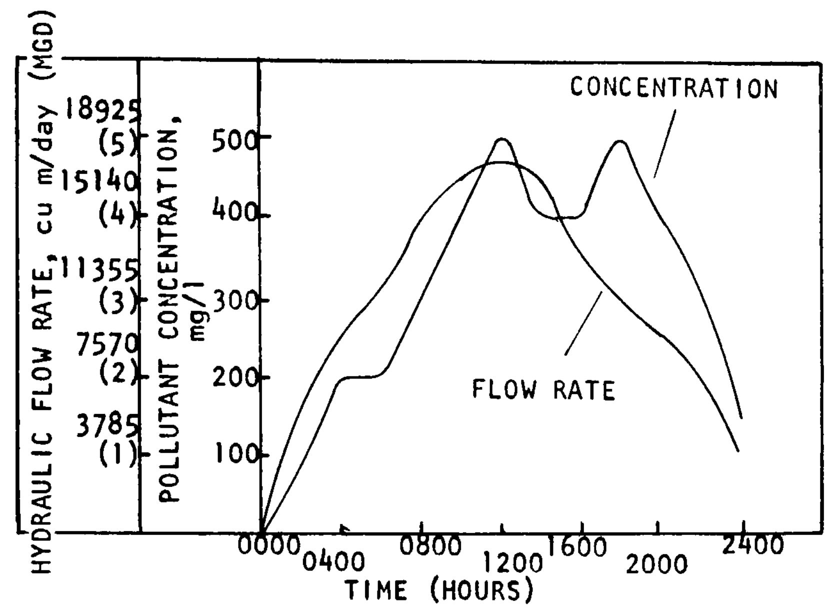


Figure VII-1. Average flow rates for twelve discrete samples (2 hour composite)

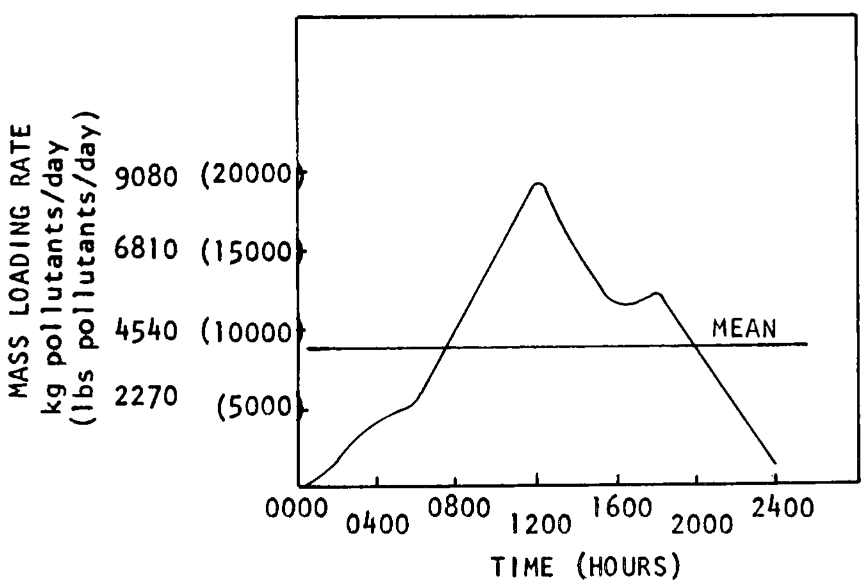


Figure VII-2. Pollutant mass loading curve expressed relative to the amount of rainfall over an area, kg/cm/ha (lb/in./acre). In this way it is possible to estimate the pollutant loading from given areas for different rainfall amounts and to determine the relationship of various amounts of rainfall on the amount of pollutants generated.

kg/curb meter (lb/curb mile)

The parameter kg of pollutant per curb meter was coined by the American Public Works Association as a convenient method of expressing the accumulation of pollutants on street surfaces. This parameter appears to have significant merit particularly when it is applied to land areas from which the major source of pollutants may originate from street surfaces such as central business districts and other commercial areas. The parameter can have significant error when utilized in areas where there is a low percentage of roadway in proportion to total drainage area such as in parklands and low housing density subdivisions. For this reason, the parameter should be utilized and interpreted with caution. Also, the parameter should always be related to some unit of time such as kg/curb meter/year (lb/curb mile/year) or kg/curb meter/days between rainfall (lbs/curb mile/days between rainfall).

DEVELOPING BACKGROUND DATA

Contributing Area

The land area contributing to a storm generated discharge should be described in as much detail as possible to permit future extrapolation of results to other areas. In the case of impact evaluation studies, a rigorous definition of the drainage area may permit preliminary estimates by the loading factor technique (1). The detail to be utilized in describing the areas will be somewhat related to the project objectives but engineers and scientists are urged to exercise every effort to present as much detail as possible in reports and technical papers. Maximum benefits are gained from storm generated discharge projects only when the data is complete enough so that it can be evaluated and extrapolated by other interested parties.

As a minimum the following parameters should be presented and quantified.

1. Drainage area and subareas
2. Land usage
3. Population density
4. Median incomes (residential)
5. Climate
6. Topography
7. Pervious and impervious areas
8. Street and curb miles length
9. Average daily traffic
10. Methods and frequency of street cleaning
11. Miles, size and slopes of sewers

Drinage Area and Subareas - The drainage area under investigation should be clearly identified on a map of suitable scale. Drainage areas may be further broken down into subareas to more precisely identify major land use categories or topographic characteristics. Sewer maps, topographic maps and aerial photographs are generally available from local authorities and should be utilized wherever possible. Advanced techniques for plotting and reproduction may be extremely valuable. Where possible, it would be useful to identify the source of maps.

Land Usage - The majority of prior and ongoing studies have broken down subareas according to land usage. The most common subdivisions are residential (single and multi-family), commercial, industrial and open lands and parks. A typical breakdown of subareas according to land usage is shown in Figure VII-3.

The U.S. Bureau of the Census data tract can be of significant value in assembling this information. Information such as land use, density, etc. is readily available from this source. It is generally possible to develop satisfactory land use information by the use of district sewer maps, aerial photographs and census tracts, or from private firms such as the National Planning Data Corporation, Ithica, New York.

Population Density and Income - Population density information (people per ha) can be utilized for evaluating residential areas. This information can be readily obtained from the U.S. Census Bureau on a block by block basis. In areas which are mixed (i.e. commercial/ residential) population density information is of less value since the non-residential activity may obscure the residential impact.

Census bureau data on median income from residential areas is also available and can be useful in further breaking down pollutional impact from residential areas. SWMM utilizes this type of information to estimate water usage and sanitary sewage contributions.

Climate - Because of the nature of urban runoff studies, climatic conditions is an extremely important parameter. Although detailed information on storm characteristics is discussed in other sections of this report, it is appropriate to point out the desirability of including a summary discussion on climate for those unfamiliar with a particular area.

An excellent source of this information is the Local Climatological Data - Annual Summary with Comparative Data, published annually by the U.S. Department of Commerce, Environmental Science Services Administration, Environmental Data Service, National Climatic Center, Asheville, N.C. 28801 (Table VII-1).

Char.	Area (acres)	Land Use
O-1	38.5	Open Land and Parks
O-2	18.8	
O-3	275.0	
O-4	9.2	
O-5	34.5	
O-6	34.5	
O-7	138.0	
O-8	32.2	
RS-1	27.6	Residential Single Family Housing
RS-2	113.0	
RS-3	160.0	
RS-4	396.0	
RS-5	216.0	
RS-6	78.0	
RS-7	137.5	
RM-1	27.6	Residential Multi-Family Housing
RM-2	85.5	
RM-3	57.5	
RM-4	11.5	
C-1	39.2	Commercial
C-2	38.0	
C-3	160.0	
C-4	46.0	
I-1	9.2	Industrial
I-2	79.5	
S-1	34.5	Schools
S-2	40.0	
H	39.0	Hospital

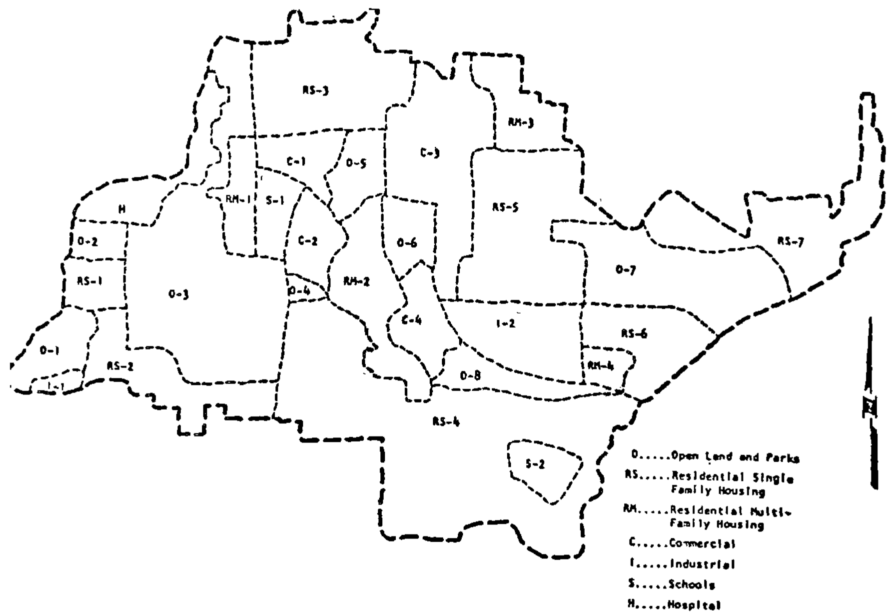


Figure VII-3. Division of Bloody Run sewer watershed into different land uses

Table VII-1. LOCAL CLIMATOLOGICAL DATA, ANNUAL SUMMARY WITH COMPARATIVE DATA, 1968

MILWAUKEE, WISCONSIN

NARRATIVE CLIMATOLOGICAL SUMMARY

The climate of Milwaukee is influenced by the general storms which move eastward along the northern border of the United States, and by those which move northeastward from the southwestern part of the country to the Great Lakes; also by the high barometric pressure systems that move eastward or southeastward across the country. For these reasons the weather changes frequently. During the winter and spring months there is seldom a period of more than 2 or 3 days without a distinct change in the character of the weather.

Milwaukee's climate is also influenced to a considerable extent by Lake Michigan. This is especially true in the spring, summer, and fall months when the temperature of the Lake water varies considerably from the air temperature. During the spring and early summer, a shift of wind from a westerly to an easterly direction frequently causes a sudden 10° to 15° drop in daytime temperatures. In the autumn, the relatively warm water of the Lake prevents nighttime temperatures from falling as low as they do a few miles inland from the shoreline.

The following averages and extremes are based upon the combined weather records made at the former city office in downtown Milwaukee, and those made at General Mitchell Field, covering a period generally from 1871 through 1964.

Milwaukee's annual average temperature for the period of record, 1871 through 1961, was 46.6°. It ranges from 21.2° in January to 70.8° in July. The highest temperature ever recorded in the City by the Weather Bureau was 105° on July 24, 1934, and the lowest was -25° on January 9, 1875. The City has an average of 13 days per year when the temperature reaches zero or lower, and 129 days when it reaches 32° or lower. Minima of 0° have been recorded as late as March 25, and 32° as late as May 27 in the spring. In the autumn, a low of 32° has been recorded as early as September 20, and 0° as early as November 21. The average number of days per year in which the temperature reaches 90° or higher is 8. Consecutive days with readings of 90° or higher seldom exceed 3, although there have been as many as 10.

The average annual precipitation is about 30 inches. About two-thirds of the annual amount occurs during the growing season. Since 1841, the wettest year was 1876 with 50.36 inches, and the driest year was 1901 with 18.69 inches.

TEMPERATURE
(From 1871 through 1964)

The Greatest Number of Consecutive Days With:

Max 90°	or above	10 days,	from Aug. 25, 1953 to Sept. 3, 1953
Min 32°	or lower	110 days,	from Dec. 6, 1874 to Mar. 25, 1875
Min 20°	or lower	46 days,	from Dec. 31, 1911 to Feb. 14, 1912
Min 10°	or lower	24 days,	from Jan. 12, 1963 to Feb. 4, 1963
Min 0°	or lower	17 days,	from Jan. 27, 1895 to Feb. 12, 1895

The long-term average annual snowfall is about 46 inches, but it varies considerably from season to season. During the winter of 1885-86, 110 inches were measured, while in 1884-85, the snowfall totaled only 11 inches.

Thunderstorms occur less frequently and with less severity in the Milwaukee area than in areas to the south and west. Hail size is generally 1/2 inch or less, although it has been noted as large as 2 inches in diameter with unusually severe storms. The maximum rainfall which has occurred in a 24-hour period is 5.76 inches in June 1917. As much as 0.79 inch has fallen in 5 minutes, 1.11 inches in 10 minutes, 1.34 inches in 15 minutes, 1.86 inches in 30 minutes, and 2.25 inches in 1 hour.

There are about twice as many cloudy days during the winter as there are during the summer. The average percentage of possible sunshine ranges from 40 percent in December to 70 percent in July.

The city office of the Weather Bureau was located on the 7th floor of the Federal Building, 517 East Wisconsin Avenue, until it was closed on May 1, 1954. The thermometers and rain gages were located on the roof. The terrain immediately around the station is fairly level; the Federal Building being located on a low ridge between Lake Michigan on the east and the Milwaukee River on the west, about 1/2 mile from the lake shore and 1/4 mile from the river. A few blocks west of the river the ground becomes gently rolling toward the west and north.

South and southwest of the station the ground is level for a distance of 2 to 4 miles, being a filled-in swamp. Between 1870 and May 1, 1954, the various locations of the city office were within 4 blocks of each other. Temperatures were influenced to a considerable extent by Lake Michigan, especially during the spring and early summer.

The airport office is located on the third floor of the Administration Building, General Mitchell Field, which is 6.6 miles south of the Federal Building. The field is located in the NNE sector of a very shallow circular depression about 4 miles in diameter. The station is about 3 miles west of the Lake Michigan shore. Temperatures are influenced somewhat by breezes from Lake Michigan during the spring and early summer. Cold air drainage from the surrounding higher terrain results in lower nighttime temperatures at the station than at other points in that vicinity.

FREEZE DATA (1871-1964)

Average date of last spring minimum of 32° or below - April 25
Latest date of killing frost, spring - May 27, 1961
Average date of first minimum of 32° or below in autumn - Oct. 19
Earliest date of first min of 32° or below in autumn - Sept. 20, 1956
Average length of growing season - 177 days
Shortest growing season of record - [illegible] days, 1894
Longest growing season of record - 223 days, 1915

U.S. DEPARTMENT OF COMMERCE
MAURICE H. STANS, Secretary
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
ROBERT M. WHITE, Administrator
ENVIRONMENTAL DATA SERVICE

Table VII-1 (continued). LOCAL CLIMATOLOGICAL DATA

LATITUDE 42° 57' N
LONGITUDE 87° 54' W
ELEVATION (ground) 672 Feet

METEOROLOGICAL DATA FOR THE CURRENT YEAR

MILWAUKEE, WISCONSIN
GENERAL MITCHELL FIELD
1968

Month	Temperature: Averages: Daily maximum	Averages: Daily minimum	Averages: Monthly	Extremes: Highest	Extremes: Date	Extremes: Lowest	Extremes: Date	Degree days	Precipitation: Total	Precipitation: Greatest in 24 hrs.	Precipitation: Date	Snow, Sleet: Total	Snow, Sleet: Greatest in 24 hrs.	Snow, Sleet: Date
JAN	28.6	14.9	21.8	48	29	-15	7	1333	0.98	0.23	27	4.6	2.0	14
FEB	29.6	11.8	20.7	45	1	- 3	17	1277	0.56	0.44	31-1	3.5	1.6	2
MAR	51.4	29.1	40.3	75	27	14	3+	758	0.31	0.09	18-19	1.2	0.7	22-23
APR	58.2	36.9	47.6	80	12	24	6+	521	2.90	0.90	16-17	0.4	0.4	24
MAY	62.1	44.3	53.2	81	15+	31	6	363	3.28	1.09	18-19	0.0	0.0	
JUN	75.3	57.2	66.3	90	9	42	13	74	7.79	2.06	25-26	0.0	0.0	
JUL	78.9	60.1	69.5	91	15+	49	3	31	3.59	1.97	23-24	0.0	0.0	
AUG	80.0	62.7	71.4	94	23+	48	28	23	2.59	1.24	19-20	0.0	0.0	
SEP	72.7	54.3	63.5	88	3	41	28	82	3.36	1.22	23-24	0.0	0.0	
OCT	61.4	43.9	52.7	84	15	28	30	403	0.94	0.37	21-22	0.0	0.0	
NOV	45.0	31.2	38.1	68	1	20	20	799	2.56	0.98	28	0.3	0.3	28
DEC	32.9	18.3	25.6	53	12	-11	31	1214	2.65	0.84	18-19	11.6	5.3	28
YEAR	56.3	38.7	47.5	94	AUG. 23+	-15	JAN. 7	6878	31.51	2.06	JUN. 25-26	21.6	5.3	DEC. 28

Month	Relative humidity: Mid.	6 AM	Noon	6 PM	Wind: Resultant: Direction	Resultant: Speed	Average speed	Fastest mile: Speed	Fastest mile: Direction	Fastest mile: Date	Percent of possible sunshine	Average sky cover sunrise to sunset
JAN	68	71	68	69	27	2.7	11.9	30	W	4	39	7.6
FEB	61	64	49	55	30	9.6	12.3	36	W	16	70	4.6
MAR	65	70	46	52	27	3.2	12.0	35	S	27+	66	6.6
APR	69	75	56	58	22	4.4	12.7	42	SW	8	55	6.3
MAY	78	80	63	64	12	1.1	9.5	36	W	16	56	6.8
JUN	82	85	65	67	21	2.4	9.8	42	SW	29	61	6.0
JUL	81	84	63	60	22	3.4	9.5	29	W	21+	78	4.9
AUG	86	88	65	69	23	2.7	9.6	31	SW	24+	76	4.6
SEP	88	92	65	73	21	4.4	9.5	33	SW	6	64	5.5
OCT	75	82	58	67	22	5.4	10.9	36	SW	27	59	5.3
NOV	78	81	65	74	30	4.8	10.5	40	N	28	38	7.4
DEC	79	81	70	76	26	5.3	12.6	41	SW	13	34	8.1
YEAR	76	79	61	65	25	3.2	10.9	42	SW	JUN. 29+	59	6.1

Standard time used: CENTRAL

Month	Number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Sleet 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures: Maximum: 90 and above	Maximum: 32 and below	Minimum: 32 and below	Minimum: 0 and below
JAN	6	4	21	11	2	1	4	0	17	30	6
FEB	15	3	11	8	1	0	1	0	20	28	3
MAR	8	5	18	11	0	0	1	0	2	20	0
APR	7	9	14	11	0	3	5	0	0	9	0
MAY	4	13	14	17	0	4	5	0	0	1	0
JUN	8	9	13	15	0	9	2	1	0	0	0
JUL	12	12	7	10	0	7	1	2	0	0	0
AUG	12	11	8	9	0	7	0	7	0	0	0
SEP	11	7	12	12	0	5	1	0	0	0	0
OCT	11	10	10	10	0	3	1	0	0	3	0
NOV	5	6	19	9	0	0	0	0	2	19	0
DEC	4	4	23	13	3	0	0	0	12	27	2
YEAR	103	93	170	136	6	39	21	10	53	137	11

Table VII-1 (continued). LOCAL CLIMATOLOGICAL DATA

NORMALS, MEANS, AND EXTREMES

Month	Temperature: Normal: Daily maximum	Normal: Daily minimum	Normal: Monthly	Extremes: Record highest	Year	Record lowest	Year	Normal degree days	Precipitation: Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year
(a)	(c)	(b)	(b) *	9		9		(b)	(b)	28		28		28	
J	25.3	12.8	20.6	57	1967+	-24	1963	1376	1.83	4.04	1960	0.31	1961+	1.71	1960
F	30.2	14.6	22.4	51	1961	-13	1965	1193	1.40	3.05	1960	0.15	1958	1.67	1960
M	39.8	23.2	31.5	77	1967	-10	1962	1054	2.31	3.80	1961+	0.31	1968	2.57	1960
A	53.1	34.1	43.6	85	1962+	17	1964	642	2.53	4.91	1951	0.81	1942	2.11	1956
M	63.9	42.9	53.4	89	1962	21	1966	372	3.16	5.27	1945	1.25	1961	2.06	1948
J	73.9	52.6	63.3	95	1965+	36	1966	135	3.64	8.28	1954	0.85	1965	3.13	1950
J	78.9	58.4	68.7	98	1963	40	1965	43	2.95	7.66	1964	0.95	1946	4.35	1959
A	77.7	57.8	67.8	95	1964	44	1965+	47	3.06	7.07	1960	0.46	1948	4.05	1953
S	70.7	49.9	60.3	93	1961+	31	1961	174	2.72	9.87	1941	0.30	1956	5.28	1941
O	60.1	39.9	50.0	89	1963	21	1960	471	2.10	6.42	1959	0.15	1956	2.60	1959
N	44.1	27.5	35.8	74	1964+	6	1964	876	2.18	3.37	1958	0.62	1949	2.18	1943
D	32.0	17.1	24.6	62	1962	-15	1963	1252	1.63	3.73	1965	0.34	1958	1.93	1942
YR	54.3	35.9	45.1	98	JUL. 1963	-24	JAN. 1963	7635	29.51	9.87	SEP. 1941	0.15	FEB. 1958+	5.28	SEP. 1941

Month	Snow, Sleet: Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity (Standard time used: CENTRAL): Mid.	6 AM	Noon	6 PM	Wind: Mean hourly speed	Prevailing direction	Fastest mile: Speed	Direction #	Year
(a)	28	28		28		8	8	8	8	28	14	28	28	
J	13.0	28.4	1943	12.8	1962	75	76	69	72	12.9	WNW	62	W	1950
F	8.5	34.0	1960	16.7	1960	75	77	67	70	12.9	WNW	58	NE	1960
M	9.4	26.7	1965	11.2	1961	79	82	68	73	13.4	WNW	73	SW	1954
A	1.1	7.0	1961	4.9	1961	76	79	62	65	13.4	NNE	66	SW	1947
M	T	0.4	1960	0.4	1960	74	78	60	60	12.3	NNE	72	SW	1950
J	0.0	0.0		0.0		78	81	60	62	10.4	NNE	57	S	1953
J	0.0	0.0		0.0		80	83	60	63	9.5	SW	59	W	1952
A	0.0	0.0		0.0		84	87	62	68	9.5	SW	50	W	1949
S	T	T	1960+	T	1960+	84	88	62	71	10.7	SSW	62	S	1941
O	T	0.8	1967	0.8	1967	76	80	62	68	11.6	SSW	60	S	1949
N	2.6	9.6	1951	6.3	1954	78	80	67	73	13.0	WNW	72	W	1955
D	9.2	26.5	1951	11.1	1959	78	80	72	75	12.7	WNW	62	SW	1948
YR	43.8	34.0	FEB. 1960	16.7	FEB. 1960	78	81	64	68	11.8	WNW	73	SW	MAR. 1954

Month	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Sleet 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures: Max.: 90 and above	Max.: 32 and below	Min.: 32 and below	Min.: 0 and below
(a)	28	28	28	28	28	28	28	28	28	8	8	8	8
J	44	6.8	7	6	18	11	3	*	3	0	20	30	8
F	46	6.6	7	6	15	9	3	*	2	0	17	28	5
M	50	6.9	6	8	17	12	3	1	3	0	7	24	*
A	54	6.5	6	9	15	12	*	4	3	0	0	11	0
M	59	6.3	7	10	14	12	0	5	3	0	0	2	0
J	64	5.9	8	10	12	11	0	7	3	3	0	0	0
J	71	5.1	11	11	9	9	0	7	1	3	0	0	0
A	68	5.1	11	11	9	9	0	6	2	2	0	0	0
S	61	5.3	10	10	10	9	0	4	1	1	0	*	0
O	58	5.3	11	9	11	8	0	2	2	0	0	5	0
N	42	7.0	6	6	18	9	1	1	2	0	2	19	0
D	40	7.0	6	7	18	10	3	*	2	0	16	28	3
YR	56	6.2	96	103	166	120	13	37	27	9	62	147	17

Means and extremes are from the existing location. Annual extremes have been exceeded at other locations as follows:
Highest temperature 105 in July 1934; lowest temperature -25 in January 1875; maximum monthly precipitation 10.03 in June 1917; minimum monthly precipitation 0.05 in March 1910; maximum precipitation in 24 hours 5.76 in June 1917; maximum monthly snowfall 52.6 in January 1918; maximum snowfall in 24 hours 20.3 in February 1924.

(a) Length of record, years.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months or years.
T Trace, an amount too small to measure.
Below-zero temperatures are preceded by a minus sign.
The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.

\# To 8 compass points only.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Degree day totals are the sums of the negative departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3; partly cloudy days 4-7; and cloudy days 8-10 tenths.

Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

Table VII-1 (continued). LOCAL CLIMATOLOGICAL DATA

AVERAGE TEMPERATURE

Year	Jan	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1931	29.6	33.4	33.7	46.6	53.0	69.0	75.5	71.8	69.6	56.7	47.1	36.2	51.8
1932	35.4	31.1	27.7	44.2	56.8	69.1	74.3	72.8	63.1	49.9	35.2	26.1	46.4
1933	33.7	22.0	32.7	43.8	55.1	73.1	74.1	70.0	68.5	50.3	35.4	26.4	48.8
1934	29.9	21.0	30.2	45.3	60.6	68.3	72.4	69.2	61.3	54.0	43.2	24.4	48.3
1935	20.4	26.6	37.6	41.5	50.4	61.6	75.6	71.6	63.8	51.8	37.8	24.4	46.9
1936	16.2	10.8	36.5	40.8	60.7	62.0	74.8	72.8	66.0	49.8	35.5	31.1	46.4
1937	23.1	24.0	31.2	42.7	55.6	63.8	73.5	74.8	63.8	48.8	35.8	25.0	46.8
1938	21.8	31.1	41.3	47.2	54.6	65.4	71.9	73.4	62.8	56.6	40.9	27.4	49.5
1939	28.6	23.2	34.8	43.7	57.9	66.0	73.2	72.0	67.5	53.2	41.2	33.8	49.8
1940	15.7	27.4	28.8	41.4	52.2	64.9	72.8	68.4	63.2	55.3	36.3	29.5	46.3
1941	25.6	23.0	29.3	49.3	58.6	66.6	74.0	70.8	64.6	52.5	40.0	32.3	48.6
1942	20.0	22.2	36.4	49.5	55.0	64.0	71.4	69.2	59.6	50.3	39.0	20.1	46.4
1943	18.6	23.1	29.0	42.6	52.8	67.0	71.8	71.4	58.0	50.3	34.0	25.1	45.3
1944	27.6	25.5	29.4	40.4	57.8	67.8	70.4	71.2	63.6	51.2	41.4	19.8	47.2
1945	17.4	24.7	44.4	46.4	50.1	60.6	67.8	69.4	61.8	48.8	37.4	20.5	45.8
1946	22.8	24.1	41.6	47.2	52.6	64.1	70.7	67.8	61.7	55.1	39.0	27.9	47.9
1947	25.6	17.6	30.0	42.8	49.9	60.8	68.8	75.8	63.9	59.4	32.6	26.9	46.2
1948	15.0	23.2	31.9	49.8	52.3	64.4	72.4	72.0	66.4	50.2	41.4	28.0	47.2
1949	25.6	23.5	33.4	44.8	57.0	69.5	74.4	72.0	58.6	53.8	36.2	28.6	48.3
1950	24.8	24.0	29.0	39.1	53.8	65.8	68.7	65.7	60.5	55.6	32.7	18.4	44.9
1951	20.4	24.3	31.5	43.0	57.3	61.0	70.4	67.2	60.9	52.0	31.5	24.7	45.4
1952	24.6	29.7	31.0	48.2	54.7	67.3	73.3	69.6	64.2	47.9	41.0	31.6	48.6
1953	27.[illegible]	28.3	35.6	43.1	55.3	67.9	72.6	73.8	64.7	57.3	43.6	29.8	49.9
1954	23.0	33.1	31.6	47.6	[illegible]	[illegible]	[illegible]	69.7	64.5	52.2	43.2	26.0	48.4
1955	21.7	24.7	31.9	50.7	58.2	65.2	76.7	76.4	63.9	52.9	33.5	22.6	48.2
1956	24.9	25.0	31.4	43.0	53.7	68.7	67.9	70.1	59.3	55.8	36.7	28.1	47.0
1957	14.[illegible]	27.8	32.4	45.0	52.7	65.0	70.9	69.2	59.5	48.6	36.5	29.7	46.0
1958	21.9	16.8	33.3	45.7	55.9	60.2	69.2	70.8	62.2	53.6	39.2	18.7	45.6
1959	13.4	19.3	30.9	45.0	59.5	67.5	70.2	73.8	64.7	47.7	29.5	32.5	46.2
1960	24.1	23.4	21.5	48.0	51.8	61.4	67.1	67.8	63.4	48.8	39.2	22.5	44.9
1961	19.4	29.8	35.2	41.2	50.8	65.3	69.9	70.3	64.8	51.2	37.6	22.8	46.5
1962	14.5	21.1	33.3	44.5	59.2	63.9	66.7	68.9	58.0	52.6	37.9	21.5	44.9
1963	8.7	15.9	35.2	45.8	52.3	65.6	70.8	67.1	61.2	58.6	41.7	13.2	44.7
1964	26.1	25.3	31.7	44.8	60.3	66.5	72.3	67.7	61.2	48.2	40.4	23.2	47.3
1965	19.5	21.2	25.3	42.7	58.6	63.1	66.9	66.8	61.7	50.8	38.5	32.9	45.8
1966	13.9	22.3	35.4	42.3	49.6	67.0	73.5	66.8	59.1	48.9	38.0	24.5	45.1
1967	24.5	17.5	33.2	44.9	50.2	66.5	68.6	66.0	60.8	50.4	35.2	28.9	45.6
1968	21.8	20.7	40.3	47.6	53.2	66.3	69.5	71.4	63.5	52.7	38.1	25.6	47.5
RECORD													
MEAN	21.1	23.2	32.7	44.4	54.4	64.5	70.8	69.7	62.6	51.5	37.6	26.1	46.6
MAX	28.3	30.4	39.7	52.3	63.3	73.5	79.2	77.7	70.7	59.3	44.4	32.6	54.3
MIN	13.8	16.0	25.7	36.5	45.4	55.5	62.3	61.6	54.5	43.7	30.7	19.5	38.8

TOTAL DEGREE DAYS

MILWAUKEE, WISCONSIN
GENERAL MITCHELL FIELD

Season	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Total
1930-31	20	3	85	522	745	1150	1100	880	971	545	304	59	6464
1931-32	0	9	54	274	537	893	1077	982	1159	626	283	19	5908
1932-33	11	1	99	473	896	1209	969	1205	1002	633	327	29	6850
1933-34	0	7	63	456	891	1195	1091	1236	1077	597	188	45	6826
1934-35	7	40	143	349	649	1257	1384	1077	852	703	453	130	7044
1935-36	0	28	107	409	815	1261	1515	1573	883	726	210	135	7662
1936-37	4	2	89	473	885	1048	1300	1146	1050	668	313	103	7081
1937-38	3	0	145	505	875	1243	1338	952	731	543	330	52	6717
1938-39	3	3	113	290	732	1168	1129	1172	935	648	266	42	6501
1939-40	2	3	94	387	718	967	1530	1093	1122	707	396	78	7097
1940-41	20	40	134	307	862	1099	1275	1180	1104	476	236	92	6775
1941-42	17	19	105	388	751	1011	1400	1200	865	469	330	105	6680
1942-43	11	25	238	456	780	1391	1438	1176	1116	671	380	104	7786
1943-44	8	12	235	456	930	1238	1156	1145	1102	733	261	70	7346
1944-45	11	19	116	430	709	1403	1476	1126	643	562	461	194	7150
1945-46	42	16	170	504	832	1379	1307	1147	727	540	385	149	7198
1946-47	6	34	140	321	781	1153	1220	1331	1085	665	474	188	7398
1947-48	29	7	179	207	968	1181	1546	1209	1029	494	399	107	7355
1948-49	4	3	73	460	704	1147	1225	1158	983	606	291	41	6695
1949-50	4	5	203	357	801	1126	1237	1144	1107	767	349	64	7164
1950-51	26	45	113	263	928	1372	1375	1137	1033	659	256	133	7340
1951-52	11	22	150	411	996	1242	1248	1019	1047	500	332	60	7038
1952-53	5	13	92	524	717	1027	1173	1020	935	651	312	54	6493
1953-54	5	0	93	264	634	1086	1296	887	1029	516	415	59	6293
1954-55	9	12	92	375	726	1137	1335	1122	1021	424	229	82	6593
1955-56	6	3	104	373	939	1308	1234	1153	1036	652	370	67	7239
1956-57	27	18	188	287	840	1139	1544	1036	1006	598	381	88	7152
1957-58	8	8	193	503	848	1087	1330	1346	977	575	291	165	7331
1958-59	13	16	133	348	768	1429	1594	1273	1049	592	215	73	7503
1959-60	13	0	117	529	1059	999	1259	1200	1342	515	402	132	7567
1960-61	40	20	142	494	766	1312	1407	978	918	708	434	86	7305
1961-62	18	9	134	422	815	1303	1561	1224	1067	623	254	119	7549
1962-63	24	22	227	395	804	1342	1749	1372	915	570	388	82	7890
1963-64	20	38	135	217	692	1601	1199	1141	1026	598	192	105	6964
1964-65	7	47	177	515	730	1290	1404	1222	1226	664	232	123	7637
1965-66	25	51	149	438	793	987	1579	1189	915	674	473	88	7361
1966-67	4	41	198	496	804	1249	1249	1325	978	596	458	47	7445
1967-68	46	53	164	460	888	1112	1333	1277	758	521	363	74	7049
~~1968-69~~	~~31~~	~~23~~	~~82~~	~~403~~	~~795~~	~~1214~~							

38

Table VII-1 (continued). LOCAL CLIMATOLOGICAL DATA

TOTAL PRECIPITATION

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1931	1.04	0.45	4.76	0.92	1.70	3.58	2.25	1.96	3.15	2.10	4.65	1.85	28.39
1932	1.65	0.94	2.20	0.54	1.53	1.67	3.12	1.94	0.90	4.85	0.86	2.15	22.35
1933	1.30	1.42	3.93	2.97	9.56	2.47	4.55	1.75	2.57	2.83	1.03	1.13	35.52
1934	1.00	0.55	1.97	1.53	2.73	2.32	1.10	1.43	4.33	2.28	8.56	1.22	29.02
1935	2.50	2.24	1.98	3.05	2.29	4.34	3.59	3.08	1.12	1.37	3.43	1.42	30.41
1936	2.54	2.32	0.67	2.30	2.55	1.93	0.28	5.92	5.59	3.77	0.34	2.14	30.35
1937	3.12	1.72	1.74	4.80	2.70	2.64	3.06	0.80	1.14	1.83	0.85	1.42	25.82
1938	4.60	3.33	3.29	0.97	3.73	6.93	2.70	6.47	6.12	0.76	1.66	1.10	41.86
1939	1.60	2.24	1.54	2.81	1.40	3.50	0.51	5.03	1.53	2.43	0.33	0.46	23.38
1940	1.57	1.33	2.07	2.96	3.80	7.54	3.91	6.68	0.55	1.48	2.80	0.95	32.64
1941	2.50	0.63	1.82	1.93	3.03	3.42	2.93	1.29	9.87	2.86	0.93	1.29	32.50
1942	1.16	0.50	1.46	0.81	4.49	4.26	3.58	4.14	3.43	2.44	3.27	2.55	32.09
1943	2.15	0.76	2.48	0.99	2.88	2.33	1.54	2.31	0.37	0.83	3.15	0.99	20.78
1944	1.40	1.69	2.46	3.74	2.33	3.42	2.77	1.54	3.05	0.29	1.54	1.14	25.37
1945	0.31	1.40	1.40	2.89	5.27	2.81	2.65	4.07	6.27	0.78	2.34	1.47	31.66
1946	1.97	0.88	2.88	0.94	2.14	2.81	0.95	1.63	1.28	1.79	2.08	1.54	20.89
1947	2.26	0.29	1.73	3.68	4.35	3.98	2.17	1.58	6.03	1.85	2.82	1.72	32.46
1948	1.07	1.68	3.59	1.91	4.05	3.19	2.16	0.46	1.24	0.33	2.44	2.50	24.62
1949	2.59	1.74	2.57	1.38	1.72	3.79	3.46	1.08	1.88	1.62	0.62	2.27	24.72
1950	2.17	1.39	2.50	3.58	2.04	5.11	6.07	3.29	1.75	0.55	1.60	2.59	32.64
1951	2.38	1.87	3.33	4.91	3.87	2.97	3.12	2.56	2.75	4.42	1.99	2.26	36.43
1952	2.08	0.82	3.67	2.95	2.86	4.03	6.69	3.59	0.36	0.17	3.37	2.10	32.69
1953	1.16	1.62	1.19	2.81	1.77	2.65	2.78	4.34	1.65	0.46	0.58	1.87	22.87
1954	0.92	1.31	1.65	3.27	1.83	8.26	5.13	3.66	4.78	3.18	1.06	2.64	35.71
1955	0.62	1.32	1.05	2.43	4.29	4.58	2.10	3.62	2.36	3.57	0.87	1.09	27.50
1956	0.57	1.43	2.36	4.14	4.55	3.87	5.37	2.96	0.30	0.15	1.62	1.03	28.35
1957	0.88	0.96	1.59	2.70	3.82	4.01	1.50	2.03	0.88	1.34	2.88	2.36	24.95
1958	1.41	0.15	0.46	1.84	2.07	1.71	1.02	1.71	2.85	3.24	3.37	0.34	20.17
1959	2.48	1.98	3.03	3.29	1.28	1.67	6.82	3.47	2.31	6.42	2.08	2.85	37.68
1960	4.04	3.05	3.80	2.92	4.27	3.28	3.50	7.07	3.25	3.06	2.12	0.35	40.71
1961	0.31	1.22	3.80	3.89	1.25	1.53	2.91	2.35	9.41	2.75	2.37	1.02	32.81
1962	2.48	2.04	1.69	1.49	2.17	1.33	3.74	1.98	1.49	2.14	0.81	0.55	21.91
1963	0.60	0.42	2.20	2.54	1.95	1.50	2.36	2.48	1.78	0.34	2.17	0.70	19.10
1964	1.16	0.41	3.05	3.81	2.57	1.70	7.86	2.62	1.74	0.17	2.29	0.98	28.18
1965	3.03	1.04	3.61	3.47	2.12	0.85	2.64	6.15	6.85	2.68	2.02	3.73	38.49
1966	2.06	1.27	3.61	2.67	2.00	1.60	3.32	3.27	0.48	1.76	2.70	2.31	27.13
1967	1.49	1.31	1.35	2.70	1.80	7.38	1.35	1.23	1.69	2.70	1.52	1.33	25.85
1968	0.98	0.56	0.31	2.90	3.28	7.79	3.59	2.59	3.36	0.94	2.56	2.65	31.51
RECORD MEAN	1.85	1.57	2.43	2.72	3.22	3.50	2.88	2.84	3.11	2.26	2.00	1.70	30.08

TOTAL SNOWFALL

Season	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Total
1930-31	0.0	0.0	0.0	T	4.2	9.0	10.1	3.8	36.3	T	T	0.0	63.4
1931-32	0.0	0.0	0.0	0.0	T	5.3	7.4	2.2	17.5	T	0.0	0.0	32.4
1932-33	0.0	0.0	0.0	T	0.6	7.9	1.5	13.8	12.9	0.8	0.0	0.0	37.5
1933-34	0.0	0.0	0.0	T	3.5	6.3	0.8	9.2	7.1	0.2	0.0	0.0	29.1
1934-35	0.0	0.0	0.0	T	T	8.1	10.2	17.0	9.2	0.4	3.2	0.0	48.1
1935-36	0.0	0.0	0.0	T	1.0	9.7	24.9	23.8	1.9	13.0	0.0	0.0	74.2
1936-37	0.0	0.0	0.0	T	0.9	3.5	0.7	1.9	13.2	T	0.0	0.0	20.2
1937-38	0.0	0.0	0.0	T	2.0	4.5	7.8	2.9	3.8	0.3	0.0	0.0	21.3
1938-39	0.0	0.0	0.0	T	0.9	4.2	15.7	5.8	10.1	0.6	0.0	0.0	37.3
1939-40	0.0	0.0	0.0	T	T	0.4	9.5	14.8	15.1	2.5	T	0.0	42.3
1940-41	0.0	0.0	0.0	0.0	18.0	1.3	7.4	2.7	4.3	T	0.0	0.0	33.7
1941-42	0.0	0.0	0.0	0.0	3.1	8.5	8.1	6.4	1.8	T	0.0	0.0	27.9
1942-43	0.0	0.0	T	T	5.1	8.1	28.4	3.5	9.4	T	0.0	0.0	54.5
1943-44	0.0	0.0	0.0	0.0	1.6	T	3.0	9.3	7.1	T	0.0	0.0	21.0
1944-45	0.0	0.0	0.0	0.0	0.8	12.5	6.4	6.7	T	T	T	0.0	26.4
1945-46	0.0	0.0	0.0	0.0	1.5	11.9	3.5	7.8	5.4	0.0	0.0	0.0	30.1
1946-47	0.0	0.0	0.0	T	0.1	6.8	26.3	5.2	9.4	0.9	T	0.0	48.7
1947-48	0.0	0.0	0.0	0.0	9.0	5.2	16.2	6.1	12.6	T	0.0	0.0	49.1
1948-49	0.0	0.0	0.0	0.0	0.0	2.8	13.7	9.5	3.7	0.3	0.0	0.0	30.0
1949-50	0.0	0.0	0.0	0.0	3.1	6.2	3.8	8.6	14.9	5.1	0.0	0.0	41.7
1950-51	0.0	0.0	0.0	0.0	5.8	20.1	27.3	10.3	15.0	0.8	T	0.0	79.3
1951-52	0.0	0.0	0.0	0.0	12.4	30.7	15.7	8.2	22.1	1.7	0.0	0.0	90.8
1952-53	0.0	0.0	0.0	T	T	6.3	10.5	1.7	6.5	T	0.0	0.0	25.0
1953-54	0.0	0.0	0.0	0.0	1.3	1.6	6.7	4.5	3.3	T	T	0.0	17.8
1954-55	0.0	0.0	0.0	T	7.6	17.6	2.8	6.7	4.4	0.0	0.0	0.0	39.1
1955-56	0.0	0.0	0.0	0.0	2.4	5.2	4.4	9.9	11.7	0.1	0.0	0.0	33.7
1956-57	0.0	0.0	0.0	0.0	0.3	10.6	11.2	3.0	9.0	0.0	0.0	0.0	34.4
1957-58	0.0	0.0	0.0	T	0.8	8.0	16.7	1.6	4.8	T	0.0	0.0	31.9
1958-59	0.0	0.0	0.0	0.0	2.1	6.9	27.5	10.8	14.5	1.5	0.0	0.0	63.3
1959-60	0.0	0.0	0.0	T	9.3	14.3	19.4	34.0	14.3	1.6	0.4	0.0	93.3
1960-61	0.0	0.0	T	0.2	2.8	2.3	3.9	2.4	14.3	7.0	0.0	0.0	32.9
1961-62	0.0	0.0	0.0	T	2.4	7.7	22.1	22.2	11.4	4.0	0.0	0.0	69.8
1962-63	0.0	0.0	0.0	0.1	0.9	6.5	8.1	6.4	7.1	T	T	0.0	29.1
1963-64	0.0	0.0	0.0	0.0	T	12.8	3.8	5.7	19.8	T	0.0	0.0	42.1
1964-65	0.0	0.0	0.0	T	1.4	8.1	23.6	10.1	26.7	4.1	0.0	0.0	74.0
1965-66	0.0	0.0	0.0	T	T	14.5	24.6	7.7	2.8	1.3	0.1	0.0	51.0
1966-67	0.0	0.0	0.0	0.0	2.0	9.9	13.1	27.1	7.4	T	T	0.0	59.5
1967-68	0.0	0.0	0.0	0.8	0.4	1.2	4.6	3.5	1.2	0.4	0.0	0.0	12.1
1968-69	0.0	0.0	0.0	0.0	0.3	11.6							

Record mean values above (not adjusted for instrument location changes listed in the Station Location table) are means for the period beginning in 1875 for temperature and 1871 for precipitation.

A horizontal line drawn on the above tables indicates a break in the data sequence due to a change in instrument exposure or a station move (see Station Location table). Data are from City Office locations through February 1941 and for the period July 1950 through December 1953, otherwise from Airport locations.

Table VII-1 (continued). LOCAL CLIMATOLOGICAL DATA

STATION LOCATION

MILWAUKEE, WISCONSIN
GENERAL MITCHELL FIELD

Location	Occupied from	Occupied to	Airline distance and direction from previous location	Latitude North	Longitude West	Elevation above: Sea level									Sea level	Remarks
							Ground									
						Ground at temperature site	Wind instruments	Extreme thermometers	Psychrometer	Telepsychrometer	Tipping bucket rain gage	Weighing rain gage	8" rain gage	Hygrothermometer	Pyranometer	
CITY OFFICE																
Chamber of Commerce Bldg Broadway and Michigan	11- 1-70	12-10-70		43° 02'	87° 54'	608										
Insurance Building, Broadway & Michigan	12-10-70	3-23-78	50 ft. N	43° 02'	87° 54'	608	114									
Mitchell Building, North Water and Michigan	3-23-78	4-22-99	300 ft. W	43° 02'	87° 54'	600	149	106	106		a100		100			a - Added 10-14-91.
Federal Bldg., 4th Floor 517 E. Wisconsin Avenue	4-22-99	3-10-32	1000ft. ENE	43° 02'	87° 54'	620	b221	126	125		117		117			b - 139 ft. to 4-29-27.
Federal Bldg., 5th Floor 517 E. Wisconsin Avenue	3-10-32	3-28-41	20 ft. S	43° 02'	87° 54'	620	c221	98	97		c88		88			c - Removed 3-1-41.
Federal Bldg., 7th Floor 517 E. Wisconsin Avenue	3-28-41	5- 1-54		43° 02'	87° 54'			125	124			115	115			
AIRPORT STATION																
Old Admn. Bldg., 1011 E. Layton Ave., General Mitchell Field, 5.75 mi. S of Post Office	4-21-27	8- 5-40		42° 57'	87° 54'	674	45	32	32				28			
New Admn. Bldg., 1011 E. Layton Ave., General Mitchell Field	8- 5-40	6-20-55	100 ft. S	42° 57'	87° 54'	674	66	33	33		31	4	31			
New Terminal Building 5300 S. Howell Avenue General Mitchell Field	6-20-55	Present	4750 feet SSW	42° 57'	87° 54'	670 670 b672	88 88 a20	35 5 d33	33 33 33	 5 c5	33 33 33	35 4 d5	34 3 d4	 b5		 Elevations as of 6-23-56. a - Field site 7-17-58. b - Effective 3-1-61. c - Removed 3-1-61. d - Effective 10-26-61.

Requests for additional information should be directed to the Weather Bureau Office for which this summary was issued.

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Topography - Topographic information is most difficult to present in final report format since typically topographic maps are prepared for rather large areas and are not easily reduced to a satisfactory scale. Where possible, reduction of topographic maps should be made. If this is not feasible, it is recommended that sources of maps be given in the report to facilitate future work.

Pervious and Impervious Areas - Pervious and impervious areas play an extremely important role in the runoff rates from various areas. This information is typically gathered from aerial photographs and can be presented in summary form in either tabular format or through the use of subarea maps. Street areas and length of curb can be handled in the same manner.

Average Daily Traffic - In certain areas of a metropolitan community, heavy vehicular traffic can generate a significant buildup of dirt and various other pollutants on streets and the adjacent right of ways. In most metropolitan areas average daily traffic (ADT) counts can be obtained from the traffic engineering department or city engineer's office. It is useful to include this information in final reports. The relationship between roadway usage and water pollution has been reported (2). The accumulation of pollutants on streets and highways is influenced by the frequency and method of street cleaning. For studies which are evaluating pollutants in urban runoff, it is desirable to initiate a program for accumulating data on street cleaning at the onset of the study. This program should include a notation of the dates of all cleaning activity, the method of cleaning employed and the volume and weight of collected materials if possible (3).

Miles, Size and Slopes of Sewers - The sewerage systems of most cities are mazes of pipes, culverts and ditches of all sizes, materials of construction and slope. Oftentimes the existing maps are not current and may require significant field inspection to verify as-built conditions.

Sewer information can be presented in tabular form which is referenced to a sewer system schematic (Figure VII-4).

Dry-Weather Flow and Quality

Dry-weather flow rates and quality characteristics are important parameters for evaluating combined sewer overflows. Hydraulic flow rates determine the excess capacity available for conveying stormwaters and/or the capacity available for bleeding back flows from off line storage reservoirs.

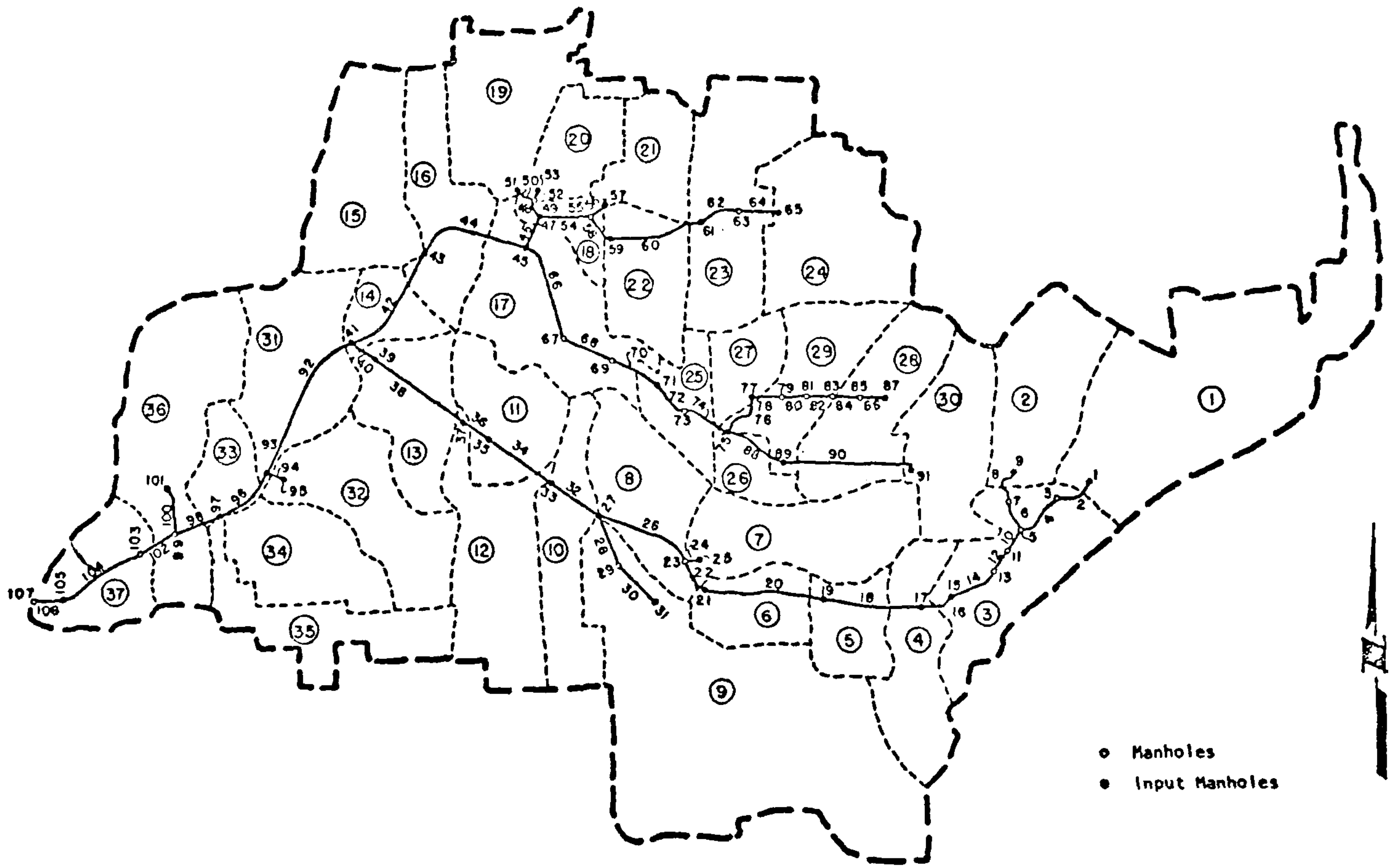


Figure VII-4. Division of Bloody Run sewer basin into subareas and numbering of the sewer system's elements

Element Number	Location or Diameter	Slope	Contributing Subarea or Length (feet)
1	input manhole		Drainage Subarea 1
2	54"	2.60%	394.0
3	manhole		
4	54"	2.30%	689.3
5	manhole		
6	48"	2.20%	380.4
7	manhole		
8	48"	2.60%	467.0
9	input manhole		Drainage Subarea 2
10	66"	1.40%	319.4
11	manhole		
12	72"	0.90%	345.3
13	manhole		
14	75"	1.00%	577.0
15	input manhole		Drainage Subarea 3
16	72"	1.40%	462.7
17	input manhole		Drainage Subarea 4
18	72"	1.80%	1428.5
19	input manhole		Drainage Subarea 5
20	78"	1.25%	1432.0
21	input manhole		Drainage Subarea 6
22	84"	1.10%	664.0
23	manhole		
24	60"	1.00%	149.7
25	input manhole		Drainage Subarea 7
26	90"	1.30%	1238.5
27	input manhole		Drainage Subarea 8
28	60"	1.20%	750.0
29	manhole		
30	60"	1.00%	700.0
31	input manhole		Drainage Subarea 9
32	10' x 8'	0.70%	700.0
33	input manhole		Drainage Subarea 10
34	10' x 8'	0.70%	900.0
35	input manhole		Drainage Subarea 11
36	10' x 8'	0.70%	438.3
37	input manhole		Drainage Subarea 12
38	11' x 9'	0.40%	1473.6
39	input manhole		Drainage Subarea 13
40	11' x 9'	0.40%	350.0
41	input manhole		Drainage Subarea 14
42	12' x 9'	0.30%	1673.1
43	input manhole		Drainage Subareas 15 & 16
44	12' x 9'	0.28%	1433.4
45	input manhole		Drainage Subarea 17
46	96"	0.60%	595.4

Figure VII-4 (continued). Division of Bloody Run sewer basin into subareas and numbering of the sewer system's elements

The dry-weather sewage characteristics can be used to predict quality and quantity of combined sewer discharges and to key into certain possible treatment schemes. For example, interceptor sewers containing high concentrations of dissolved BOD may alert design engineers to potential difficulties in meeting discharge requirements with treatment schemes which remove only particular contaminants (screening, flotation, sedimentation).

Dry-weather flow rates and characteristics are also necessary input to certain predictive models. The EPA Stormwater Management Model utilizes dry-weather characteristics to estimate solids accumulation in sewers, velocities required for scour and the determination of the resultant sewage/stormwater mixture to estimate combined sewage characteristics. Oftentimes flow characteristic information is available from various locations in the collection system such as lift stations, or metering stations. Pump station records can provide long term records which are invaluable sources of information.

When this information is not readily available it may be necessary to install sampling/gaging stations to collect the necessary data. The need for this data dictates that time series sampling be conducted as hourly variations (or as low as five minutes depending upon the drainage area and study needs) if flow and characteristics are desired. The parameters to be analyzed would generally be BOD (total and dissolved), suspended solids and fecal coliform as a minimum. A data record of at least one week is desirable. Quality characteristic data is sometimes available from past studies or sewage treatment plant records.

Prior to initiating this program, it is important to consider the potential impact of industrial wastes and to make sure that various contributing industries are operating at normal conditions if they have any significant impact on wastewater characteristics.

Establishment of satisfactory raingage networks must be tailored to the objective of the specific project. Criteria for raingage networks have been defined in Section V. Because of the need for historical records it is often not feasible to install raingages for projects of only 1 to 2 years duration. However, where a project is attempting to correlate predictive model results to observed runoff hydrographs it may be necessary to install one or more gages to supplement existing raingage information. In this case it is recommended that the following criteria be utilized.

A. One centrally located gage for watersheds up to 48.5 ha or 0.48 sq km (120 acres or 0.187 sq mi).

B. Three evenly spaced gages for 260 ha or 2.6 sq km (640 acres or 1 sq mi) watershed with a length to width ratio of 4.

C. Five evenly spaced gages for 2600 ha or 26 sq km (6400 acres or 10 mi) watershed with gages spaced about every 2.42 km (1.5 mi).

D. All gages should be selected, installed and operated according to Weather Bureau Observing Handbook No. 2, Substation Observations, Unites States Department of Commerce, Environmental Science Services Administration Weather Bureau.

RECOMMENDED METHOD OF EVALUATING STORM GENERATED DISCHARGES

Method of Constructing Hyetographs

Hyetographs are graphical representations of the variation of rainfall intensity with time. They can be constructed from recording raingages with relative ease.

In order to prepare a hyetograph it is necessary to select a time over which to calculate the rainfall intensities. For hydrologic models it may be of interest to calculate rainfall intensities for periods as short as 1-5 minutes. For other purposes, less frequent intensities may be desired.

The accuracy of calculated rainfall intensities is subject to the chart speed and the recording scale of the raingage. Typically recording raingages have a horizontal (time) scale of one hour - 9.65 cm (3.8 in.) and a vertical (rainfall) scale of 2.54 cm (1 in.) of rainfall - 2.06 cm (13/16 in.). For this scale the minimum readable data is approximately 0.64 cm (0.025 in.) of rain and 10-20 minutes or an intensity of

$$\frac{0.064 \text{ cm } (0.025 \text{ in.})}{10 \text{ minutes}} \times \frac{60 \text{ minutes}}{\text{hour}} = 0.384 \text{ cm/hr } (0.15 \text{ in./hour})$$

The sensitivity of raingages can be increased by utilizing a faster chart speed or a digital printer which prints rainfall depth in a binary-decimal code suitable for automatic data processing procedures.

Hyetographs can be produced by taking the data from a recording raingage (Figure VII-5), transforming the data into proper format (Table VII-2), and then plotting the transformed data on rectilinear graph paper (Figure VII-6).

Method of Constructing Pollutographs

The term pollutograph was coined by the authors of SWMM as a means of defining the mass per unit time discharge rate of pollutants. As such, it can be applied to any wastewater constituent calculated as kg (lbs) emitted as a function of time. The pollutograph is extremely useful in

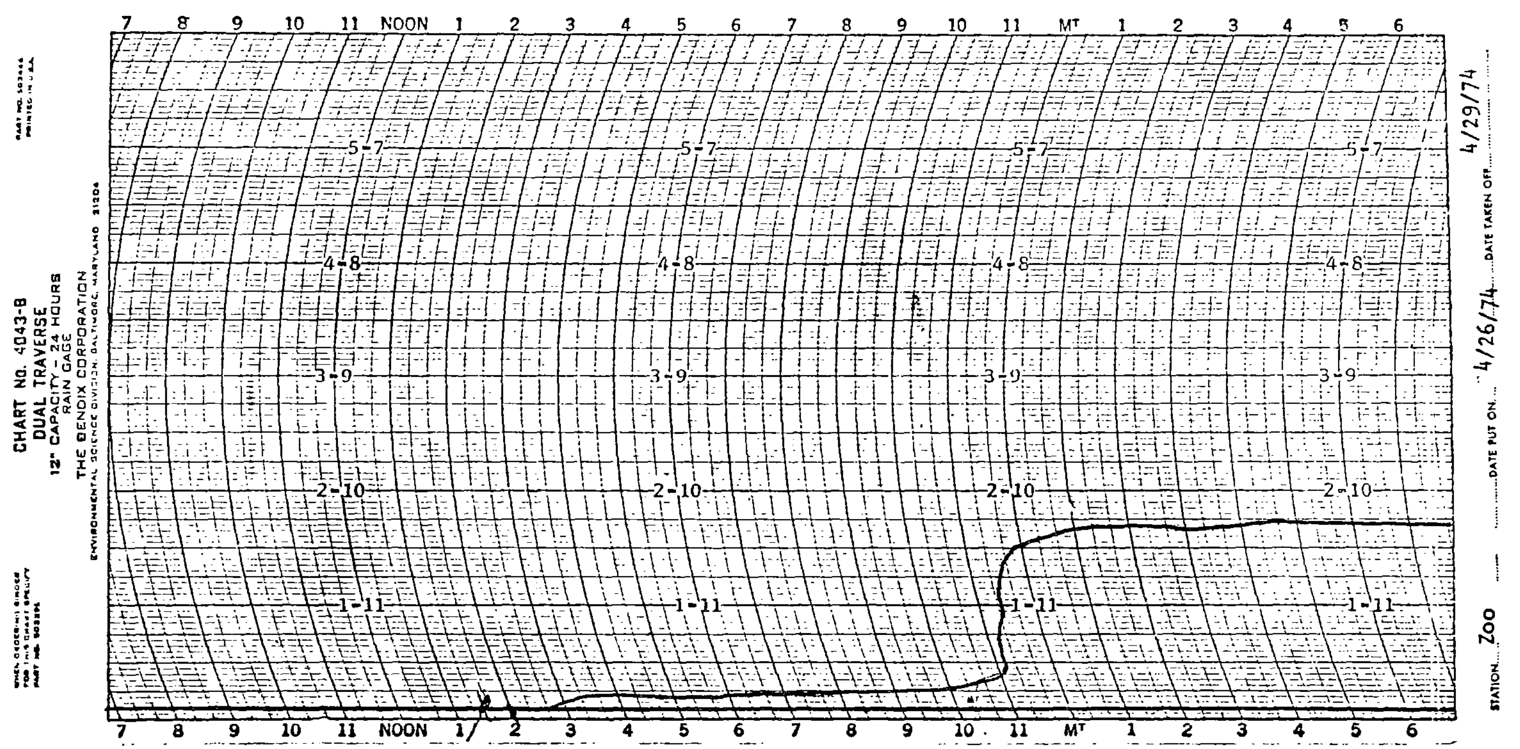


Figure VII-5. Recording raingage chart

Table VII-2. RAINFALL HYETOGRAPH

November 20, 1974

Date of Storm: April 26, 1974
Gage Location: Fire Station

Time	Gage reading	Increment, in.	Increment, cm	Intensity, in./hour	Intensity, (cm)/hour	Time	Gage reading	Increment, in.	Increment, cm	Intensity, in./hour	Intensity, (cm)/hour
0000	--					1100	0.14	0.04	.102	0.12	.305
0200	--					1120	0.16	0.02	.051	0.06	.152
0040	--					1140	0.24	0.08	.203	0.24	.610
0100	--					1200	0.32	0.08	.203	0.24	.610
0120	--					1220	0.38	0.06	.152	0.18	.457
0140	--					1240	0.47	0.09	.229	0.27	.686
0300	--					1300	1.05	0.58	1.47	1.74	4.420
0200	--					1320	1.50	0.45	1.14	1.35	3.429
0240	--					1340	1.57	0.07	.178	0.21	.533
0300	0.00	0.00	0.00	0.00	0.00	1400	1.65	0.08	.203	0.24	.610
0320	0.05	0.05	.127	0.15	.381	1420	1.72	0.07	.178	0.21	.533
0340	0.05	0.00	0.00	0.00	0.00	1440	1.74	0.02	.051	0.06	.152
0400	0.05	0.00	0.00	0.00	0.00	1500	1.75	0.01	.025	0.03	.076
0420	0.06	0.01	.025	0.03	.076	1520	1.75	0.00	0.00	0.00	0.00
0440	0.09	0.03	.076	0.09	.229	1540	1.75	0.00	0.00	0.00	0.00
0500	0.10	0.01	.025	0.03	.076	1600	--				
0520	0.10	0.00	0.00	0.00	0.00	1620	--				
0540	0.10	0.00	0.00	0.00	0.00	1640	--				
0600	0.10	0.00	0.00	0.00	0.00	1700					
0620	0.10	0.00	0.00	0.00	0.00	1720					
0640	0.10	0.00	0.00	0.00	0.00	1740					
0700	0.10	0.00	0.00	0.00	0.00	1800					
0720	0.10	0.00	0.00	0.00	0.00	1820					
0740	0.10	0.00	0.00	0.00	0.00	1840					
0800	0.10	0.00	0.00	0.00	0.00	1900					
0820	0.10	0.00	0.00	0.00	0.00	1920					
0840	0.10	0.00	0.00	0.00	0.00	1940					

Table VII-2 (continued). RAINFALL HYETOGRAPH

Time	Gage reading	Increment, in.	Increment, cm	Intensity, in. (cm)/hour		Time	Gage reading	Increment, in.	Increment, cm	Intensity, in. (cm)/hour	
0900	0.10	0.00	0.00	0.00	0.00	2000					
0920	0.10	0.00	0.00	0.00	0.00	2020					
0940	0.10	0.00	0.00	0.00	0.00	2040					
1000	0.10	0.00	0.00	0.00	0.00	2100					
1020	0.10	0.00	0.00	0.00	0.00	2120					
1040	0.10	0.00	0.00	0.00	0.00	2140					

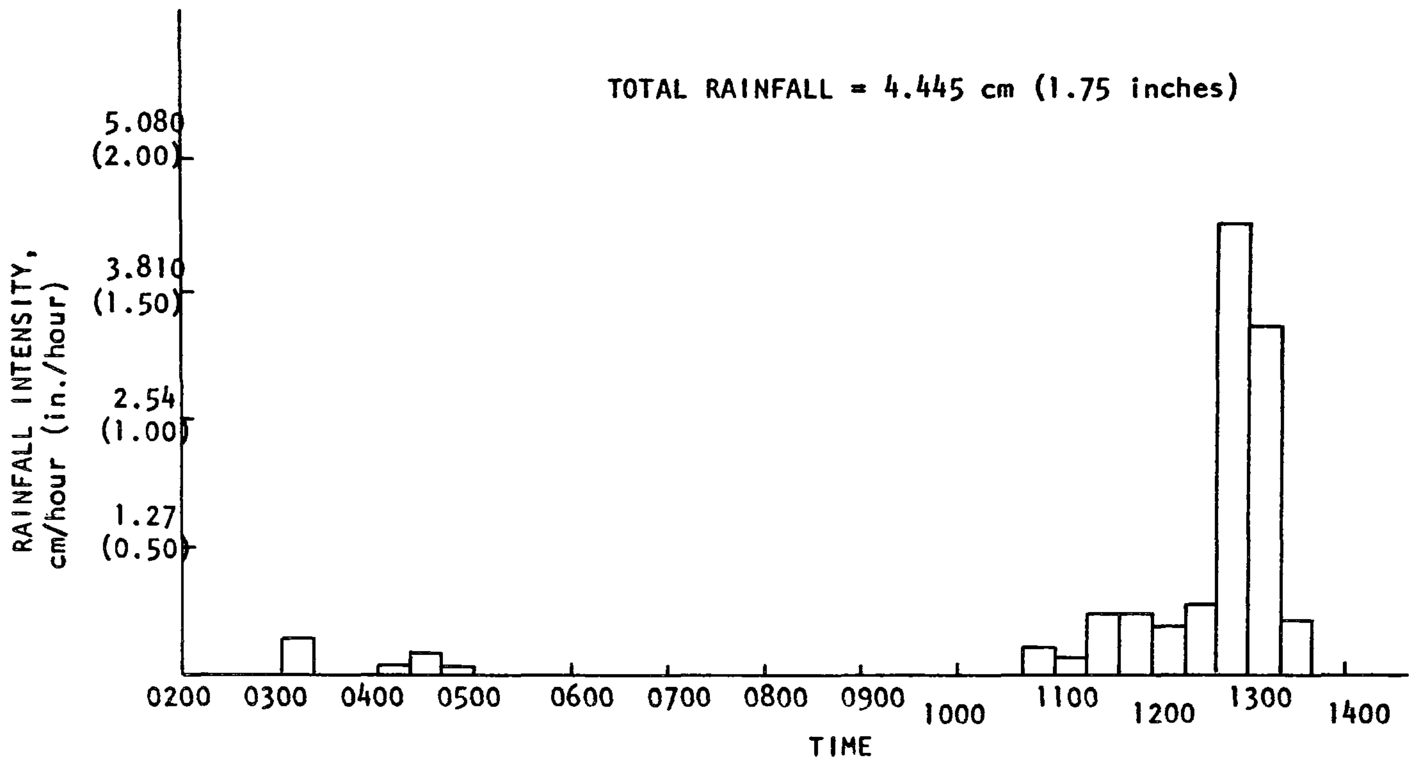


Figure VII-6. Rainfall hyetograph - Racine, Wisconsin, April 26, 1974 storm generated discharge studies because it indicates the rate at which various pollutants are discharged.

Pollutographs are developed in SWMM by multiplying the hydraulic flow rate times the pollutant concentration at various points in time. Confirmation of the accuracy of calculated pollutographs requires a continuous record of flow and a series of discrete analyses of the pollutant(s) in question.

The pollutograph in Figure VII-7 was constructed by calculating the mass emission rate from the flow rate and suspended solids concentrations in Figure VII-8. Pollutograph information is particularly valuable as input to time variable water quality models and as a means of evaluating the loading rate on various treatment devices.

Method of Constructing Hydrographs

A hydrograph is a graph of stage or discharge against time. Many methods of preparing hydrographs may be utilized. Hydrologists for example, may be interested in monthly and annual mean flow to display a record of runoff at a stream flow station. Engineers evaluating storm generated discharge sites are more concerned with hydrographs from specific storm events.

Oftentimes the objectives of a particular project will dictate the level of sophistication of the hydrographs which will be generated. Mathematical models such as SWMM have the capability to generate surface stormwater inlet hydrographs given the proper hyetograph and land characteristics, to route these hydrographs through a conveyance system and ultimately to generate an outlet hydrograph at an overflow point in the system. SWMM is capable of generating reasonably accurate hydrographs for predictive purposes (4). Because of the complexity of the model, readers are referred to the users manual for operational details. The latest edition of the users manual was published in March, 1975 and is EPA report No. EPA-670/2-75-01. A somewhat less complicated method for generating hydrographs has been prepared by URS Research Company (5). Utilizing the unit hydrograph concept (the hydrograph of 2.54 cm (1.0 in)of direct runoff from a storm of specified duration) and the empirical equations of Epsey, one may synthesize a unit hydrograph to describe a specific study area. The unit hydrograph can then be modified to reflect any runoff rate or runoff duration for the study area. Readers interested in utilizing the unit hydrograph procedure are urged to remember that the procedure is a statistical representation. A rather detailed discussion and attempt to quantify estimating error in this procedure has been made.

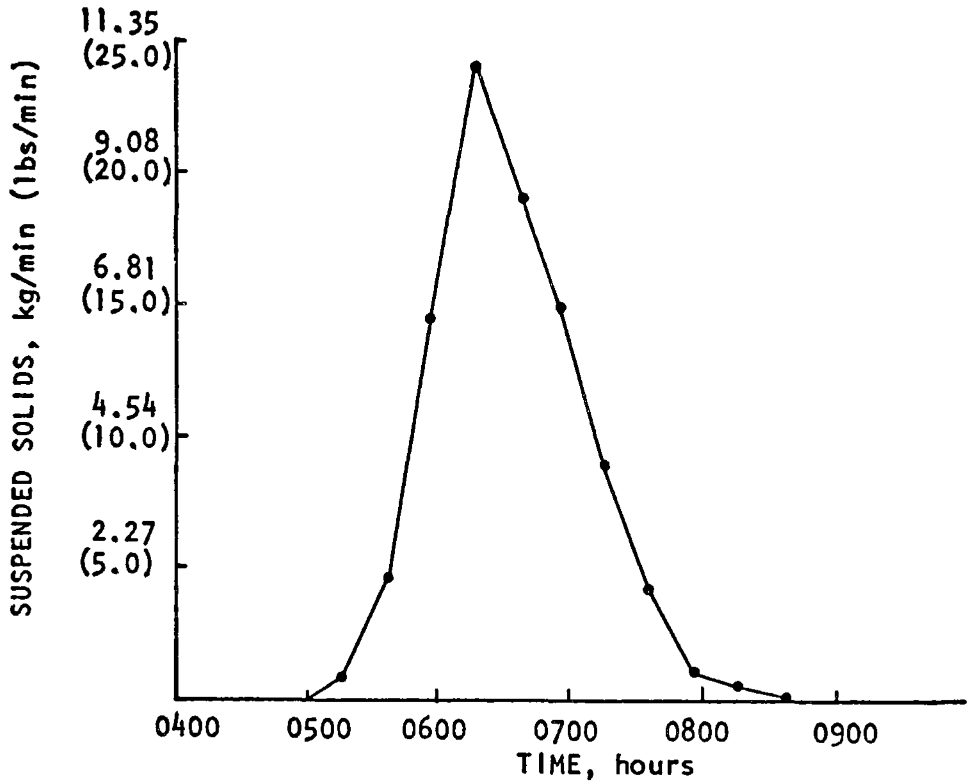


Figure VII-7. Pollutograph

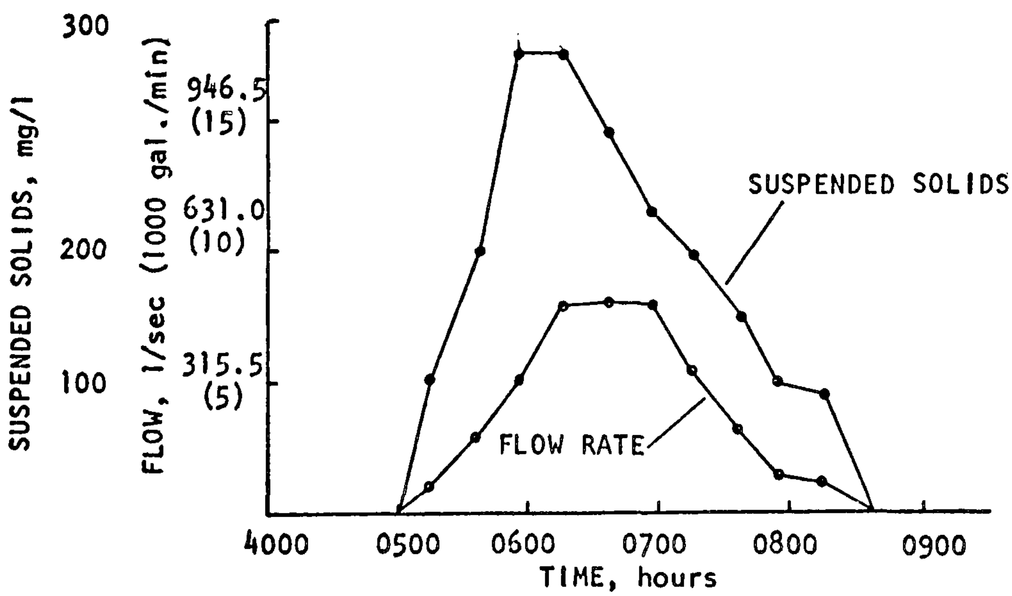


Figure VII-8. Suspended solids and flow variation with time

Synchronization of Hyetographs, Hydrographs & Pollutographs

Stormwater studies and operational facilities require data input from numerous raingages, flow measuring devices and automatic samplers. Although it is extremely difficult to synchronize timing of these devices it is often vitally important to the success of a project that this control be exerted.

Experience in Racine, Wisconsin has indicated that a significant effort must be exerted to assure that data collection is synchronized. The Racine project involved the following monitoring equipment:

A. Three - remote recording raingages (hand wound clock).

B. Three - remote Honeywell Automatic Water Quality Data Acquisition Systems (continuous chart recorder).

C. Three - remote Sigmamotor sequential samplers (electrically operated timers).

D. Two - inplant Parshall flumes and two overflow weir liquid level recorders (electrically operated chart recorders).

E. Eight - inplant sequential samplers (electrically operated timers).

In spite of almost daily checking of chart speeds and time verifications, electrical failures and other mechanical/electrical malfunctions caused significant problems with data synchronization. The following suggestions may be useful in minimizing the problems of data synchronization:

1. Perform daily checks on all clocks, recorders, and charts for time accuracy.

2. Where feasible use event recorders to document activities at remote sites, i.e. event recorders can be utilized to document sampling events on remote samplers.

3. Utilize multiple recorders for inplant monitoring to minimize the possibility that charts are recording at different speeds.

4. Verify chart times and mark the actual time on the chart. Adjust chart position if necessary.

5. Utilize lights or buzzer alarms to notify personnel in event of power failures.

6. Where real time data logging from remote sites is contemplated, provide system power checks to insure that the monitoring station is on line and monitoring the proper data.

Even with these safeguards in practice it will be necessary to constantly alert operating personnel to the importance of instrument synchronization in order to assure accurate results.

EVALUATION OF STORM GENERATED DISCHARGES

Storm generated discharges are now recognized as having a deleterious impact on the surface waters of the United States. The problem is complex and not easily comprehendible. The uncertainty and unpredictable nature of these discharges presents engineers a most difficult challenge in providing cost effective sysems to control the discharge of pollutants.

Storm flow monitoring and evaluation programs (other than those just studying stormwater characteristics alone) generally fall into one of the following categories:

- Evaluation of impact on receiving water quality
- Facilities design studies
- Process evaluation
- Compliance with regulatory requirements

It is anticipated that monitoring and evaluation programs for each of these four categories will vary substantially. Accordingly a model program has been developed for each category. These model programs reflect the authors' evaluation of the state-of-the-art and should be considered as a guideline for data collection programs. Local conditions may dictate modifications and engineers are urged to seriously evaluate data collection programs before initiating work.

Evaluation of Impact on Receiving Water Quality

It is extremely rare that existing quality data can be used in evaluating the impact of storm generated discharges because receiving water data is generally collected with no regard to the occurrence of storm events. Thus there is generally no way of isolating the effect of the storm.

In order to collect valid information on receiving waters it is almost mandatory that a special monitoring program be established. If data collection is to be used for verifying model predictions it will be necessary to develop a program to yield the necessary data.

It is recommended that unless special circumstances warrant continuous monitoring, the data collection be accomplished manually. It is difficult to staff a project to respond to storm monitoring, however, reviews of the literature as well as the authors' personal experience

4. Does the waste contain toxic materials (heavy metals primarily) that would adversely affect the BOD test and perhaps biological treatment?

5. Does the waste contain a significant amount of high specific gravity solids (sand, etc.) which might adversely affect plant operations? Are special considerations to handle this material warranted?

6. Does the waste contain significant quantities of grease which might adversely affect screening or filtration?

It is important to recognize that storm generated wastewaters are significantly different than dry-weather municipal wastewaters. Engineers are urged to carefully evaluate the characteristics to insure that the selected treatment process will perform as expected. Variations of characteristics within and between cities must be considered when selecting treatment processes. Sampling and analytical procedures must be carefully selected to insure the validity of collected data.

Process Evaluation

Detailed procedures for evaluating treatment processes are included in Section VIII.

Compliance With Regulatory Requirements

At the present time there are no known nationwide standards or requirements for monitoring storm generated discharges or treatment facilities for these wastes. However, it is anticipated that these requirements may be promulgated in the near future. The cost of monitoring will be significant since some areas of the country have as many as 60-70 overflow events per year and in some cases hundreds of overflow points. Should regulations require monitoring of all overflow points, it will be necessary to carefully consider the analysis requirements and the overall feasibility of such action.

Where overflow monitoring is required it is recommended that flow measurement equipment and automatic sampler systems be installed which are capable of providing samples proportional to flow. A single composite sample in many cases will be adequate to insure compliance with regulations. The following parameters should in most cases adequately characterize the discharge.

- TOD
- BOD (including dissolved)
- Total Kjeldahl Nitrogen
- Total Phosphorus
- Fecal Coliform
- Suspended Solids
- pH

indicate that a few thorough and complete water quality surveys are more useful than a year of data which, because of cost, must necessarily be less intense.

Parameters to be monitored during water quality surveys are of course specific to a particular project. It is recommended, however, that the following parameters be given serious consideration in water quality surveys:

BOD_5 - total and dissolved
TOD
Suspended Solids
Total Kjeldahl Nitrogen
NO_3 and NO_2 by NO_2 Method
Total Phosphorus
Fecal Coliform
pH
Settleable Solids - occasionally
Dissolved Oxygen
Temperature (when required by models)

These parameters are viewed as representing a thorough definition of water quality for most situations. The particulate nature of storm generated pollutants does require the careful consideration which this list of parameters provides.

Facilities Design Studies

Studies conducted to develop design information for treatment systems for storm generated discharges must be directed toward the specific problem. Since these studies are directed toward developing suitable unit processes to detain and/or treat potential overflows, sampling and analysis procedures must be selected to yield the data necessary to select suitable treatment processes. Some important points to consider are:

1. If screening is to be employed, discrete suspended solids analyses may be required to determine if solids loading may be the limiting factor for screen design during first flush conditions.

2. What is the dissolved organic concentration and does it change significantly during a storm? Is dissolved organic removal required or can discharge requirements be met with a physical process?

3. Oxygen demand should be measured by methods other than just the BOD_5 test since the literature indicates that the BOD_5 of storm generated discharges is only a fraction of the potential ultimate oxygen demand.

SECTION VIII - METHODS FOR EVALUATION OF STORMWATER TREATMENT PROCESSES

Prevention or reduction of storm generated discharges on a volumetric or constituent basis can be accomplished in a myriad of ways. Included are:

1. Land use planning and city planning to provide balance between pervious and impervious areas.

2. Installation of porous pavement.

3. Allowances for surface storage.

4. Street cleaning programs.

5. Sewer and catchbasin cleaning programs.

6. Street maintenance programs (summer & winter).

7. Use of polymers to increase flow in the sewers or to prevent surcharging.

8. Flushing of sewers.

9. Sewer maintenance and rehabilitation programs to minimize infiltration.

10. Pumping down of sewers in anticipation of a storm event.

11. Separation of sewers.

12. Construction site erosion control.

13. Limiting surface chemical pollutants such as fertilizers, pesticides, herbicides, deicers and toxic compounds (e.g. lead in gasoline).

Each of the above measures is intended to minimize the pollutional aspects of storm runoff and/or combined sewer overflows. These preventative measures are intended for use in dry-weather and as such are not of concern in the evaluation of wet weather control or treatment of wet weather discharges. Only those methods which are used to retain or treat potential storm generated discharges will be considered for evaluation. The reader is referenced to the U.S. EPA report entitled "Urban Stormwater Management and Technology: An Assessment" (1) for a thorough description and application of the following treatment processes and for examples of pilot or prototype installations of the processes.

BRIEF INVENTORY OF CONTROL AND TREATMENT METHODS

In order to develop methods for evaluating treatment processes for storm generated discharges it is first necessary to understand the principle of operation and operating variables associated with each type of system. Listed below are many of the treatment processes studied for storm generated discharge control:

1. Storage

    a. In-line
    b. Off-line (with and without settling)

2. Physical and Physical/Chemical

    a. Coarse screening
    b. Fine screening
    c. Gravity sedimentation
    d. Swirl concentrator
    e. Tube settling
    f. Sedimentation-filtration-adsorption
    g. Screening/high rate filtration
    h. Adsorption-coagulation-tube settling-multi media filtration
    i. Coagulation-tube settling
    j. Series high rate filtration
    k. Screening/dissolved-air flotation

3. Biological

    a. Contact stabilization
    b. Trickling filter
    c. Biological contactors
    d. Lagoons

4. Disinfection

    a. Chlorination
    b. Sodium and calcium hypochlorite
    c. Chlorine dioxide
    d. Ozonation

Following is a general discussion of how these basic categories are usually utilized.

Storage

Two types of storage facilities are generally considered for storm generated discharges. In-line storage is an attempt to utilize existing unused sewer capacity to retain combined sewer flow during wet weather. This is accomplished by controlling the levels in the sewers through a series of dams, gates, or flow restrictions, thereby providing storage by creating backwater.

An extensive monitoring and control system is required to prevent upstream flooding conditions. Depth of flow must be monitored in major trunk sewers in the system and manual overrides of the control system must be maintained. This type of system is best used where the sewer grades in the vicinity of the interceptor are relatively flat and where the interceptor capacity is great. The initial effectiveness of this type of system is limited only by the total unused volume of the sewerage system which is governed by the elevation profile. Once the sewerage system is full and flowing at maximum capacity its effectiveness is limited by the hydraulic characteristics of the sewers, the dry-weather treatment plant capacity and the intensity-duration of the runoff.

The second type of storage facility is "off-line" and includes lagoons, lakelets, reservoirs, underground silos or tanks, underwater bags, deep tunnels, mined labyrinths and conventional rectangular concrete tanks. These devices are used to retain storm generated flows. A general flow diagram for storage facilities is shown in Figure VIII-1. At a specified point in the interceptor a regulating device is set up so that flows in excess of dry-weather treatment plant capacity or in excess of the downstream interceptor capacity are diverted to the storage facility. The diverted flow may be pretreated by screening, a swirl concentrator or other means to remove gross solids and by chlorination to eliminate odors and to disinfect the discharge. Flows in excess of the storage capacity are bypassed either around the facility or through the tank to take advantage of the chlorine contact time and the sedimentation which may occur in the tank. At the end of the overflow condition when flow subsides in the downstream interceptor, the contents of the tanks are bled back to the dry-weather treatment plant or to a separate facility for treatment. Solids retained in the storage tank may be removed at the site or resuspended through the use of mechanical or diffused air mixers and also be bled back to the treatment plant. These facilities are generally designed to accept the maximum hydraulic flow expected at the overflow point. They are limited by the total available storage capacity at the onset of an overflow event.

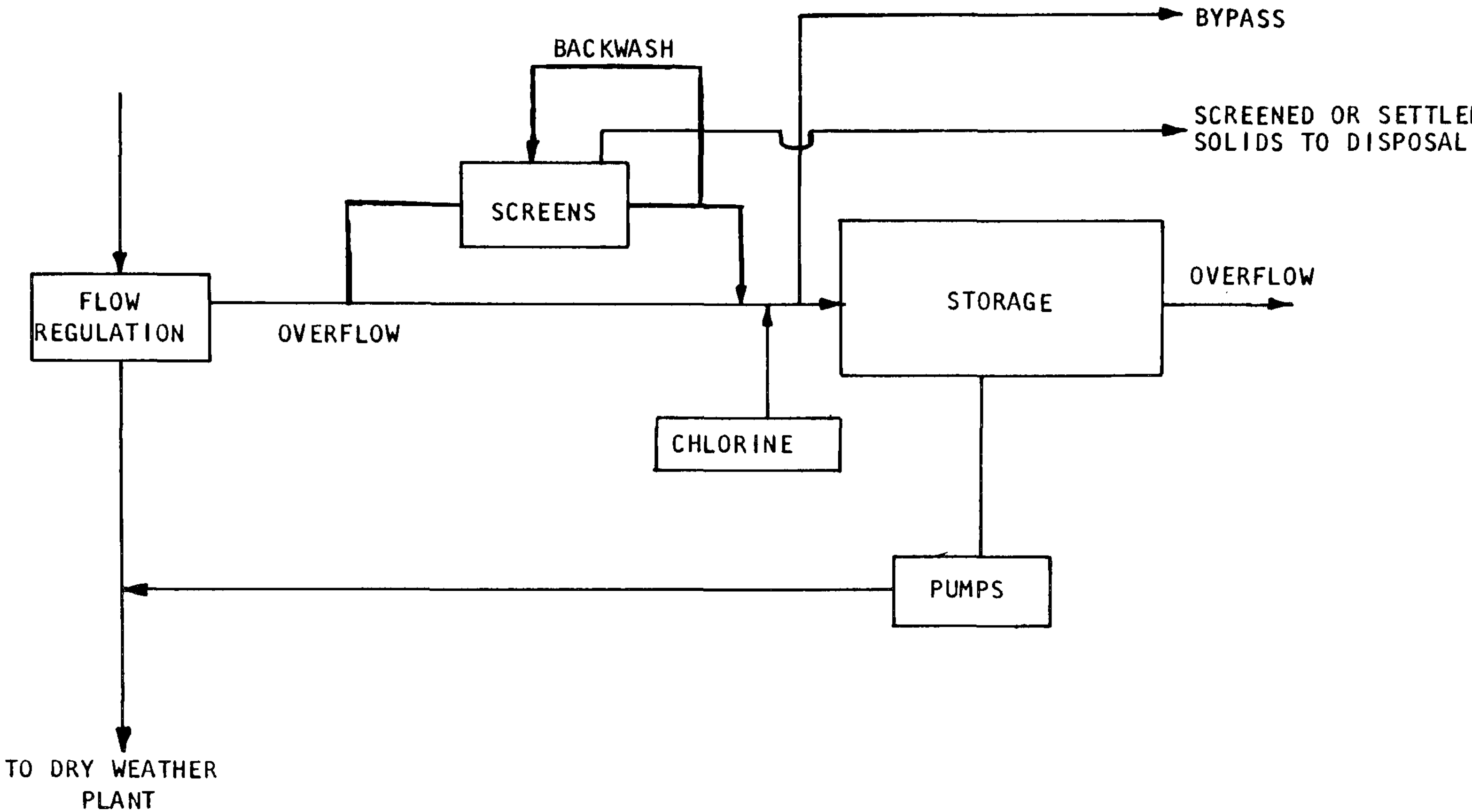


Figure VIII-1. Storage process diagram

The available storage capacity is determined by the rate at which the storage facility can be emptied between storm events. Pumpback or bleed-back rates must be as high as possible to prepare the facility for subsequent storms. However, the pumpback/bleedback rate must be low enough to prevent downstream overflows and to prevent overloading the dry-weather treatment plant either hydraulically or on a solids basis. Pumpback/bleedback rates on existing or planned storage facilities range from 12 hours to 50 days.

Physical and Physical/Chemical

Screening - Screens are used for removal of gross solids and particulate matter from storm generated discharges. Basically, screens operate on the principle that all solids with an effective diameter larger than that of the screen opening will be retained on the screen and removed from the flow. In practice, some solids smaller than the screen openings are also retained because the mat of solids formed on the screen surface acts as a "precoat" and lessens the dimensions of the screen openings. Because of the formation of this solids mat, the screens must be cleaned either mechanically or by use of a backwash system when hydraulic headlosses become excessive.

Screens are classified by the sizes of the openings. Those with relatively large openings are used as pretreatment devices. These include bar screens, coarse screens, and fine screens. Their major use in combined sewer overflow treatment is for the removalof large solids and grit for the protection of downstream equipment.

Types of screens used as the major process for treating storm generated discharges include fine screens, and rotary fine screens. The fine screens and the microscreens are essentially the same device. The only difference is the size of the screen opening. Fine screens have openings that range between 66 and 3323 microns while openings on microscreens range from 15 to 65 microns (1). Screens of this type are relatively simple devices. The screening medium, usually a tightly woven wire mesh, is fitted on the periphery of a drum. The horizontal drum, usually 0.9 to 3 meters (3-10 ft) in diameter and 0.6 to 5 meters (2-15 ft) long (2) (3) (4), rotates continuously at 4 to 7 revolutions per mintue. Wastewater enters one end of the drum and flows radially through the rotating screen. The driving force through the screen is the head between the inside of the screen, and the screened water chamber, generally 0.15 to 0.6 meters (0.5 to 2.0 ft) of water. Seals at each end of the drum prevent the wastewater from escaping around the ends of the drum into the screened water. As the drum rotates, filtered solids trapped on the screen are lifted above the water surface. As they reachthe top of the drum the solids are backwashed from the screen into a sludge trough by high pressure spray jets. Operating variables which may affect efficiency of treatment by screens of this type include mesh size, rotational speed, backwash rate, raw flow rate, suspended solids mass loading rate, and particulate characteristics.

Rotary fine screens are similar to the microscreen in that tightly woven wire mesh fabric fitted around a drum is used to strain the waste. The drum rotates about a vertical axis at high speeds (30 to 65 rpm). The influent introduced into the center of the rotating drum, is directed along horizontal baffles that distribute the flow evenly to the entire surface of the screen. Flow passing through the screen is discharged to the receiving water or routed for further treatment. The reported screen opening sizes ranged from 74 to 230 microns (1). Backwashing to remove the retained solids is done at discrete intervals by high pressure spray jets on both sides of the screen.

Physical-Chemical Treatment - Physical-chemical treatment elements considered for treatment of storm generated discharges include clarification with or without chemicals, filtration and carbon adsorption. These three process units are generally operated in series to obtain the best possible effluent quality. A schematic diagram of this type of system is contained in Figure VIII-2. These processes are well suited to treatment of storm generated discharges because of their adaptability to automatic operation, instantaneous startup and shutdown, and their resistance to shock concentrations or toxic substances.

The bulk of the flotable and settleable solids are removed in the clarification process. With the use of chemical aids such as alum, lime, or ferric chloride, colloidal solids and some dissolved solids may also be removed in this step. The clarifier may be one of many types including gravity settling basins, tube settlers or flotation clarifiers. Following clarification, a filter media is used for polishing the effluent by removal of residual suspended solids. Sand filters which may be used include both gravity filters and pressure filters. Soluble organics remaining after clarification and filtration can then be reduced by activated carbon adsorption in a gravity flow, pressure flow or upflow carbon column.

Effluent quality from a system as described is comparable or possibly better than the effluent from a secondary treatment plant. Efficiency of the system is not subject to varying quality of the influent flow. It is subject, however, to variability in hydraulic flow.

In addition to the multiple unit processes just described, filtration may be used alone to treat storm generated discharges. To obtain the best possible effluent from filtration a multimedia filter is preferred where the diameter of the media decreases with layers (depth) in the filter. This is generally accomplished through the use of coal (anthracite) as the less dense larger diameter particles for the top layer and sand as the more dense smaller diameter particles for the bottom layer. With this type filter, solids capture is distributed through the bed rather than just at the surface. For use on storm generated discharges the filter should be preceded by a fine screening

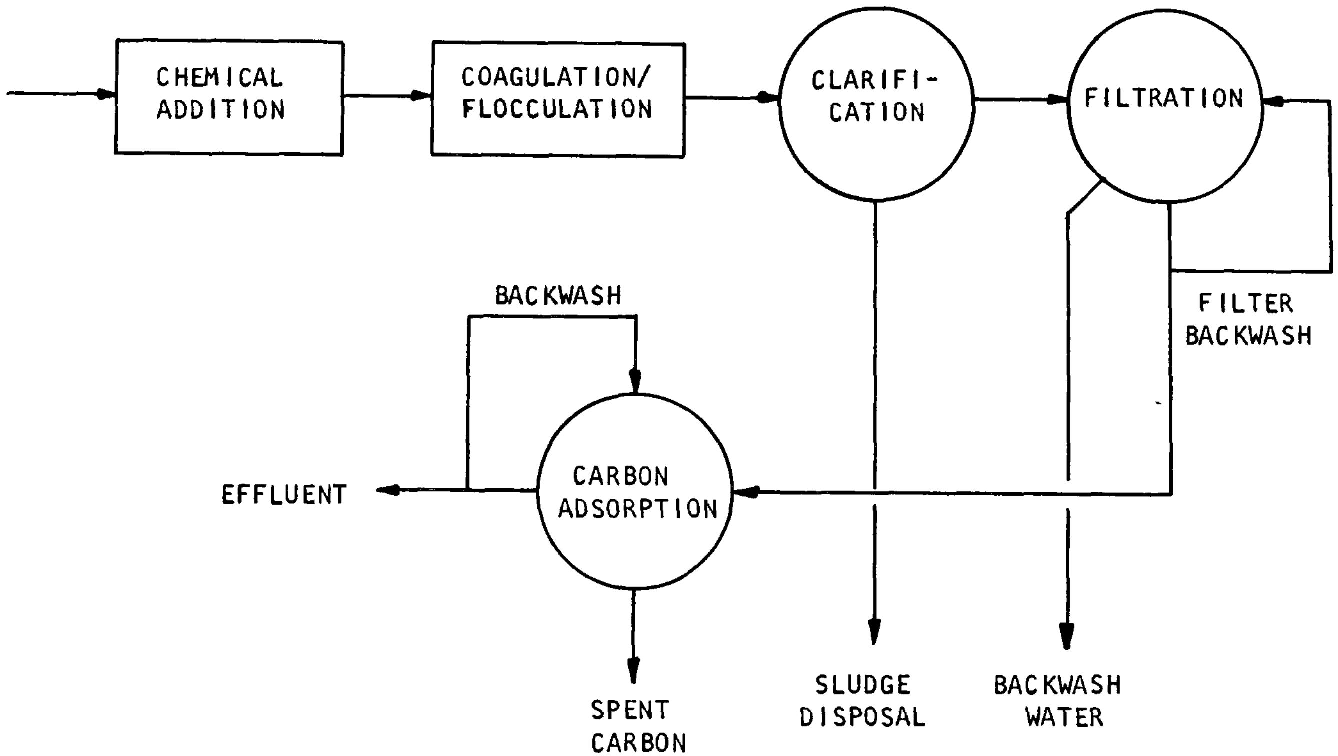


Figure VIII-2. Physical-chemical process diagram device to prolong filter runs. The filter which is operated on a gravity basis should be equipped with a backwash system utilizing air scour to break up mud balls and to redistribute the filter media. The system must also be provided with either storage or treatment for the backwash. The backwash system is initiated when the headloss through the filter bed increases above a predetermined level or when breakthrough occurs.

Dissolved Air Flotation - The process of dissolved air flotation is based on the principle that air is soluble in water proportional to the total pressure of the air in contact with the water. When the pressure on water, saturated with air at an elevated pressure, is suddenly reduced to atmospheric pressure, the dissolved air is released from solution in the form of minute air bubbles. These air bubbles become attached to particulate matter or are enmeshed within a floc structure; the net result being that the bulk density differential between the air-solid structure and the water medium is greater than between the initial solid and water, but in a reverse direction. The solids are allowed to float to the surface of the flotation tank where they are removed by overhead scrapers.

The amount of air introduced into the system is a function of the efficiency of saturation, the amount of flow pressurized and the operating pressure. Pressurization flow with combined sewer overflow is generally from one of two sources. Either a portion of the raw flow is pressurized (split flow) or a portion of the effluent is pressurized (recycle flow). The minimum amount of pressurized flow which is effective is 20% when calculated as the ratio of pressurized flow to unpressurized flow. Most flotation units operate at gage pressures of 2.8 to 4.2 kg/sq cm (40-60 psi). Operating parameters which may affect operation of the units include chemicals used, chemical dosage, percent pressurized flow, surface loading rate (both hydraulic and solids) and operating pressure.

Dissolved air flotation is effective for removals of suspended solids, fine flotables, oils and grease, and, when used with chemicals, colloidal solids. A schematic diagram of the flotation process utilizing split flow pressurization is shown in Figure VIII-3. Screening is usually prerequisite to prevent materials of high specific gravities from settling to the bottom of the flotation tank.

Biological Systems

Biological systems by their very nature must be operated continuously to maintain a viable biomass or be able to borrow the biomass from a system which does operate continuously. For this reason they are generally located at or near existing dry-weather treatment plants.

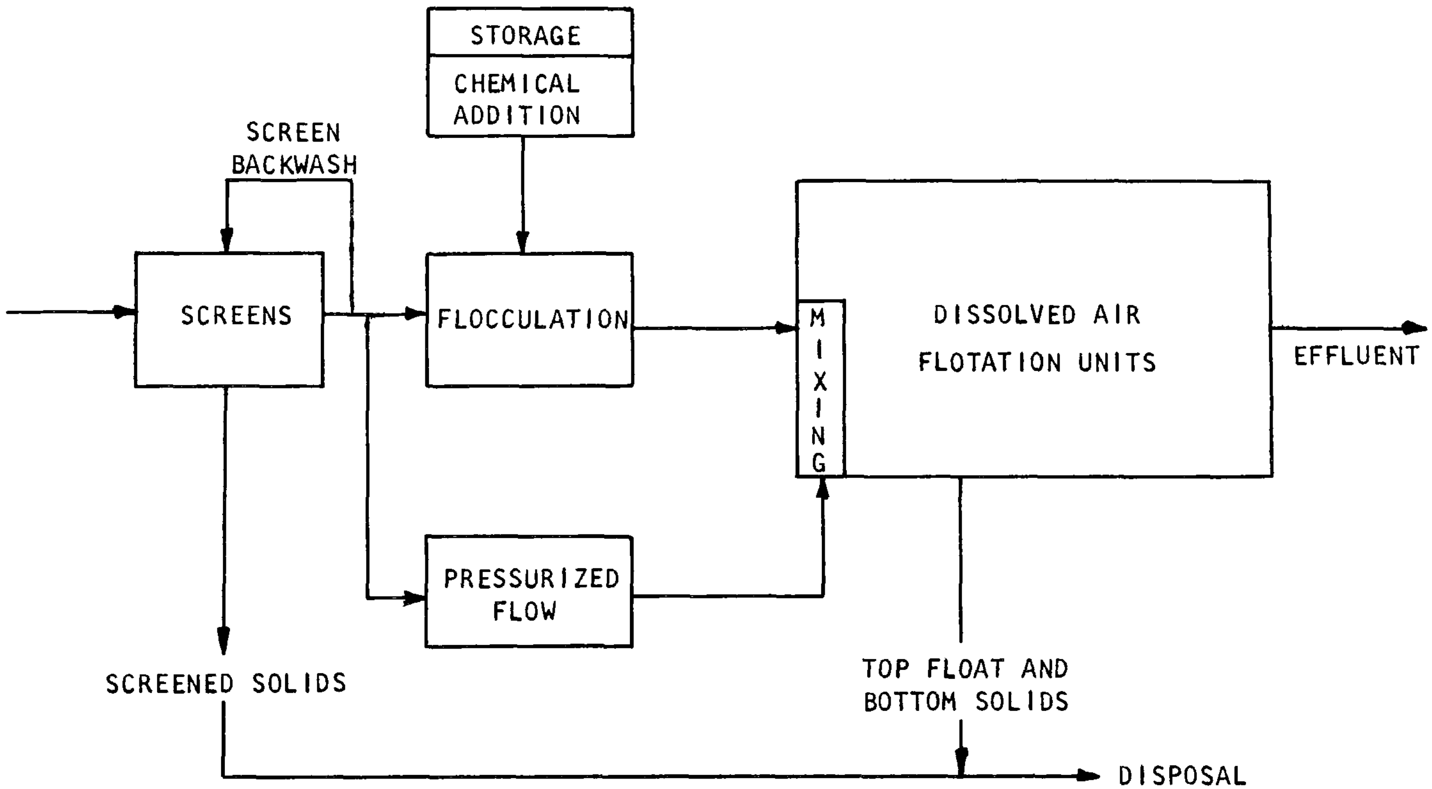


Figure VIII-3. Dissolved air flotation process diagram

Two unit operations are common to all systems - a unit where the waste is contacted with the biological solids for assimilation of the organics and a sedimentation basin for separation of suspended solids, including the biological solids.

Contact Stabilization - A schematic diagram of the contact stabilization process integrated with an existing dry-weather treatment plant is shown in Figure VIII-4. The process basically consists of two aeration chambers and a clarifier. In the first aeration chamber the biomass or aerated return sludge is contacted with the combined sewer overflow to be treated. The particulate organics and a portion of the soluble organics are adsorbed on the biological solids. After a short period of aeration, 15 to 30 minutes, the solids are separated from the liquid in the clarifier. Solids separated in the clarifier are returned to the second aeration tank for reaeration or stabilization. This reaeration time usually lasts from one hour up to many days.

Because this system requires a ready supply of activated sludge, it can only be operated at an existing treatment plant utilizing a biological treatment process. Operating parameters which may affect the efficiency of the process include sludge stabilization time, food to microorganism ratio, contact time, and sludge reaeration time (5).

Trickling Filter - In this process, a biological growth is supported on a stationary medium and the wastewater is distributed over the surface and allowed to flow through the media. Organic matter is absorbed from the waste in this process and converted into new biomass, gases and energy. Portions of this biological growth are constantly sloughed off of the medium by hydraulic scouring. For this reason the discharge from a trickling filter must be settled in a clarifier. For dry-weather operation, a once-through system is generally not sufficient to accomplish the desired levels of removal so most systems are provided with recirculation.

Operating parameters which may affect the efficiency of these units include surface area, recirculation rate and surface loading (both hydraulic and organic).

Rotating Biological Contactors - The operating principle of these units is identical to that of trickling filters. But instead of the biological growth supported on a stationary medium, it is supported on large diameter (3.1 meter [10 ft]), closely spaced rotating discs which are partially submerged (50%) and rotated at low speed in a tank containing the wastewater (6). Excess biological growth sloughs off of the discs and must be separated in a clarifier. Both trickling filter and rotating biological contactors must be in use continuously to maintain a viable biological growth.

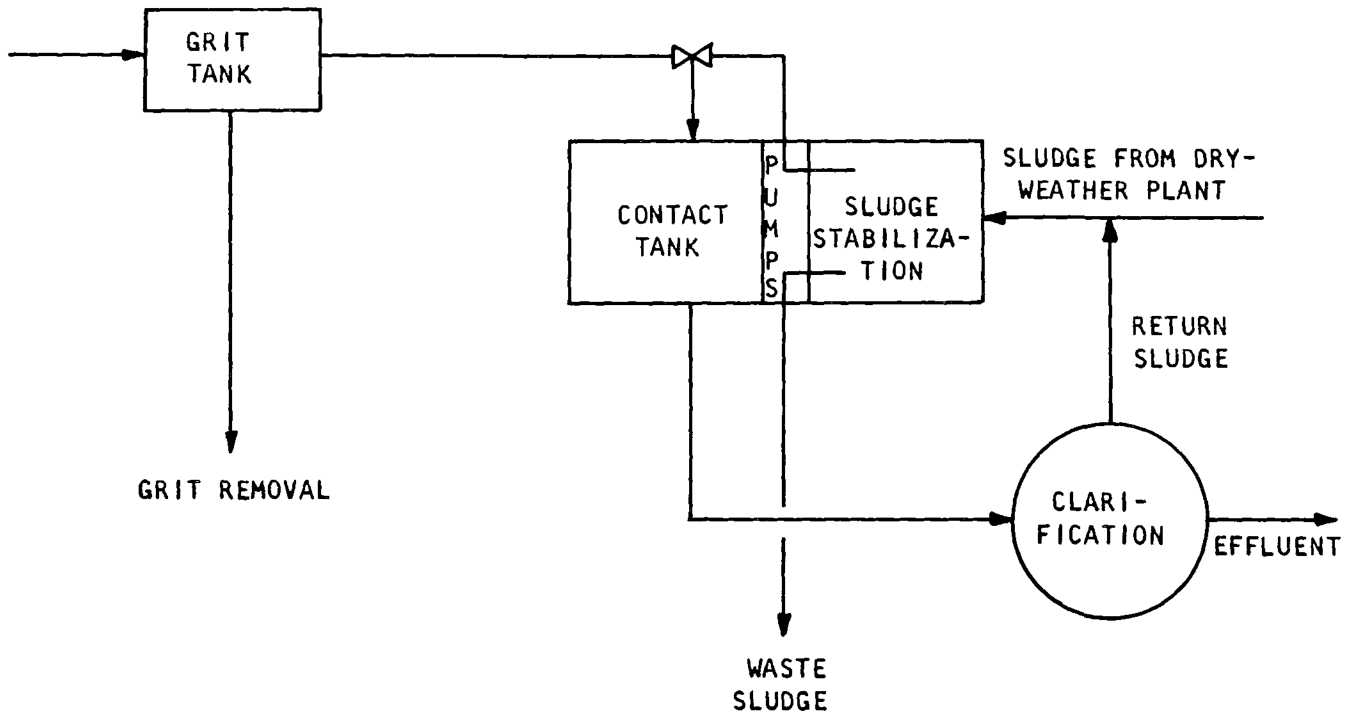


Figure VIII-4. Contact stabilization process diagram

Operation variables which may affect the efficiency of this system include surface area submerged, rotational speed, loading rates (hydraulic and organic) and the number of units in series.

Lagoons - Three types of treatment lagoons have been used for storm discharges and combined sewer overflows. These are oxidation ponds, aerated lagoons and facultative lagoons (1). All are, in effect, biological treatment systems. Oxidation ponds and aerated lagoons are aerobic processes with the difference being the source of oxygen. Oxidation ponds, which are generally very shallow, rely on surface reaeration and algal oxygen production to maintain aerobic conditions for biological degradation of organics. Sedimentation also occurs in the oxidation ponds.

Aerated lagoons, being deeper than oxidation ponds, rely on artificial means to maintain aerobic conditions in addition to surface reaeration. These articifical means may consist of mechanical surface aerators, turbine aerators or diffused air systems.

Facultative ponds are the deepest of the three (or as deep as aerated lagoons) but do not have artificial means of providing oxygen. In this way the ponds are allowed to develop two distinct types of treatment, aerobic near the surface due to algae and surface oxygen transfer, and an anaerobic zone near the bottom sludge deposits.

Generally all types of lagoons require some form of post treatment for removal of suspended solids and/or algae. Loadings to the lagoons are generally reported in terms of g BOD/day/sq m (lb BOD/day/acre).

Disinfection

Almost all storm generated discharge treatment or storage systems provide disinfection of some sort. In addition, the chemical used for disinfection may also be used for odor control. The various types of disinfection involve the use of chlorine gas, sodium or calcium hypochlorite, chlorine dioxide or ozone.

EVALUATION OF TREATMENT PROCESSES

Process Efficiency

Evaluation of a treatment process will depend on whether the treatment system is a prototype installation or a demonstration (pilot) unit. When evaluating a prototype system, the total pollutional reduction at the overflow site must be determined. This includes evaluation of the effluent from the treatment system as well as the bypass around the unit and the discharge at upstream and downstream points. Also included must be the volume and quality of residuals which are pumped back to the dry-weather treatment plant and their possible effect on the efficiency of that plant. When evaluating demonstration or pilot units the efficiency of the treatment process is of specific concern. The purpose of a pilot unit is to determine whether or not the process will work on the particular waste and to optimize the process variables for most efficient operation.

A generalized flow diagram has been developed that is applicable to all storage/treatment schemes. It is shown in Figure VIII-5. Sewage generated during a storm event flows through the combined sewer 1 (all numbers refer to Figure VIII-5) until it reaches a flow regulating device. Flow in excess of that which can be handled hydraulically in the downstream sewer 2 or interceptor is allowed to enter an outfall sewer 3. The storage/treatment system located at this overflow is generally designed to meet some maximum design flow rate or volume. Any flow in excess of the design rate or volume is bypassed through another sewer 4 to the receiving stream. Flow to the treatment system 5 will result in two separate flows; the treated effluent 6 and the residual sludge 7 and/or stored flow 9 which is pumped back to the dry-weather treatment plant after a storm event. Flow which goes to the receiving stream may be combined into a single stream 8 consisting of treated effluent and treatment bypass.

When evaluating a treatment system various types of efficiencies may be determined. These include volumetric efficiency (how much of the total overflow is treated or retained?), overall efficiency (how much of the contaminant(s) is prevented from overflowing to the receiving stream?) and treatment efficiency (what portion of the contaminant(s) is removed in each unit process of the treatment scheme?). Both volumetric efficiency and overall efficiency must take into account all flows bypassing the storage/treatment unit for a study approaching the overall drainage area.

Volumetric efficiency requires only measurement of total flow in the discharge at the outfall 3 and in the bypass 4. It is a measure of the percentage of overflow which has been treated in the facility. A graphical representation of the meaning of the volumetric efficiency is illustrated in Figure VIII-6. The curve is a recording of flow at 3. The shaded portion of the area under the curve (area labeled C) represents the bypass volume (all flow in excess of the design flow rate Q_D) as measured at 4. The ratio of area B to the total area under the curve (B+C) is the volumetric efficiency. Additional valuable information can be obtained from this plot. The various ratios that can be developed and the significance of each is listed in Table VIII-1. These ratios are useful when an evaluation of system design is attempted or when alternatives for improving efficiency are investigated. Among the alternatives which can be studied are, for example:

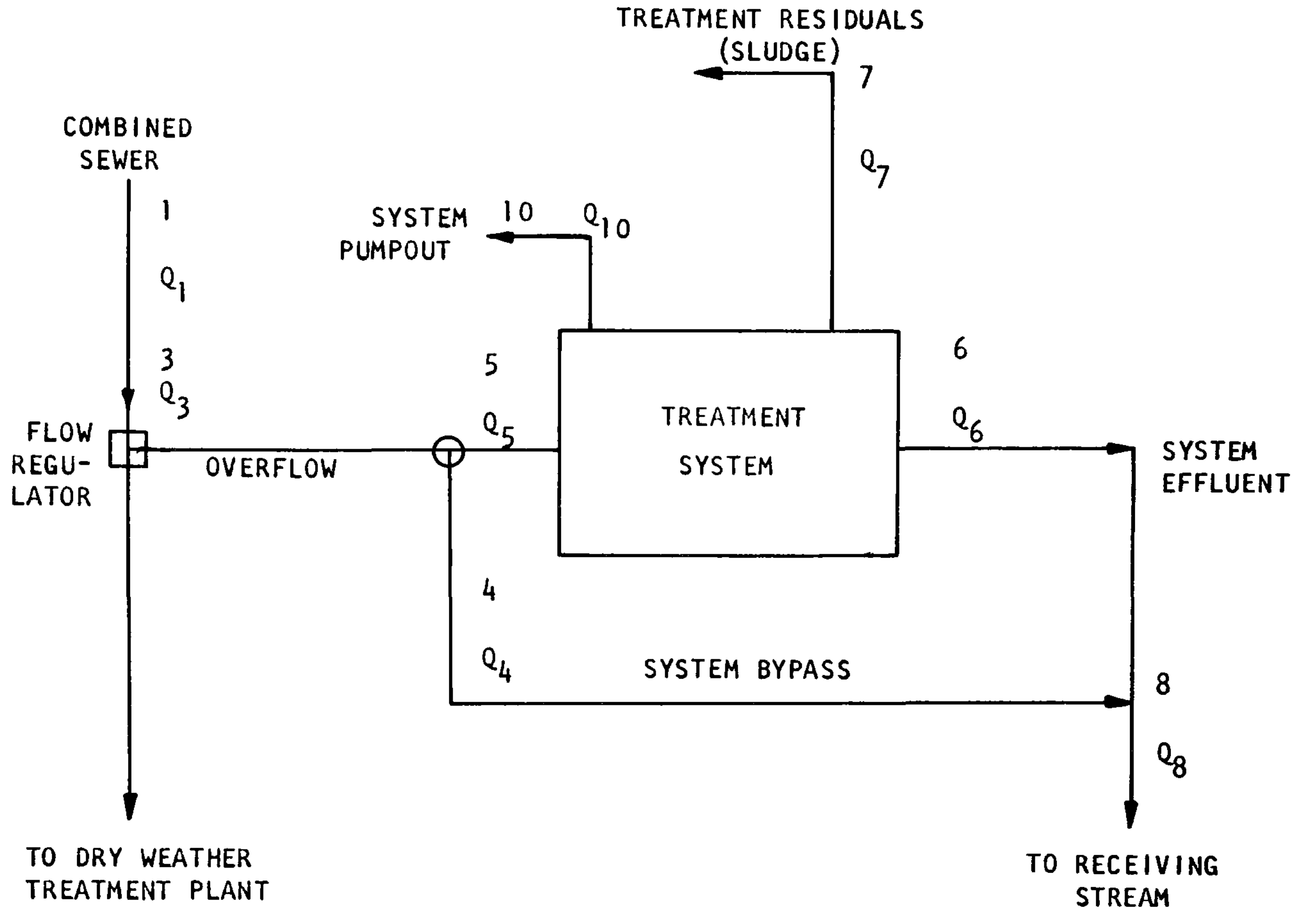


Figure VIII-5. Generalized combined sewer overflow treatment system

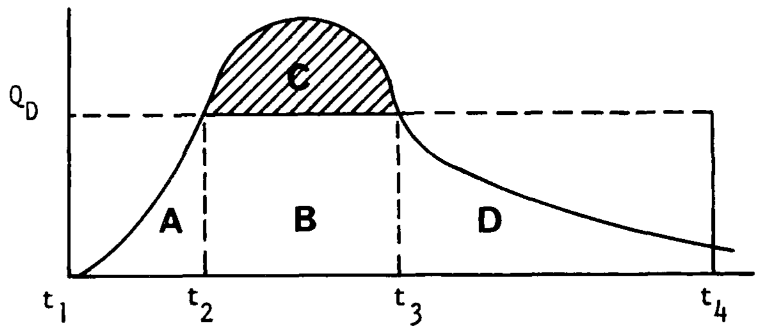


Figure VIII-6. Graphical illustration of a hypothetical flow rate to a treatment system

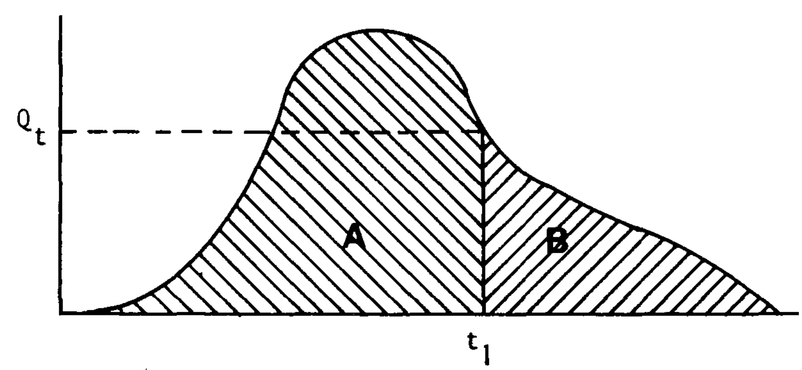


Figure VIII-7. Graphical illustration of a hypothetical flow rate to a storage tank

Table VIII-1. RATIOS DEVELOPED FROM INFORMATION IN FIGURE VIII-6

Ratio		Significance
C	Total volume bypassed	Also equals the storage capacity required to provide treatment for 100% of the overflow
$\frac{C}{B}$	$\frac{\text{bypassed volume}}{\text{treated volume}}$	Ratio of untreated to treated flow
$\frac{C}{B + C}$	$\frac{\text{bypassed volume}}{\text{total overflow}}$	Equals the portion of the total flow which does not receive treatment
$\frac{B}{B + C}$	$\frac{\text{volume treated}}{\text{total overflow}}$	Equals the portion of the total flow which receives treatment
$\frac{B}{A + B + D}$	$\frac{\text{volume treated}}{\text{total capacity}}$	Portion of the amount actually treated to the maximum potential treatment capacity
$\frac{A + D}{A + B + D}$	$\frac{\text{unused capacity}}{\text{total treatment capacity}}$	Portion of capacity unutilized
$\frac{B}{A + D}$	$\frac{\text{volume treated}}{\text{unused capacity}}$	Ratio of used to unused capacity
$\frac{D}{C}$	$\frac{\text{unused capacity after a bypass}}{\text{volume bypassed}}$	Indicates the need or effectiveness of storage and/or flow attenuation
$\frac{t_3 - t_2}{t_4 - t_1}$	$\frac{\text{time of bypass}}{\text{total time of overflow}}$	Portion of time that design flow (Q_D) is surpassed
$\frac{(t_4 - t_3) + (t_2 - t_1)}{t_4 - t_1}$	$\frac{\text{total time without bypass}}{\text{total time of overflow}}$	Portion of time operating at below design rate

1. How much storage capacity is required to provide treatment of 100% of the overflow?

2. What volumetric efficiency can be achieved by the addition of limited storage (in-line or off-line) or by increased treatment capacity?

For storage systems a similar type of volumetric efficiency can be determined utilizing a curve such as that found in Figure VIII-7. To obtain a plot similar to that shown in Figure VIII-7, only one flow recorder is necessary - in the total discharge stream 3. The initial storage capacity available must be known, so that only the flow in excess of this volume is counted as bypass or overflow. The total area under the curve (A+B) represents the total volume of storm generated discharge at the storage site. If the first discharge from the tank or bypass around the tank occurs at t_1, the volume A represents the total amount captured (or the available space at the start of the overflow) and the volume B is the total tank overflow or bypass. Several informative relationships may be obtained from a plot of this type. For example, A/(A+B) is the portion of the total overflow detained by the storage tank. Q_T represents the design rate for any treatment system which must be added for 100% capture and treatment. B represents additional storage capacity needed for 100% storage. Also, if the treatment system is started at the beginning of the discharge the effective storage volume is greater and the required design treatment rate, Q_T, may be less.

The development of a "design" curve such as those found in Figures VIII-6 and VIII-7 is up to the discretion of the design engineer when designing either a new facility or when contemplating expansion of an existing facility. In cases where new facilities are being constructed, empirical methods can be used to develop a design hydrograph. When an existing facility has been in operation the actual operating hydrographs can be utilized, or as in the case of new facilities, an empirical hydrograph can be developed for the desired recurrence interval. The choice of the design storm will be a function of the regulatory constraints and/or available funds and/or receiving water quality objectives.

Another type of efficiency to be considered is the overall efficiency. Unlike volumetric efficiency, which considers only the quantitative data of how much flow was treated or stored, the overall efficiency is concerned with determining the amount of pollutants which are prevented from being discharged to the receiving water. An analysis of this type requires both measurement of the volume and sampling of the various flows. To determine the overall efficiency of the system, a material balance between the point of overflow 3 and the receiving stream 8 is all that is required. No information is required concerning the process parameters or other operating variables of the equipment. This "black box" approach will yield all information necessary to determine operating efficiency for either the individual treatment process or for the entire system.

In order to determine the efficiency of a system it is recommended that samples be taken at constant time intervals and when composited, they may be proportioned either according to the flow rate at the time the sample was taken or according to the volume of flow since the last time the sample was taken. Either of these methods will provide a sufficiently representative sample. A third method of sampling and compositing that is sufficient is to take samples of equal volume at equal intervals of flow volume. However, this type of sampling will be variable. The ideal method of sampling would be to draw a sample continuously, with the flow of sample being proportional to the flow rate. However, an automatic sampler of this type with proven field reliability for storm generated discharge studies, may not be practical to require at this time. A complete discussion of sampling can be found in Section IV and a discussion of compositing methods is contained in Reference 7.

In determining the interval between samples, especially when using automatic samplers, the duration of the average treatment run should be estimated and divided by the number of samples available. For example, if the average run is estimated to be 4 hours and 24 samples are available, the sampling interval will be 10 minutes. For runs that last longer than the average the samples can be removed and replaced with new bottles and the sampler reprogrammed. In the above determination it is assumed that the median run will be less than the average. Also, samples should not be proportioned until after a run is complete, since in the case of short duration runs, a large amount of each sample will have to be taken to provide a composite quantity large enough for analysis.

For compositing done at equal volumes of flow with a variable time interval, the volume interval chosen for taking the sample should be equal to the average total volume treated divided by the number of sample jars available. For example, if the average volume of discharge treated is 18,925 cu m (5 million gal.) and 24 samples are available, one sample would be taken every 788 cu m (0.21 million gal.). In this case again, if it appeared that more than 24 samples would be taken, the sampler could be reprogrammed.

It should be noted that when the process efficiency variability of certain treatment processes, specifically physical-chemical, is to be determined, the constant volume variable time increment sample is recommended. The reasoning for this type of sampling is that with these systems there is a more direct time dependent relationship between the influent and effluent quality than in a biological treatment process for instance. Figure VIII-8 contains hypothetical plots of an influent flow and the resultant quality from a physical or chemical treatment system and from a biological treatment system.

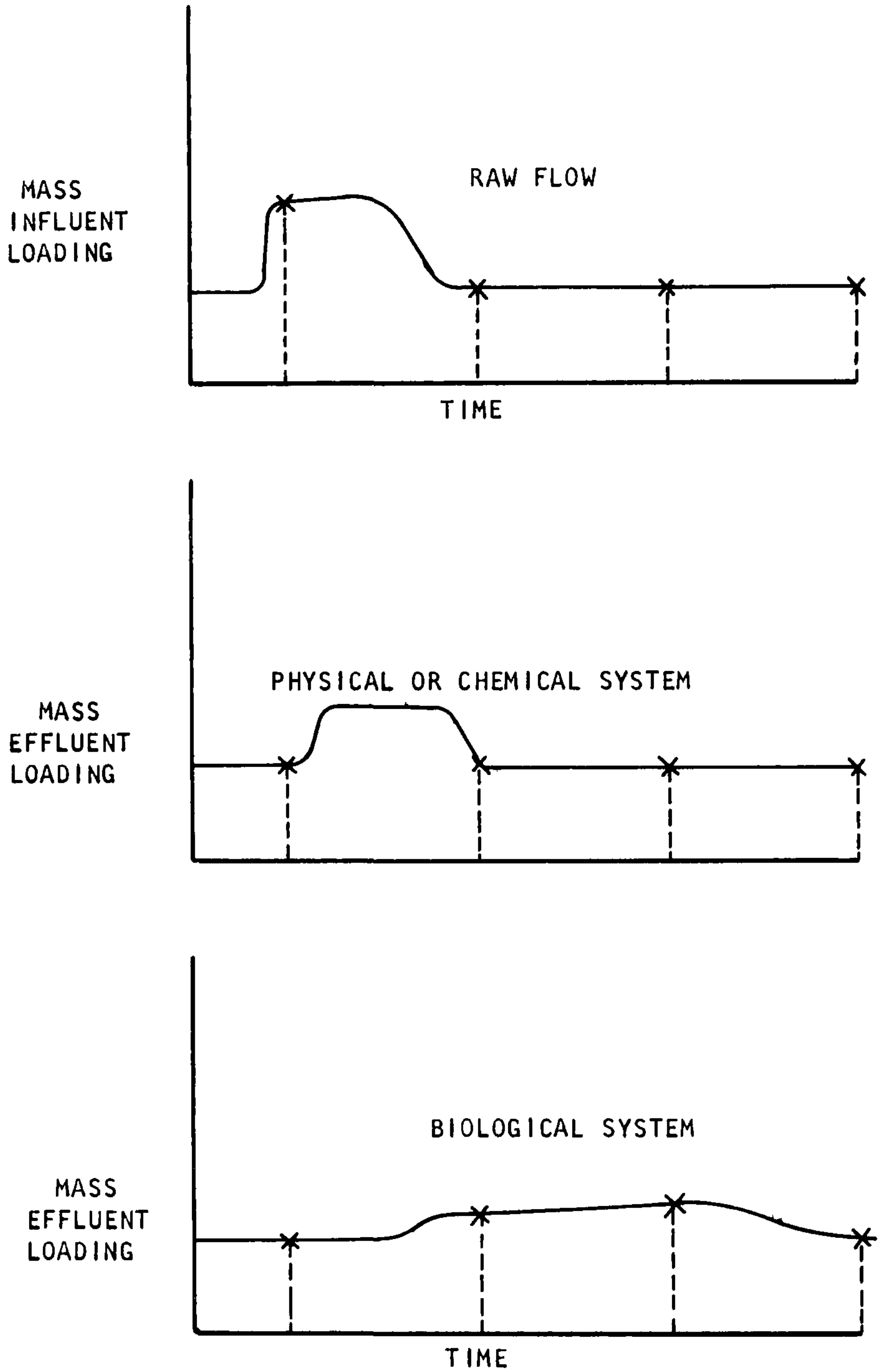


Figure VIII-8. Hypothetical mass loading on two different types of treatment processes and the resultant effluent quality pattern

Although the area under the two effluent curves is identical (same mass in the effluent), the constant time interval sampling will miss the effluent breakthrough from the physical or chemical system, but the biological system with more process mixing and damping effect will show the effects of the poorer effluent quality to a less degree but for a longer period of time. Thus, although both effluents would be of equal quality the physical chemical system would result in samples of higher quality. Therefore, it is recommended that when sampling programs for process efficiency are designed, it is important that a great deal of thought be given to the type of effluent variability that can be expected, and the sampling programs chosen to correspond to these needs.

For almost all types of systems, only two sampling and flow measuring locations are needed. These are at the point of overflow 3 and at the effluent from treatment 6. The flow rate at 4 can be calculated as the difference between the flow rates at 3 and 6, and the quality parameter concentration at 4 will be the same as at 3.

To determine the total mass of a contaminant removed, a single composite of the influent and effluent including bypass is necessary. With this type of sample the determination of overall efficiency is relatively simple for any parameter.

$$E_0 = \frac{V_6 (C_3 - C_6)}{V_3 C_3} \times 100$$

(subscripts refer to Figure VIII-5)

where: E_0 = overall efficiency (%) for a specified parameter

V_3 = total volume of discharge at the overflow point

V_6 = total volume of effluent from treatment

C_3 = parameter concentration at the overflow point

C_6 = parameter concentration in the treatment effluent

Any volumetric or concentration units may be used as long as they are consistent throughout. The overall efficiency can be calculated using the above equation for any parameter. The recommended parameters for study are discussed in Section VI.

The process efficiency for the treatment system alone can be calculated as:

$$E_p = \frac{(C_3 - C_6)}{C_3} \times 100$$

The total loading on the receiving body of water can be simply calculated as follows:

$$L_T = V_6C_6 + (V_3 - V_6)C_3$$

where L_T = total mass loading from a discharge point including treatment effluent and bypass

With the above information, the percent of the total loading due to the bypass alone can be easily calculated.

In many cases analyses using the above equations may be sufficient. However, they do not reflect the variability in overflow constituent parameters and flow rates which are peculiar to storm generated discharges, nor do they show the time dependent variability of treatment efficiency, or shock loadings to the receiving stream. In order to determine this type of efficiency the discrete samples which are collected must be analyzed separately. The overall efficiency can still be determined as follows:

$$E_0 = \frac{(V_6C_3|_{t=t_1} + V_6C_3|_{t=t_2} + \ldots + V_6C_3|_{t=t_n}) - (V_6C_6|_{t=t_1} + V_6C_6|_{t=t_2} + \ldots + V_6C_6|_{t=t_n})}{(V_3C_3|_{t=t_1} + V_3C_3|_{t=t_2} + \ldots + V_3C_3|_{t=t_n})}$$

where $t = t_1$ = the first time increment

$t = t_n$ = the last time increment

However, the main purpose of the discrete analysis is to determine the mass loading on a treatment process, the variance in treatment efficiency as a function of mass loading, and the effluent mass loading to a receiving stream as a function of time. It is recommended that for each time increment that the actual sample be taken in the middle of the time increment. For example, in the above example of efficiency determination the samples are taken at $t_{.5}$, $t_{1.5}$, $t_{2.5}$, etc.

The following is an example of how the above type of analysis can be performed. Hypothetical flow and quality data for one storm event is presented in Table VIII-2. The data is analyzed for a dissolved air flotation unit utilizing split flow, with a surface area of 185 sq m (2,000 sq ft). The samples were taken as described above. The raw data obtained during operation of the unit is contained in columns 1 to 4 of Table VIII-2. A flow diagram is constructed by determining the average flow rate during each time increment, i.e.,

Table VIII-2. HYPOTHETICAL DATA ANALYSIS (DISSOLVED-AIR FLOTATION SYSTEM)

Time increment, No.	Time increment, min	Volume in the increment, cu m	Volume in the increment, (gal.)	Suspended solids, Raw, mg/l	Suspended solids, Effluent, mg/l	Average flow rate, l/sec	Average flow rate, (gpm)	Loading rate, l/min/sq m	Loading rate, (gpm/sq ft)	Loading rate, kg/day/sq m	Loading rate, (lb/day/sq ft)	(Influent) kg/min	(Influent) (lb/min)	(Effluent) kg/min	(Effluent) (lb/min)	Treatment Efficiency, %
1	(0-10)	94.6	(25000)	200	75	158	(2500)	51	(1.2)	14.6	(3.0)	1.9	(4.2)	0.72	(1.6)	62.5
2	(10-20)	302.8	(80000)	500	300	505	(8000)	163	(4.0)	117.1	(24.0)	15.1	(33.4)	9.1	(20.0)	40.0
3	(20-30)	246.0	(65000)	400	250	410	(6500)	132	(3.2)	76.1	(15.6)	9.8	(21.7)	6.2	(13.6)	37.5
4	(30-40)	151.4	(40000)	450	200	252	(4000)	81	(2.0)	52.7	(10.8	6.8	(15.0)	3.0	(6.7)	55.5
5	(40-50)	159.0	(42000)	200	100	265	(4200)	85	(2.1)	24.4	(5.0)	3.2	(7.0)	1.6	(3.5)	50.0
6	(50-60)	132.5	(35000)	150	70	221	(3500)	73	(1.8)	15.6	(3.2)	2.0	(4.4)	0.91	(2.0)	53.7
7	(60-70)	131.6	(30000)	75	50	189	(3000)	61	(1.5)	6.8	(1.4)	0.86	(1.9)	0.54	(1.2)	33.3
8	(70-80)	37.8	(10000)	75	40	63	(1000)	20	(0.5)	2.2	(0.45)	0.29	(0.63)	0.15	(0.33)	46.6
9	(80-90)	30.3	(8000)	75	40	50	(800)	16	(0.4)	1.8	(0.36)	0.23	(0.50)	0.12	(0.27)	46.6

$$\frac{\text{total flow during time increment}}{\text{total time during increment}}$$

These values are shown in Column 5 and plotted in Figure VIII-9.

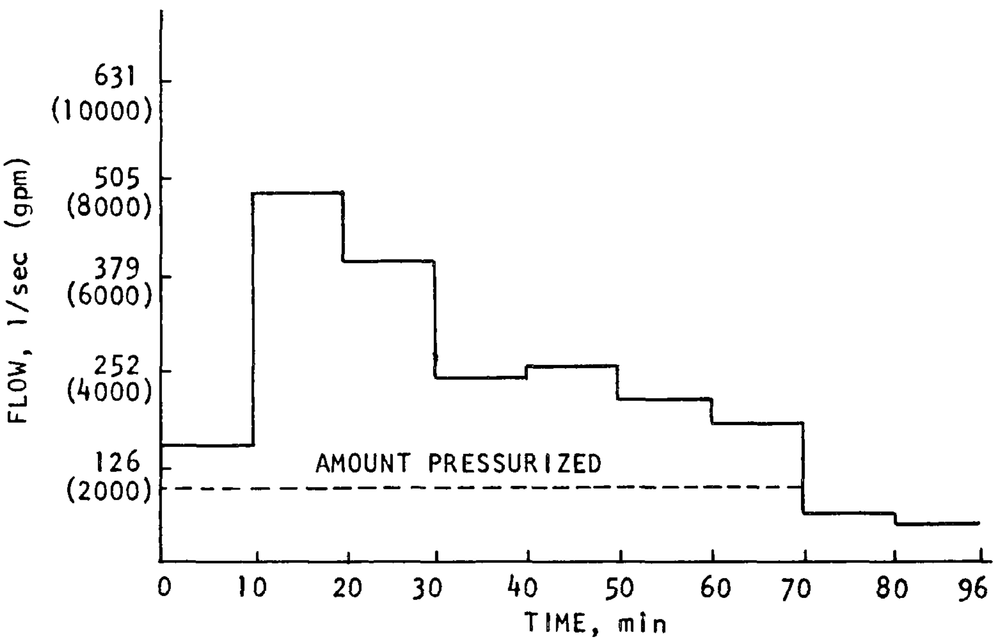


Figure VIII-9. Flow diagram (total flow to a treatment unit)

Loading diagrams for flotation units are calculated on the basis of both flow and solids. The hydraulic loading rate (l/min/sq m [gpm/sq ft]) is based on the flow to the units. A tabulation is presented in column 6, Table VIII-2 and plotted in Figure VIII-10. As can be seen, the shape of this plot is identical to the flow diagram. However, if the percent recycle (ratio of pressurized flow to unpressurized flow x 100) is plotted on the same graph, the varying conditions of operation will be evident. In the example it is assumed that 25% recycle is used based on a design total loading of 163 l/min/sq m (4.0 gpm/sq ft) (101 l/sec [1600 gpm] pressurized, 405 l sec [6400 gpm] unpressurized). With flotation units the quantity pressurized is generally held constant at the design flow (i.e., 101 l/sec in the example).

Solids loading expressed as kg (lbs) of suspended solids per day per sq m (sq ft) of surface area is calculated (column 7) and plotted in Figure VIII-11. Pollutographs, or mass per unit time, can be constructed for flow to the unit and effluent from the unit. The effluent pollutograph

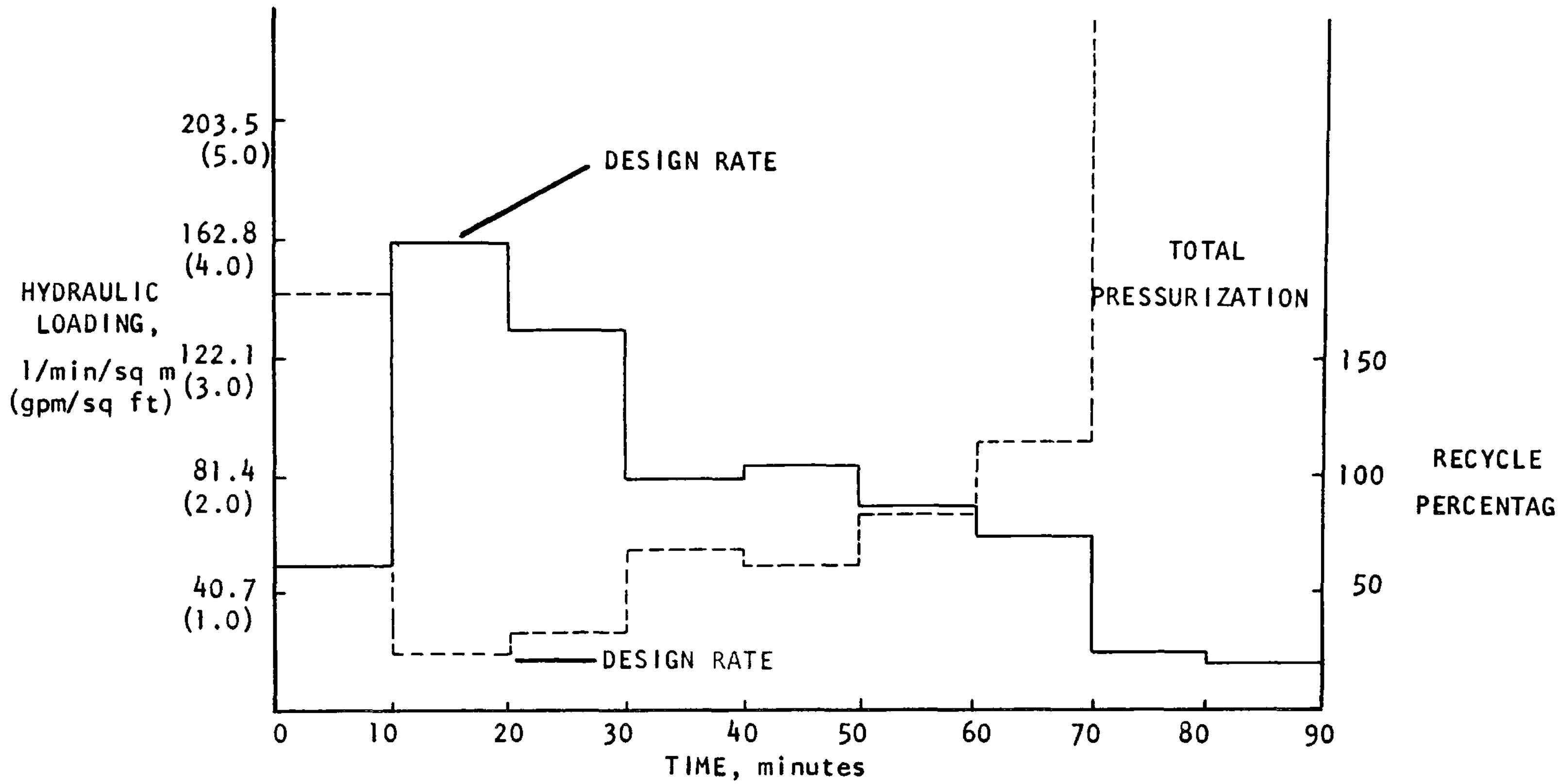


Figure VIII-10. Hydraulic loading rate to a flotation unit (split flow) indicating change in recycle percentage

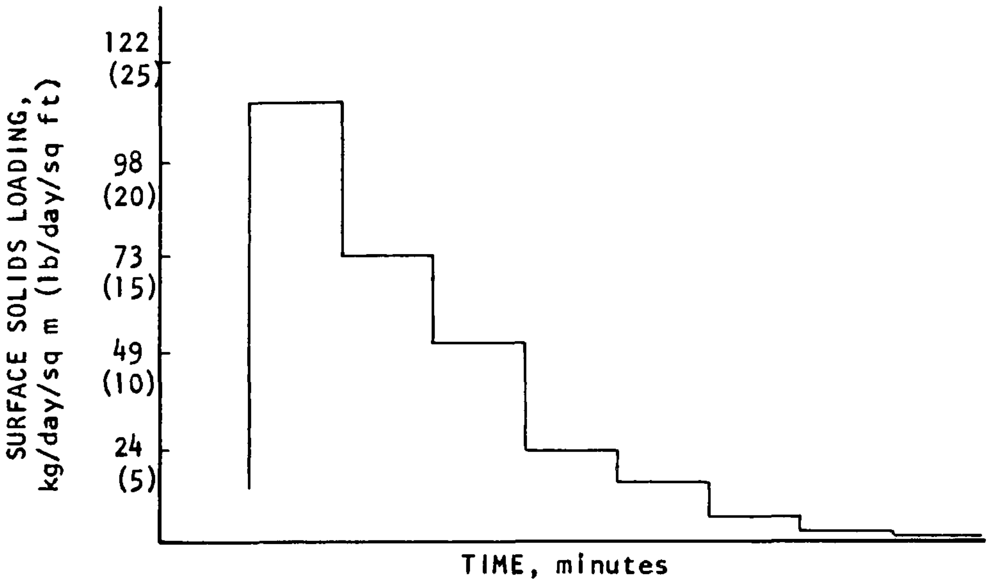


Figure VIII-11. Solids loading as a function of time

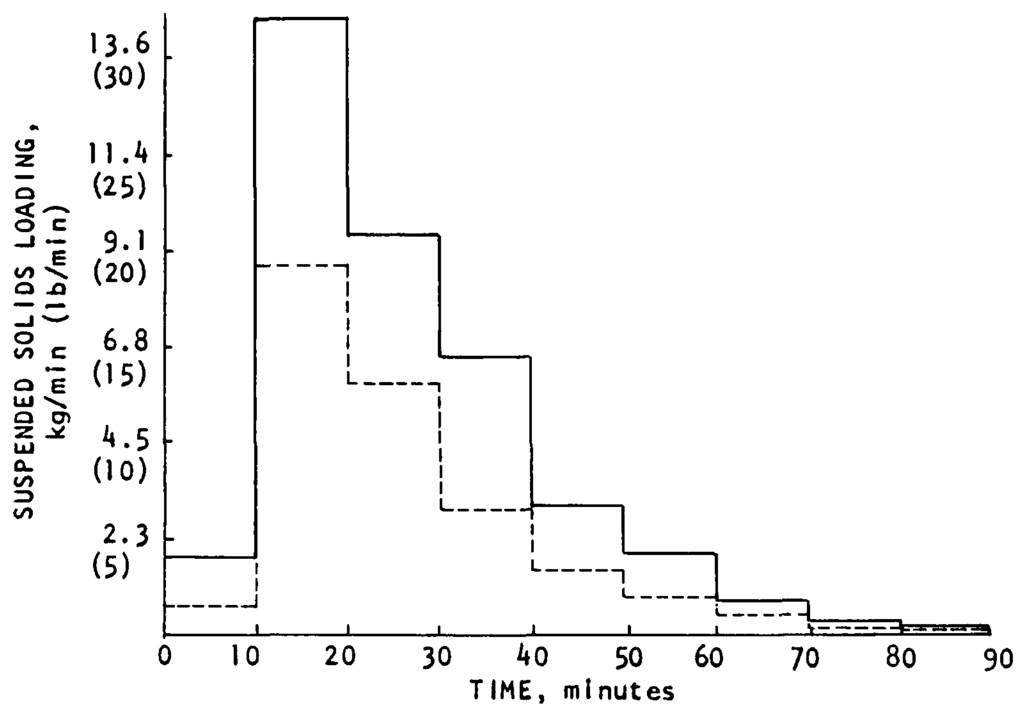


Figure VIII-12. Pollutograph for suspended solids (loading vs time) is the same as the receiving water body loading. The incremental loading for influent and effluent streams are contained in columns 8 and 9 of Table VIII-2 and plotted in Figure VIII-12.

Efficiencies for each time increment are calculated (column 10) and plotted in Figure VIII-13. As can be seen in the plot, the efficiency remains relatively constant over a wide range of operating conditions even though loadings vary significantly.

With plots such as those shown in these examples comparisons of different storm events or different treatment methods are simplified.

The efficiencies described in the preceding discussion should be calculated for each individual storm event (i.e. the volumetric efficiency and the overall treatment efficiency for each constituent). Sufficient storm events should have the samples analyzed separately and the incremental efficiencies calculated to determine the variability of the parameter concentration and effect of treatment at various loading conditions.

The efficiency for an entire year (or longer if possible) of operation should also be determined. This should be expressed as both the average efficiency, and as the weighted efficiency. The average efficiency is the sum of the individual efficiencies divided by the number of values:

$$\text{Average } E_0 = \frac{\sum_{n=1}^{n} E_0}{n}$$

This efficiency can be calculated for both the volumetric efficiency and the treatment efficiency. This value only indicates the average efficiency of a series of runs. It does not indicate the amount removed during the same series of runs because of the differences in volumes treated and differences in concentrations. The weighted efficiency must be used to determine the percentage of the total volume treated or the percentage of each constituent removed on a yearly basis. The weighted average is calculated on both a total volumetric basis and on a total kg (lb) basis.

Volumetric efficiency can be determined using the following relationship.

$$\text{Average Volumetric } E_0 = \frac{\sum_{n=1}^{n} V_6}{\sum_{n=1}^{n} V_3} \times 100$$

where V_6 = total volume to treatment or storage for each overflow event

V_3 = total volume of discharge for each overflow event (subscripts refer to Figure VIII-5)

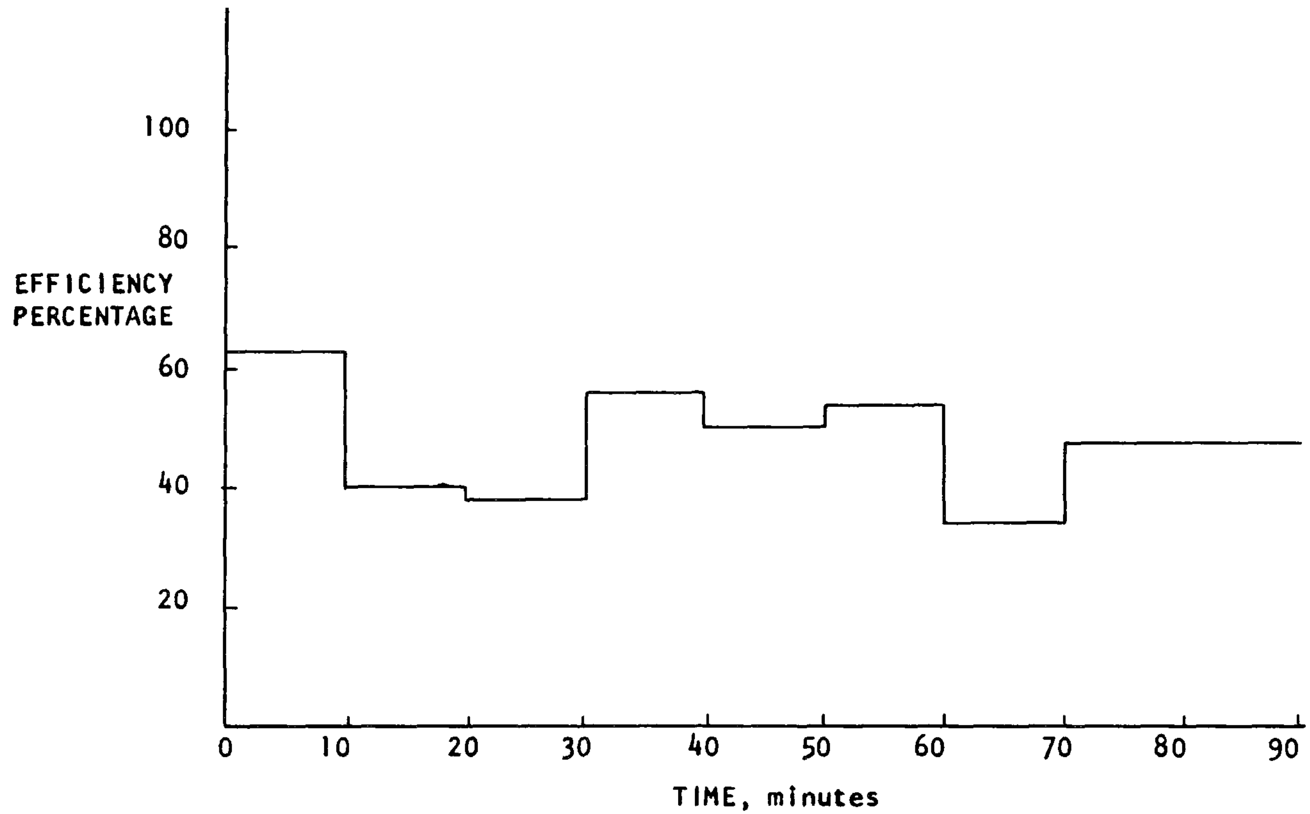


Figure VIII-13. Overall efficiency at each time increment

Similarly, the weighted overall efficiency for each waste constituent is calculated using the following (bypass streams included):

$$\text{Weighted Average } E_0 = \frac{\sum_{n=1}^{n} V_6(C_3-C_6)}{\sum_{n=1}^{n} V_3C_3} \times 100$$

If only the treatment process efficiency is desired the following equation applies:

$$\text{Weighted Average } E_p = \frac{\sum_{n=1}^{n} V_6\ (C_3-C_6)}{\sum_{n=1}^{n} V_6C_3}$$

One aspect of the overall efficiency that has generally been ignored is the additional loading on the dry-weather treatment plant when it receives residuals from the storm flow treatment or storage systems. Off-line storage tanks retain large quantities of the storm generated discharges. During the first flush and possibly during extended overflow events the strength of the retained flow is greater than that of normal sewage. With some storage systems (flow-through types) additional solids are captured by utilizing the tank as a sedimentation basin. Following a storm event when flow in the interceptor has subsided, the retained flows are pumped or bled back to the dry-weather treatment plant.

Unless 100% of the retained contaminants are removed at the treatment plant, they cannot be considered to have been completely removed from the overflow. Because of the strength of the waste to be pumped back and the added load to the solids handling capacity of the treatment plant, the efficiency of the plant may actually be reduced. With a small stormwater installation the effect on a dry-weather treatment plant may be negligible. However, if the storm generated discharge for an entire city, drainage basin or sewerage district is retained, the volumetric and pollutional loading may be significant. The problem may be as severe with the disposal of sludges from stormwater generated treatment systems.

In a well run treatment system it is generally attempted to obtain as concentrated a residual as possible to minimize storage space for the residuals. Unlike many of the pilot unit or demonstration units in existence where the residuals are put right back in the sewer, any full scale system must provide storage for the solids generated or removed. These solids must be treated in one of two ways, either by on-site dewatering and disposal or by pumping or bleeding back to the dry-weather treatment plant. If the latter, the shock load on a treatment plant by a slug of the high concentration waste may cause an upset or decrease efficiency of the plant. Although at the present time there is no simple way to predict or measure the effect of treatment residuals on the operation of a treatment system, both the volume and strength of the residuals must be recorded. Thus, when evaluating a stormwater treatment system, careful attention should be paid to the resultant effect on the existing dry-weather treatment plant.

Application Data

The general purpose of storm flow treatment process projects at the present time is to determine the applicability of various processes to the treatment of these discharges and to determine their effectiveness for removal of pollutants. However, sufficient information should also be provided about the system and its application in one location to enable engineering and economic analyses to be performed for application in a different location. A uniform method of reporting results should be initiated. General information, not necessarily required for determination of process efficiency for each individual project, but essential when trying to determine process applicability to other sites, should be reported. This data includes:

1. Rainfall data
2. Drainage area description
3. Sewerage system data
4. Physical description of the treatment system
5. System operation
6. System costs
7. Sludge handling facilities
8. Dry-weather treatment plant data
9. Combined sewage data (for combined systems only)

The general information required is the same for all types of treatment systems.

Rainfall Data - Each storm event treated should be described. Rainfall intensity and duration in the study area should be reported. Differences in the rainfall history may affect the quality and quantity of discharge. Intensity should be calculated at 5 to 15 minute intervals so that a rainfall hyetograph may be constructed. If more than one raingage is used in the study area the location of the raingages and the method of calculating the complete area rainfall intensity should be stated. From this information and the rainfall duration the average intensity can be calculated. Antecedent rainfall should also be reported (i.e., dry-weather days prior to the event studied). This may also affect the quality of the overflow because of the buildup of solids in the sewerage system. Also, the rate and volume of runoff may be affected by the antecedent rainfall. In summary, the data should include the following information:

1. Rainfall intensity (cm/hr [in./hr] at 5-15 minute intervals).
2. Rainfall hyetograph (see Section VII).
3. Rainfall duration.
4. Average rainfall intensity (cm/hr [in./hr]).
5. Location of raingages.
6. Method of calculating intensity.
7. Antecedent dry-weather days.

This data will be useful in determining whether the rainfall event is typical for the study area and comparable to rainfall patterns in other locations of interest. A complete discussion of rainfall data can be found in Section V.

Drainage Area Description - The type of area contributing to the runoff will affect both the quantity and quality of the storm generated discharge. Data to be reported includes:

1. Total area contributing to wet weather flow (ha [acres]).
2. Topography.
3. Land use and population density.
4. Imperviousness.
5. Runoff coefficient.
6. Specific curb length (m/ha [ft/acre])

Sewerage System Data - The physical size and characteristics of the sewerage system can affect the amount and characteristics of the discharges. In a combined sewer the characteristics of the overflow will be dependent to some extent on the time of day that the overflow occurs because of the diurnal variation of both the dry-weather flow and sewage constituents. The diurnal variation in the sewer may take on more significance when consideration is given to the pumpback of stored flow or treatment residuals. Information which should be reported includes:

1. Physical size of the main trunk and interceptor sewers.
2. Design flow capacity.
3. Number of discharge points in the contributing area.
4. Type of flow regulating device.
5. Type of discharge conduits.
6. Dry-weather flow variation (for combined systems only) and infiltration etc.
7. Dry-weather sewage constituent variation (for combined systems only).

Physical Description of the Treatment System - A complete description of the treatment and/or storage system should be reported. For many applications the physical size of the system may be a determining factor for selection. The following information should be included:

1. A plan view of the system.
2. Physical dimensions of each piece of equipment and tanks.
3. A list of all appurtenant equipment.
4. Design hydraulic and constituent loading rate for each piece of equipment.
5. Chemical feed rate and storage capacity.
6. Total land requirements.
7. Laboratory equipment requirements at the site.
8. Description of flow measurement and recording equipment.
9. Description of sampling equipment and sampling points.
10. Description of provision for sludge storage and/or handling.

System Operation - Information to be reported for system operation is of two types. General information including schematic diagrams, process and instrumentation diagrams, and maintenance programs is the first type. Specific information on each individual type of system is the second. The former is summarized below and the latter is described for each type of treatment system later in this section.

The complexity of the system operation will become evident with the following information.

1. Schematic diagram of the system.
2. A process and instrumentation diagram.
3. A narrative description of the system operating including controls.
4. Startup and shutdown procedures.
5. Maintenance schedule.
6. Description of sampling procedures.
7. List of sample analyses and methods.

System Costs - A complete breakdown of system costs, as installed, should be included. The capital and construction cost breakdown should include individual costs for the following.

1. Engineering costs.
2. Land.
3. Site preparation.
4. Purchased equipment (pumps, mixers, etc.).
5. Installation and erection.
6. Concrete.
7. Piping.
8. Electrical

9. Instrumentation and controls.
10. Building including utilities.

This list may not be all-inclusive for every type of system. Other capital costs required to render the system operational should also be reported. These costs are reported at the total dollar cost, including extras and any escalation clause costs, at the time of construction completion, and dated such. For example, if a bid were accepted at a cost of 1.0 million dollars on January 1, 1975 and construction was completed on January 1, 1976 at a cost of 1.1 million dollars, the later date and costs would be used. For true comparison of capital costs the dollar value must be adjusted for present worth. This can only be done by using one of the cost indices. The Construction Cost Index of Engineering News Record is recommended for use.

Annaul expenditures costs are much more difficult to report on the same basis for comparative purposes. The annual costs consist of some charges which are expended whether or not the system operates (amortization of capital costs, routine maintenance, insurance, etc.), some are dependent upon the duration of operation (labor and power), some are dependent upon the rate of treatment or loading to the units (chemicals and power), and some are dependent upon the number of times that the system operated (laboratory analysis, residual handling, system cleanup, data analysis). Each of these categories should be reported separately and their basis explained. Actual costs experienced for the treatment/storage system and a theoretical basis for comparative purposes should both be reported.

For the actual annual costs the following information and bases should be supplied on a yearly basis.

1. The number of storm events during which operation occurred.
2. The total volume stored or treated during the year and the pounds of the appropriate contaminants removed.
3. Amortization costs and the basis for their calculation (percentage rate and length of payment).
4. Insurance cost.
5. Total number of man-hours expended and the pay scale for
    a. routine maintenance
    b. operation of the system
6. Total chemical cost including the type of chemical, chemical dosage and cost of chemicals per unit weight.
7. Total power cost including the kw-hr used and cost/kw-hr.
8. Cost for laboratory analyses and data analyses.
9. Cost of residual handling at the treatment/storage site, (i.e. hauling cost or pumping cost).
10. Actual sludge dewatering and disposal cost at the dry-weather facilities based on the prevailing cost for dry-weather sludge cost/ton of solids.

The total annual operating cost calculated using the sum of the above individual costs should be reported for each year of operation. These costs divided by the total treated flow with the appropriate conversion factors will yield an actual cost on a volumetric basis such as ¢/cu m (¢/1000 gal.).

Costs reported in the above manner are not suitable for comparative purposes because of the many possible variations. For example, with the same system, equal volumes of storm flow may be treated in two consecutive years. However, this same total volume may be generated by 10 storm events in one year and 40 storm events the next year. Identical monies will be expended in both years for amortization, insurance and chemicals. However, labor costs for operation and routine maintenance, power costs, laboratory costs, data analysis costs and sludge handling costs may be four times greater the second year.

Another example which shows the possible variations would be treating the same number of storm events but with the total volume treated the second year being 4 times as great as the first year. In this example amortization, insurance, labor, laboratory analyses, data analyses and power cost may be the same with only chemical costs and sludge handling costs different. The cost per cubic meter (1000 gal.) treated would approach only one fourth the cost the second year.

In order to compare total annual costs for different systems or for the same system at different locations, the method of reporting these costs must be standardized.

The following method which standardizes all of these variables is proposed for reporting annual costs. Many assumptions must be made. These include the following:

1. Fifty discharge events occur per calendar year at one week intervals.
2. Flow rate to the systems is 50% of design flow for systems operating at variable flow rates (due to excess capacity at the onset and near the end of a discharge).
3. The duration of each discharge is six hours.
4. Amortization rate is 7.5% for 25 years.
5. The insurance rate is 1% of the capital equipment cost.
6. Labor costs are $12.00/man-hour including overhead and supervision for all labor and classifications. Between operation maintenance and associated materials must also be estimated.
7. Power cost is $0.03/kw-hr.
8. Chemical cost is a truck load rate not including delivery.
9. Sludge handling cost at the dry-weather facility at 2.5¢/cu m (10¢/1000 gal.).

Total annual costs calculated on the above basis can be used for comparisons when computed as cost/cu m (/1000 gal).

Other cost ratios which should be reported includes the following:

1. Capital cost expressed as $/cu m/day ($/mgd).
2. Operation and maintenance costs for both the actual and theoretical cases, expressed as $/kg ($/lb) of constituent removed, and $/storm event.

Sludge Handling Facilities - A description of all facilities for handling residuals from the treatment or storage of stormwater runoff should be provided. If none are used, such as with a pilot plant where residuals are routed back to the sewer during operation, a discussion of possible methods for treatment with a complete analysis of the sludges should be given. If possible, bench scale tests for sludge treatment methods should be performed. The description of sludge handling facilities should include the following:

1. Description of the physical equipment (size, volume, etc.).
2. Procedure for operation or schedule for pumpback.
3. Complete analysis of the sludge generated.
4. Volume generated as a percentage of the treated flow.
5. Method for ultimate disposal of the residuals.
6. Source of the residuals.

Dry-Weather Treatment Plant Data - Information concerning the design capacity and diurnal flow variation to the dry-weather treatment plant is necessary for design of storage facilities for combined sewage or treatment residuals from storm flow treatment. Efficiency of the dry-weather plant may be affected by the volume or pollutional aspects of the pumpback rate. Any decrease in dry-weather plant treatment capacity efficiency must be attributed to the pumpback if excessive. The data required is:

1. Design capacity.
2. Diurnal flow variation.
3. Diurnal constituent parameter variation.
4. Efficiency of treatment.
5. Solids handling capacity.
6. Estimate of effects of pumpback on treatment efficiency.

Combined Sewage or Urban Runoff Data - Flow of combined sewage to the treatment system should be recorded for instantaneous rate and totalized. In addition to the flow through the treatment system samples taken at constant time intervals and composited, for both raw discharge and treatment effluent, should be analyzed. In addition, frequent discrete samples should be obtained on selected storm events to characterize the overflow on a time basis.

Specific Information for Each Type of Treatment System

In addition to the general information to be reported for all types of systems, each type of system has operating parameters that affect efficiency of the units. With most demonstration or pilot units these equipment variables are closely regulated to determine the optimum operating conditions and to determine efficiency at the various operating conditions. When reporting results of operation of these units all pertinent information must be generated. The following items discuss the minimum amount of information to be reported and the method of reporting such for each type of system.

In-Line Storage - None of the methods previously discussed for measuring efficiency are applicable for this type of system. The effectiveness of in-line storage is measured by the difference between potential overflow and actual overflow. The important parameter that should be measured or calculated is the total storage capacity before installation of the control devices and the total storage capacity after installation. The amount of pollutants captured is determined by the composite quality of the flow in the sewers.

Flow measurement is also an important parameter to determine for this type of system. The difference between normal dry-weather flow and the flow to the dry-weather plant during and following storm events represents the total amount of stormwater captured. Both of these flows should be measured. The total amount of overflow from all discharge points in the network should be measured and sampled to determine the total flow and constituents to the receiving stream. The time it takes to restore the sewers back to dry-weather flow conditions should also be reported.

In summary the specific information that should be reported for in-line storage systems includes:

1. Total storage capacity for wet-weather flow before and after installation of the system.
2. Flow measurement of,
    a. Dry-weather flow
    b. Wet-weather flow to the dry-weather plant.
3. Composite samples of each overflow should be obtained.
4. Record of sewer recovery to dry-weather conditions.
5. Annual operating results.

Off-Line Storage - In addition to evaluation of each individual storm event (both volumetric and constituent parameter efficiency) a running account of available storage capacity should be maintained as well as a record of the pumpback. The records should be kept over an entire overflow season. The logic behind this type of record is that with a storage system the frequency of rainfall will affect the volumetric efficiency. Two rainfalls occurring at close intervals will, in all likelihood, yield a lesser efficiency because of the available storage space than the same two rainfall events at a longer interval. The pumpback or dewatering rate will affect efficiency in the former case. Pumpback or dewatering procedures must be described fully.

If chemicals are used to aid settling in the storage tank or for disinfection, the chemical injection points and methods of proportioning chemicals should be described.

Bar Screens or Coarse Screens - Because this equipment is used only for pretreatment and the materials captured are generally not included in analyses of the overflow (rags, leaves, paper, etc.) only the general data plus the total volume captured (cu m [ft^3]) need be reported. The method and cost of disposal of the captured material should be reported.

Screens (other types) - In the description of the physical equipment the following information regarding screens should be provided.

1. Mesh size.
2. Size of openings.
3. Wire diameter.
4. Type of backing material.
5. Total open area of the screen (as % of screen area).
6. Material of construction.
7. Screen diameter and length.
8. Submergence.

The method of cleaning the screens during operation and for maintenance should be reported to include the following information:

1. Type of backwash system.
2. Type of spray nozzles.
3. Source of backwash water.
4. Backwash rate in l/sec (gpm) and l/sec/m (gpm/ft).
5. Method of backwash system activation if not continuous.
6. Method and frequency of cleaning to maintain integrity.

During operation of the screen the following data and information should be reported.

1. Hydraulic and solids loading with respect to time on selected runs.
2. Operating variables including:
   a. Screen submergence
   b. Screen rotation rate
   c. Backwash frequency
   d. Backwash rate
   e. Headloss
3. Total sludge volume produced and its concentration.
4. Volumetric and constituent parameter efficiency.

Physical-Chemical Treatment - Each element in the processes described require specific information to be reported.

Clarification - The type of clarifier used will determine the information to be reported. For a flotation separator report the same information as listed in the following section on dissolved air flotation.

With a gravity clarifier, report the following:

1. Design overflow rate.
2. Design surface loading rate.
3. Type of mechanism used for removal of floated scum (grease & oil) and settled sludge.
4. Provisions for handling or storing the residual sludges.
5. Sludge volume and concentration.
6. Variability in loading rates during operation.
7. Volumetric and constituent parameter efficiency.
8. Chemicals and dosages if used.

If tube settlers are used information to be reported includes all of the above plus the following:

1. Tube configuration and dimensions.
2. Material of construction.

Filtration - The filter and all operating parameters should be described fully. This includes:

1. The type of filter - pressure or gravity.
2. Type of filter media and depths of the various media.
3. Size or gradation of filter media.
4. Bulk density and particle size.
5. Design loading rates (hydraulic and solids).
6. Source of backwash water and type of backwash system.
7. Backwash rate and frequency.

8. Disposition of backwash water.
9. Constituent parameter efficiency.

Carbon adsorption - The following specific information should be reported.

1. Type of system utilized - upflow, downflow, gravity or pressure, parallel or series.
2. Type of activated carbon used.
3. Particle size and variation.
4. Design rate (hydraulic and constituent).
5. Exhaustion rate.
6. Backwash rate if required and disposition and source of backwash waters.
7. Provisions for carbon regeneration or disposal.
8. Constituent efficiency.

Each of these individual elements should be analyzed for:

1. Actual loading rates as a function of time.
2. Total residual solids.

Dissolved Air Flotation - In addition to determination of efficiencies the following information and data should be reported:

1. Design overflow rate (l/min/sq m [gpm/sq ft]) based on unpressurized flow and on total flow.
2. Design surface loading rate (g/day/sq m [lb/day/sq ft]).
3. Method of pressurization.
4. Degree of saturation (% saturation).
5. Operating pressure.
6. Source of pressurized flow (i.e. total pressurization, split flow or recycle).
7. Design pressurized flow rate expressed as the ratio of pressurized flow to unpressurized flow.
8. Data to be acquired:
    a. Actual overflow rates and solids loading rate as a function of time.
    b. Total residual sludge volume and concentration.
    c. Chemicals used and their dosage.

Contact Stabilization - Both volumetric and overall efficiencies should be reported for this type of biological system. In addition, the following information and data should be reported:

1. Sludge age at the start of treatment.
2. Sludge return rate and transfer rate.
3. Contact time (as a function of time).
4. Reaeration time (as a function of time).
5. Sludge concentration in reaeration tank.
6. Mixed liquor concentration.
7. Aeration rate (cu m/min [cfm]).
8. Hydraulic and solids loading rate to the final clarifier as a function of time.
9. Total amount of solids produced and added to the dry-weather system.
10. Description of the dry-weather treatment plant associated with the storm generated discharge system.

Trickling Filter - For this type of biological system specific information about the equipment and operation should include the following:

1. Type of filtering media and material and total volume of media.
2. Void space (5) and total surface area (sq m/cu m [sq ft/cu ft]).
3. Type of distribution mechanism.
4. Depth of filter.
5. Design loading rate (hydraulic and organic loading rate) based on once-through and based on recirculation (if used).
6. Actual loading rate as a function of time (once through and with recirculation).
7. Design recirculation rate.
8. Dry-weather operation to maintain biological growth.
9. Description of the dry-weather treatment plant associated with the storm generated discharge system.

Because a clarifier must be used in conjunction which a trickling filter to remove the sludge sloughed off of the filter all variables previously reported for the clarifier in a physical-chemical system must also be reported for this system.

Biological Contactors - In addition to a physical description of the system, the following information should be reported.

1. The number and diameter of the discs and their materials of construction.
2. Total surface area of the disc and surface area submerged.
3. Rotational speed.
4. Number of modules in series or in parallel.
5. Design loading rates.
6. Actual loading rates (hydraulic and constituent parameter) as a function of time.
7. Dry-weather operation to maintain a viable system including loading rates.

As with other biological systems, a clarifier is an integral part of the system and all variables associated with the operation of a clarifier must be reported.

Lagoons - Lagoons are similar in operation to storage tanks except for on-site treatment by aeration or oxidation. Stored flow is generally not pumped back to a dry-weather treatment plant but to a receiving stream. For this type of system, only the efficiencies need to be reported plus the quantity, concentration and final disposition of residual sludges. This is in addition to the general information.

Disinfection - Specific information to be reported when disinfection is used should include:

1. The specific type of disinfectant used, its strength and the method of addition.
2. Type of device used to provide contact time.
3. Design and actual contact time.
4. If chlorine is used, the chlorine residual in the effluent.
5. If ozone is used, describe completely the ozone generation equipment (air or oxygen feed gas) and cost per unit of ozone generated ($/kg [$/lb] or kw-hr/kg[kw-hr/lb]).

ECONOMIC DECISION MAKING CONSIDERATIONS

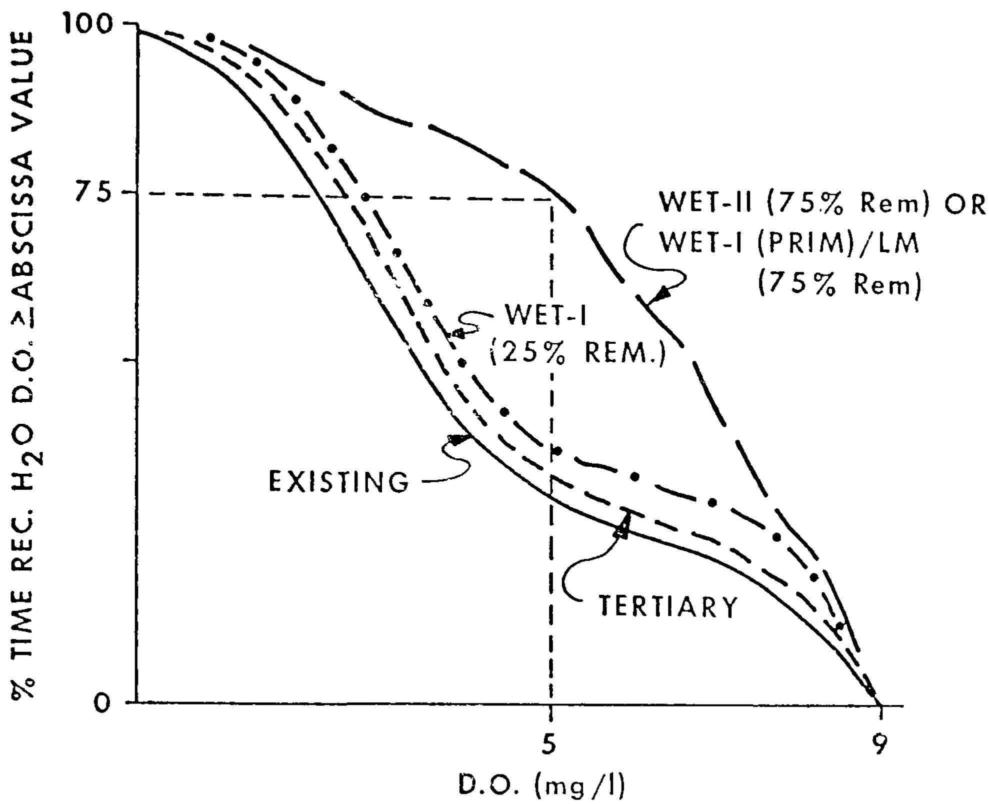
It is becoming increasingly apparent that the problems of discharges resulting from rainfall events will be solved on individual bases rather than by all encompassing effluent guidelines. In other words, the solutions rendered will be determined by a combination of desired receiving water quality and allowable economic investments. Thus, each situation will require an in-depth determination of what impact the present storm generated discharges have on the receiving waters and just what the change in water quality would be for various degrees of storm generated discharge abatement. This type of approach has become the obvious as a result of various surveys and needs studies which have shown the cost of implementing complete storm generated discharge abatement to be an order of magnitude greater in cost than any other water pollution control abatement undertaking.

It is also imperative that any study concerning storm generated discharges take into account other sources of water pollution affecting the receiving body of water, most notably the discharge from the existing municipal and industrial sewage treatment plants. A solution methodology must be employed which will show the most cost-effective means of improving water quality. This methodology must take into consideration the receiving water impact and must be site specific looking at tertiary dry-weather treatment versus wet weather flow treatment, structural solution and non-structural solutions, the possibility of integrated dry-weather and wet-weather systems, the possibility of integrating flood and erosion control technology with pollution control technology and the integration of land management and non-structural techniques.

In order to optimize the above type of analyses, it will probably be necessary to use computerized techniques, especially for assessing the water quality impact. Just as important is that the critical or limiting parameters which affect the water quality be identified and the long term quality of the receiving water be estimated.

A hypothetical example of this type of approach is presented in Figure VIII-14. These curves represent the percentage of time the receiving water D.O. level is greater than or equal to a D.O. level on the abscissa. They should represent at least one year's continuous flow of data. This case is for D.O., but actual studies would use the parameter or parameters found to be the most critical in that particular case. By this analysis we can make true cost-effectiveness comparisons based on the total of receiving water impacts and associated abatement costs.

For example, if we desire 5 mg/l D.O. in the receiving water 75% of the time as a standard, then we need to go to an advanced form of wet-weather treatment or primary wet-weather treatment integrated with land management. The latter is most effective at 3 million dollars in cost. This or similar methodologies can help set cost-effective standards as well as select alternatives.



CONTROL ALTERNATIVES	% BOD REMOVAL		COST ($\$\times10^6$)
	DRY WEATHER	WET WEATHER	
EXISTING	85	0	–
TERTIARY	95	0	6
WET-I (PRIMARY)	85	25	1
WET-II (ADV)	85	75	6
WET-I/LAND MGMT.	85	75	3

Figure VIII-14. Hypothetical example of the economic solution methodology approach

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SECTION X - GLOSSARY

APWA - American Public Works Association

ASTM - American Society for Testing and Materials

ATP - Adenosine tri-phosphate

Average Efficiency - The mean value of percent removals achieved by a treatment facility for a series of events.

Bleedback - Dewatering a storage facility by means of gravity drainage to a sewerage system.

BOD - Unless otherwise noted, this refers to the standard five day Biochemical Oxygen Demand test.

BOD_x - This refers to a Biochemical Oxygen Demand test with an incubation time of x days.

COD - Unless otherwise noted, this refers to the standard Chemical Oxygen Demand test.

Composite Sample - Consists of more than one, and usually a number of samples which have been mixed together for analytical purposes.

CSO - Combined Sewer Overflow - any discharge from a combined sewer, usually associated with the addition of stormwater to the combined sewer system.

DAF - Dissolved Air Flotation

Dewater - The removal of a stored amount of a storm or combined sewer discharge from a storage facility to further treatment or ultimate disposal.

Dry-Weather Flow - That flow in sanitary or combined sewers that contains no stormwater.

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FC - Fecal Coliform

First Flush - A term used to describe the early portion of a storm or combined sewer discharge which oftentimes has a significantly greater contaminant concentration than the remainder of the discharge.

FS - Fecal Streptococci

Grab Sample - This is a single simple sample taken at any particular instant and analyzed by itself. A number of grab samples, either taken randomly or according to a programmed schedule can be mixed together to form a composite sample.

Hyetograph - A graph plotting rainfall intensities during various time increments versus time.

MF - Membrane Filter

MPN - Most Probable Number

PCB - Polychlorinated Biphenyls

Pilot System - A facility used for testing a process on a scale much smaller than would actually be required. Subject to scale-up errors.

Pollutograph - A graph plotting pollutional loading in mass per unit time versus time or pollutional concentration per unit time.

Prototype - A facility used for testing a process either at full scale or at a scale such that no scale-up errors would be expected if full scale application were to follow.

Pumpback - Dewatering a storage facility using pumps.

Storm Generated Discharge - Any discharge from a storm or combined sewer resulting from a precipitation event.

Stormwater - The water resulting from a precipitation event which may stay on the land surface, percolate into the ground, run off into a body of water, enter a storm sewer, enter a combined sewer, infiltrate a sanitary sewer, or evaporate.

Stormwater Runoff - That stormwater flowing overland.

Storm Sewer Discharge - The discharge from a storm sewer resulting from stormwater runoff entering the storm sewer system.

SWMM - Abbreviation for the EPA Stormwater Management Model.

TC - Total Coliform

TOC - Total Organic Carbon

TOD - Total Oxygen Demand

Weighted Efficiency - An expression of the percent removal achieved by a treatment facility for a series of events determined by the total mass removal divided by the total mass treated from all the events.

Wet-Weather Flow - The flow in sanitary or combined sewers that contains some stormwater.

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16. ABSTRACT

This report contains recommendations for standard precedures to be followed in the conduct of projects dealing with pollution assessment and abatement of storm generated discharges. The purpose of this project was to develop standard procedures needed to insure that all discharges and treatment processes could be evaluated by the same means. The procedures chosen were those found to be the most applicable and optimum for the field of storm and combined sewer overflow pollution control.

The project efforts were devoted to the major areas listed below.

1. Recommended methods for sampling and sample preservation.
2. Appropriate monitoring instrumentation available.
3. The choice of quality parameters to be utilized.
4. The analytical procedures to be followed.
5. The methods for evaluating storm generated discharge pollution.
6. The standard procedures for evaluating treatment processes treating storm generated flows.

Choice of the recommended procedures was based upon the U.S. EPA research and demonstration project reports in this and associated fields, other published literature, ongoing U.S. EPA funded projects, and the contractor's experience in the field of stormwater pollution control.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Water Pollution, Sewage Treatment, Surface Water Runoff, Sewage, Contaminants, Water Quality, Cost Analysis, Storm Sewers, Overflows--Sewers, Combined Sewers, Hydrology, Chemical Analysis, Water Chemistry, Bacteriology, Sampling, Samplers, Precipitation (Meteorology)--Hydrology	Water Pollution Control/ Treatment, Combined Sewer Overflow, Storm Sewer Discharges, Treatment Process Evaluation, Sample Preservation, Laboratory Procedures, Precipitation Monitoring	13B

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