# A PRACTICAL GUIDE TO WATER QUALITY STUDIES OF STREAMS

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

CWR-5

# A PRACTICAL GUIDE TO WATER QUALITY STUDIES OF STREAMS

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# ACKNOWLEDGEMENTS

THE writing of this small book has been an enlightening but humbling experience. I started with the firm faith that my many years in this business of stream pollution control had given me all the knowledge needed to do the job by myself. I never have been more badly mistaken.

When I started to explain the why of some of the things I knew, I learned that I had no logical explanations. There were other things I thought I knew which I learned I did not know at all. And finally, most embarrassing of all, I learned that some of my most cherished bits of knowledge simply were all wrong.

How did I learn these things? By being fortunate enough to be a member of the National Field Investigations Center, Division of Technical Support, Federal Water Pollution Control Administration, which has examined water quality in streams from border to border and coast to coast of this Nation. I have drawn heavily on the Center staff's experience and expertise, which have been freely given. I will not say that this book would not have been possible without their help. But I say sincerely that it would have been much less complete and far less factual and reliable than I now believe it to be.

Especial acknowledgments are due some, but sincere thanks are due all who have been so generous in their help. A. D. Sidio has long been insistent that I attempt this job and has consistently supported me in my efforts. K. M. Mackenthun has advised me not only on aquatic biology, but also, with his experience as author of several books, on authorship. A. W. West provided the "handy-dandy" calculation factors in the Appendix. C. E. Runas has assisted in the selection and preparation of illustrations. These others, below, have been consulted on their specialties or have reviewed and commented on the manuscript, or both. To avoid any indication of partiality, I am listing them alphabetically.

J. E. ARDEN, Engineer
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C. R. HIRTH, Chemist
L. E. KEUP, Biologist
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J. P. LONGTIN, Physicist
C. N. SHADIX, Chemist
N. A. THOMAS, Biologist
L. A. VAN DEN BERG, Engineer

I have talked to so many that I may have overlooked some. If so, my apology will have to be a poor substitute for my expressed gratitude to them.

Thus, what started out to be one man's opinion has ended as a group's cooperative project. But regardless of that, responsibility for the contents to follow is mine.

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# PREFACE

A 769-page volume has been evolved over the years to direct the chemist, the bacteriologist, and the biologist in the analysis and examination of water samples. "Standard Methods for Examination of Water and Wastewater"[1] is intended to ensure maximum accuracy and reproducibility of laboratory results. The individual who has had occasion to examine data obtained from samples split between two or more laboratories sometimes wonders whether that objective has been attained. Such failures probably can be blamed more on the rugged individualism of laboratory personnel generally than on any inherent inadequacy of "Standard Methods." In fact, its use is accepted, and rightly so, as an integral of any proper study of stream pollution. No report on a polluted stream is complete without the statement "Laboratory procedures were in accordance with 'Standard Methods for the Examination of Water and Wastewater'."*

It is axiomatic that no analytical result is any better than the sample from which it was obtained. Yet there is no tome comparable to "Standard Methods" to guide the individual who supervises a stream pollution study in obtaining samples that represent stream conditions. Those without experience in such studies must rely almost entirely on their logic, ingenuity, and intuition. All too often the neophyte's supply of these traits does not prove to be equal to the task and failure follows. The capabilities of even the experienced investigator in this field frequently are taxed to the limit in resolving some puzzling feature of the complex reactions and interactions of pollution in a stream.

It is said that woman is fickle and unpredictable.[2] Any man who has lived with both is hard put to decide which is more fickle and unpredictable—a woman or a stream. For a stream also is a living and capricious being, and its quality at any given point is constantly changing. Unless controlled, stream flow is rarely constant. As flow changes, dilution and mixing of wastes, depth, currents, velocity, turbulence, reaeration, and time-of-water travel vary. Temperature, with its effects on solubility of gases and on rates and types of chemical and biological reactions, changes from day to night and with the seasons. Light, an important factor in biological reactions, varies with cloudiness, with turbidity of water, from day to night, and from season to season. Few changes can be more abrupt than those caused by a sudden "gulley-washing" thunderstorm. Not only does stream flow increase, with all of its accompanying changes, but the runoff

* The Federal Water Pollution Control Administration is in the process of selecting or developing its own official standard methods for all of its laboratories. At this time it still relies very heavily on procedures in "Standard Methods."

brings to the stream large quantities of various materials, often with drastic results. The diurnal variations in sewage characteristics are well known and industrial wastes may vary with process changes even more abruptly and frequently than sewage. Superimposed on such changes in raw wastes may be failures or bypassing of waste treatment devices.

This very changeability makes the study of stream pollution a challenging and fascinating activity. In forty years devoted largely to studies of water quality I have never found two streams that behaved just alike, and have never approached the task of interpreting the data of a completed stream study without a tingle of pleasant anticipation. Often I have been frustrated by some bit of apparently inexplicable data. Never have I been disappointed by lack of a challenge in making the data yield the secret of what was happening in the stream.

This very variability may have discouraged anyone from attempting to produce a "Standard Methods for the Examination of Stream Pollution and Natural Purification." It may even be presumptuous to think of doing so, for the rigidity possible in many laboratory procedures cannot be applied to the almost limitless varieties of stream types and of pollutional situations. Nevertheless, certain fundamental practices can be applied more or less uniformly in all stream pollution studies. Following these practices cannot ensure invariable and complete success of all studies, but at least it will lessen the probability of failure.

The following pages are offered, then, with the hope that they will be of real help to the beginner in this fascinating field, and may even include a useful tip or two for the "old pro." I do not pretend that they constitute the last word on the subject. I sincerely hope, rather, that they represent merely a beginning, and that others will contribute from their own experience to revision and expansion of this beginning until a "Standard Guide to the Conduct of Water Quality Studies" becomes a reality.

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August 1969

# 1

# INTRODUCTION

THE successful completion of any major project by a group of persons involves certain general fundamentals that are common to all undertakings. Also involved are specific details that are peculiar to the individual project.

Establishment of objectives, assignment of responsibilities, planning, supervision, scheduling activities, review of progress, improvisation as necessary, communication, are examples of elements essential to all major projects. It should not be necessary to provide a comprehensive text of these fundamentals in a guide to stream pollution studies even though some of them are neglected on occasion. General comments on the fundamentals are included at appropriate points, with most emphasis in the final chapter.

Specific procedures peculiar to stream pollution studies, on the other hand, are dealt with at some length. General principles and techniques rather than exact methodology are covered. For example, the reader will not find here a description of, or the circuitry for, a fluorometer for determining "Rhodamine WT" in measuring time-of-water travel. He will, rather, find discussions of various techniques by which time-of-water travel may be measured.

The detail of the suggested procedure given in each case is that which is considered most desirable. In actual practice it is rarely, if ever, possible to conduct a study of the desired detail. Almost inevitably limitations of time, personnel, facilities, or budget require reductions from the ideal plan. The conduct of practically every stream study represents a compromise between the desirable and the feasible. The mark of the experienced investigator is the ability to attain the study objectives within the limitations of the facilities available to him.

Each of the following chapters, except the last, is devoted to a single factor, principle or procedure involved in studies of water quality. Chapter 2, for example, deals with objectives of stream studies. It lists some of the reasons for conducting studies and discusses the importance of careful and thorough delineation of the objectives of a particular study before it starts. Chapter 15 has suggestions for preparation of a report on water quality.

The last chapter suggests an orderly sequence for the conduct of stream studies. It attempts to wrap the essence of the preceding chapters in one package, without excessive repetition.

The material herein is limited, insofar as is reasonable, to information that is not ordinarily found in textbooks and technical articles. There must be, of course, a modicum of familiar material to serve as a platform from which to present less familiar material. But published articles that are particularly appropriate to subjects under discussion are referred to rather than duplicated or abstracted. For example, in Chapter 14 the reader is referred briefly to articles by Streeter for methods of calculating the oxygen sag curve. On the other hand, there are several pages (perhaps more than the subject deserves) of discussions of problems in measuring BOD-DO relationships that usually come to light only through experience or in bull sessions, and rarely are committed to paper.

The material is limited, also, to studies of water quality of streams. Many of the principles and practices discussed apply equally well to studies of other bodies of water, such as reservoirs or lakes and estuaries. However, factors that are peculiar to these other water bodies, such as temperature stratification and fluctuations of tides, are not included.

Finally, the reader soon will realize that this volume does not say "Do thus and so and such and such is guaranteed to result." Would that it could be otherwise, but experience teaches the exceptions as well as the rules. This, then, is not a book of recipes, but is hopefully a stimulator of thought. Very few generalities are stated without the modification that they "usually" occur. And if there are generalities that are not so modified they "usually" should be. For in the unpredictable realms of stream behavior and water quality reactions almost anything can happen—and frequently does. So, about the only thing a recorder of these behaviors and reactions can do is point out certain possibilities and thus arouse awareness of some of the problems that may be encountered. This, hopefully, will encourage thoughtful consideration and application of sound judgment, patterned to the individual situation, to the solution of those inevitable problems.

# 2

# OBJECTIVES

STREAMS are studied for many reasons. The U.S. Corps of Engineers, for example, studies them to determine how floods may be controlled, how they may be prepared and used for navigation, and how their potential for power production may be realized. The U.S. Bureau of Reclamation examines them to determine how best to use them for irrigation and for power production. The private power company's principal interest, naturally, is power production, Both state and federal fish and game agencies are concerned with their capabilities for fish and waterfowl propagation. Water supply consultants evaluate them as sources of municipal and industrial supply. And sanitary engineers and their associated bacteriologists, biologists, and chemists study them to determine the effects of the waste products that are poured into them, and how best to protect them against those effects so that they may remain useful for the other purposes.

Phelps, one of the truly "grand old men" of the stream sanitation profession, has an excellent treatise on the interactions of wastes and streams in his book, "Stream Sanitation."[3]

Many types of water quality studies may be undertaken, with the objectives determining the type. It is impossible to overemphasize the necessity for a clear statement of objectives at the start of any study. Neglect of this essential preliminary step may result in neglect of some critical bits of information or, conversely, in expenditure of needless and wasteful time, effort and money.

## CATEGORIES OF STREAM STUDIES

Most studies fall into one of two general categories. One is designed to determine water quality at a single point or at isolated points. This involves one or more unrelated sampling stations on a stream system. Sampling may be occasional, perhaps at weekly, monthly, or even quarterly intervals, but probably will continue over a protracted period. Laboratory determinations may range from coliform bacteria, only, at a bathing area to a rather complete series of mineral, sanitary chemical, bacteriological and biological determinations where base line water quality is being determined.

The other category of stream studies is designed to determine changing water quality throughout a reach as the water travels downstream. This involves a series of related sampling stations, selected to reflect both instantaneous changes in water quality as waste discharges or major tributaries enter, and the slower changes that result from natural purification. Samples may be collected at frequent intervals, possibly even several times a day, for a limited period. Laboratory determinations are those that reflect changes in constituents that result from natural purification and those that reveal effects of constituents of wastes discharged in the reach.

## EXAMPLES OF OBJECTIVES

There probably have been nearly as many objectives of water quality studies as there have been studies. Listed below are brief examples of some of them:

### Water Quality at a Single Point

1. Establishment of a base-line record of water quality.
2. Investigation of suitability as a source of municipal, industrial, or other water supply.
3. Investigation of suitability for recreational use, including swimming.
4. Investigation of suitability for propagation of aquatic life, including fish.
5. Day-to-day monitoring of raw water sources of municipal, industrial, and other water supply.
6. Monitoring effects of waste discharges.
7. Surveillance to detect adherence to or violation of water quality standards.
8. Detection of sudden changes in water quality caused by slugs of wastes resulting from spills, deliberate discharges or treatment plant failures.
9. Source of samples for demonstration of or research on analytical methods.

### Water Quality at Related Points

1. Determination of patterns of pollution downstream from waste discharges and effects on water uses.
2. Determination of adherence to or violation of water quality standards.
3. Determination of characteristics and rates of natural purification of streams.

4. Projection of effects of pollution to other conditions of flow and temperature than those occurring during study.
5. Estimation of waste assimilative capacities of streams.
6. Estimation of reductions in waste loads necessary to meet water quality requirements.
7. Determination of causes of fish kills or other disasters involving deterioration in water quality.
8. Determination of existing water quality before some change in conditions, such as a new or increased waste discharge or impoundment of a reservoir.
9. Research on methods of stream study.
10. Demonstration of methods of stream study.

## WRITTEN OBJECTIVES

These examples of possible objectives reflect the wide range of operations that may be involved in stream studies. They emphasize the necessity of a clear definition of objectives for a particular study.

The objectives should be put in writing for several reasons. The act of putting them on paper requires careful consideration of what the objectives actually should be. The written word is far less apt to be misunderstood by those involved in the operations than is a verbal statement. The written objectives should define not only the purposes of the study but also the limits, and thus should discourage the pursuit of interesting but nonessential bypaths. They fix the responsibility of those charged with supervision of the study. They provide a basis for judging the extent to which the results of the study meet the needs that justified the undertaking.

Plain good business requires that any major project start with written objectives.

# 3

# PHYSICAL CHARACTERISTICS OF STREAMS

A STREAM'S physical characteristics greatly influence its reaction to pollution and its natural purification. An understanding of the nature of these influences is important to the intelligent planning and execution of stream studies. Important physical factors include temperature, turbidity, depth, velocity, turbulence, slope, changes in direction and in cross sections, and nature of the bottom.

Effects of some of these factors are so interrelated that it is difficult or even impossible to assign more or less importance to one or the other of them. For example, slope and roughness of the channel influence both depth and velocity of flow, which together control turbulence. Turbulence, in turn, affects rates of mixing of wastes and tributary streams, reaeration, sedimentation or scour of solids, growths of attached biological forms and rates of natural purification.

## MIXING OF WASTES

Physical characteristics of stream channels largely control distances required for mixture of wastes with stream flow.

Wastes mix in three directions in a stream: vertically (from top to bottom); laterally (from one side to the other); and longitudinally (leveling out of peaks and valleys in strength of waste discharges as water moves downstream). The distances in which wastes mix in these three directions must be considered in the selection of sampling stations and specific sampling points, and of sampling frequencies.

### Vertical

Vertical mixing almost always is the first of the three types to be complete in a stream. Laminar flow would prevent vertical mixing, but laminar flow is very nearly nonexistent in surface streams.

The movement of a drop of water downstream has been idealized as that which would occur if the drop were attached to a point on the circumference of a wheel moving downstream, with the bottom of the wheel on the stream bed and the top of the wheel at the water surface. Obviously this type of movement produces vertical mixing.

Shallow water and high velocities result in rapid vertical mixing but even in deep water with low velocities vertical mixing is relatively rapid. Large differences in temperature and in solid content between wastes and streams can cause density stratification that prevents rapid vertical mixing. Density differences sufficient to overcome the vertical mixing tendency of turbulence in streams occur only infrequently, however. Wastes discharged to most streams mix vertically within a tenth of a mile, or within a few tenths at most. Therefore, it is rare that a stream need be sampled at more than one depth.

## Lateral

Lateral mixing usually occurs well after vertical mixing has occurred, but long before longitudinal mixing is complete. Two factors can be important in lateral mixing.

Differences in solids and especially in temperature of wastes and stream water can cause the wastes to stratify and travel across the stream more rapidly on surface or bottom than they would if mixed vertically at the point of discharge. This phenomenon is most effective at very low velocities since even moderate turbulence quickly destroys stratification, causes vertical mixing, and slows the lateral movement of the wastes.

Change in direction of stream flow also is effective in lateral mixing. As a stream enters a bend in the channel, momentum of the water tends to maintain the flow in a straight line and the main current travels around the outside of the bend. The current tends to remain on that side of the stream even below the bend until there is a reverse change in direction of the channel. The current then tends to cross toward the opposite bank on the outside of the second bend. This, combined with normal vertical mixing, can cause rapid and rather complete lateral mixing. When a stream passes through two approximately 90-degree reverse bends that are reasonably close together, at a moderate velocity, it can be assumed that lateral mixing of wastes from upstream is well advanced.

However, there is an exception to this as there is to most generalizations. Colored wastes and turbidity from small tributaries have been observed to hug one bank for many miles in wide, shallow (one to two feet deep), swift streams with rocky bottoms in spite of several reverse bends in these distances. Turbulence in these streams quickly causes vertical mixing and destroys any vertical density stratification that would tend to carry the wastes across the stream. Presumably the energy of turbulence overrides the energy of momentum that tends to cause cross channel travel on bends, and such travel is minimized.

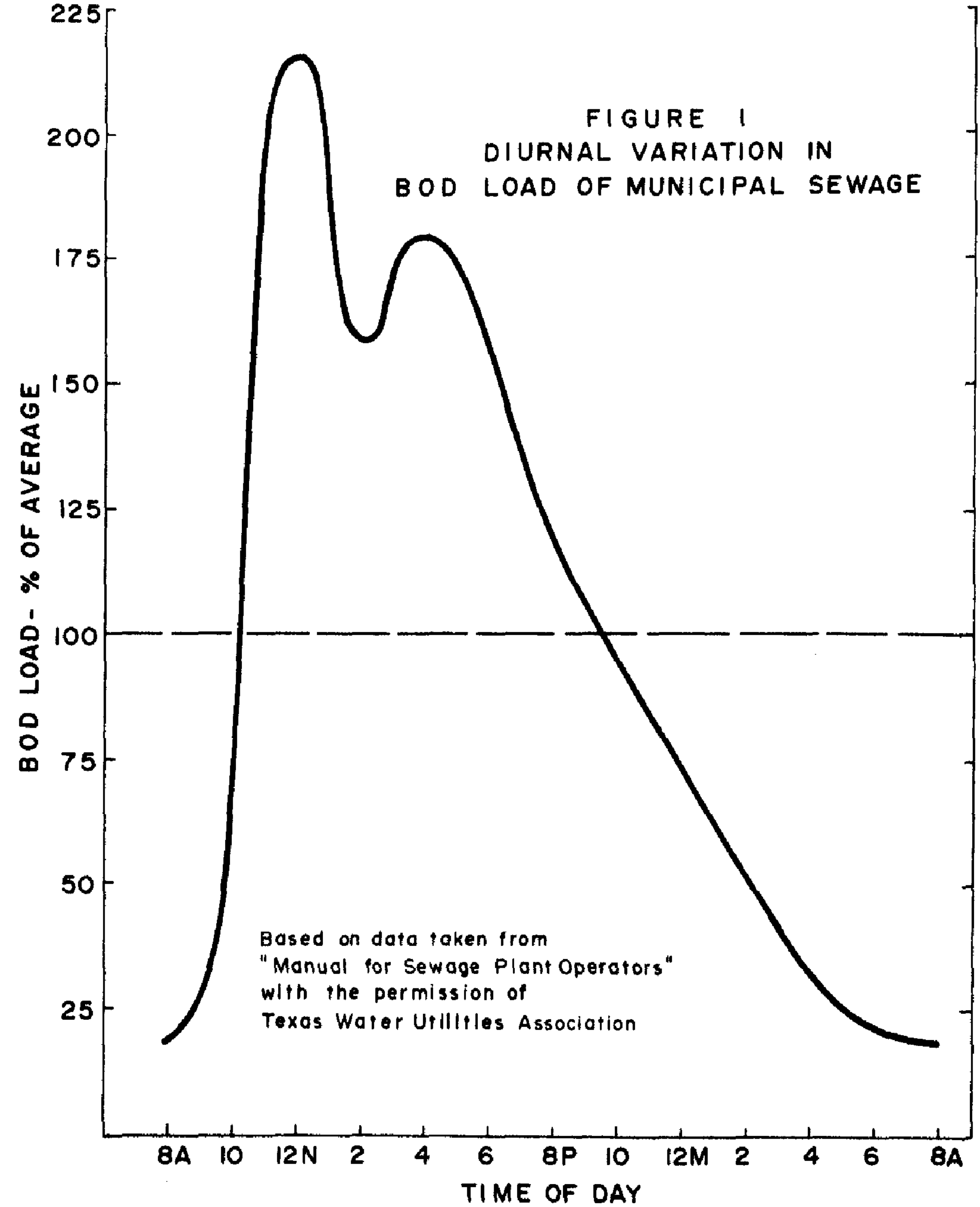
Whereas turbulence may cause vertical mixing within a few tenths of a mile, the distance for lateral mixing generally is dependent on the occurrence of relatively sharp reverse bends. As a general rule-of-thumb, the distances for adequate lateral mixing is in miles rather than tenths. Frequently a stream must be sampled at two or more points at one or more stations downstream from a source of waste or a tributary stream because of slow lateral mixing.

## Longitudinal

Results on a constituent of sewage determined on samples collected at frequent intervals closely below a source of sewage and plotted against time of sample collection exhibit a peak in concentration corresponding to the peak in sewage-producing activities in the municipality (Figure 1). When the same procedure is repeated several miles downstream, the same peak occurs. The peak, however, is not so high as it was just below the source of sewage, and it is wider. Finally, when the sampling is repeated far enough downstream, the peak disappears and the concentration is relatively uniform throughout the day. This smoothing-out of the effects of an irregular waste discharge is the result of mixing longitudinally (Figure 2).

Such mixing is caused by differences in times required for individual particles of water to travel from the point of waste discharge to the downstream sampling stations. Differences in both vertical and horizontal velocities cause these differences in travel time. Water flowing near the bottom of the channel is slowed by the friction with the bottom. Water traveling on and near the surface likewise is slowed by friction with the air. The maximum velocity usually occurs at about four-tenths of the depth, measured from the surface, with the average velocity at about the six-tenths depth. Particles of water tend to travel repeatedly from top to bottom and back again as they move downstream at varying velocities.

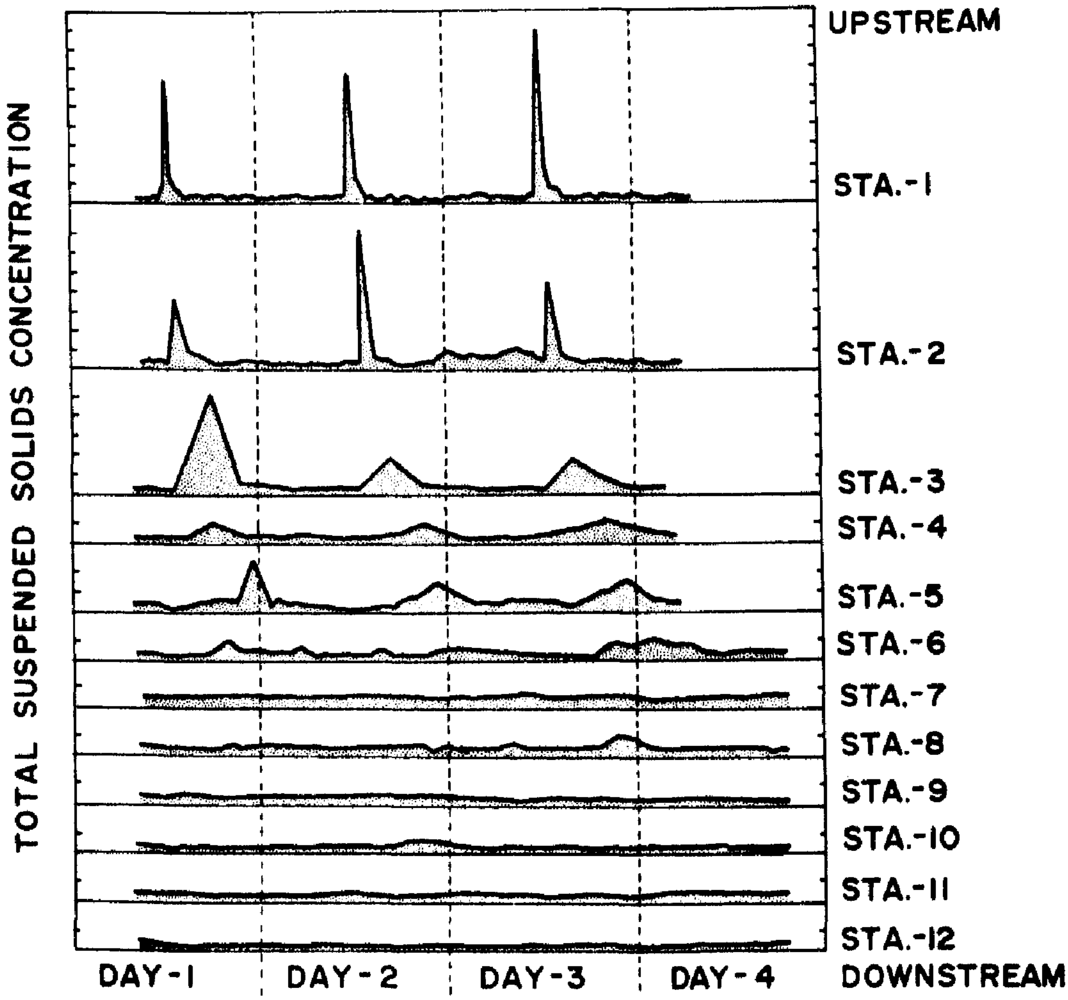
The vertical distribution in velocity has less effect on longitudinal mixing, however, than does lateral velocity distribution. Although the overall movement of water is downstream, the main current tends to flow through variable, but limited, portions of the stream cross sections. Water near one or the other bank, or both, may be relatively quiet and slow moving, and in eddy areas may actually flow some distance upstream. Any particle of water that passed a point of waste discharge with the main current may wander into a quiet area downstream and remain there




for some time before rejoining the main current and proceeding downstream.

Thus the water passing a point downstream from a source of waste is not the identical mass of water that passed the source at some specific earlier time. It is, rather, a mixture of particles of water that passed the source at different times and spent various times in traveling to the downstream point. Variations in waste discharge ultimately are averaged-out at some distance downstream to produce uniform concentrations of waste constituents throughout the day.

FIGURE 2
RESULTS OF LONGITUDINAL MIXING




Variations in cross sections and changes in direction of the channel that permit areas of quiet water and eddy currents are major causes of longitudinal mixing. A stream with a relatively straight, uniform channel must travel farther to achieve both lateral and longitudinal mixing than one with an irregular, winding channel. Completion of mixing longitudinally may require tens of miles in a stream compared with the miles necessary for lateral mixing.

Consideration of longitudinal mixing distances can be important in deciding frequency of sampling. More frequent sampling is required to yield representative results just below an irregular waste discharge than is necessary some distance downstream where mixing longitudinally has been completed.

## REAERATION

The effects of channel characteristics on reaeration have been so thoroughly explored and reported on that they will be discussed here only briefly. Oxygen first enters the water surface from the atmosphere by solution. From the very thin surface film of saturated water, the DO tends to mix through the remaining unsaturated water by the extremely slow process of molecular diffusion. Increasing temperature increases the rate of diffusion. The rate of reaeration also is speeded up tremendously by turbulence, which carries the thin surface layers of oxygen-saturated water into the depths and exposes new films of undersaturated water to the atmosphere to dissolve more oxygen. Turbulence is controlled, in turn, by depth and velocity of the water.

The depth and velocity relationship to reaeration is expressed by a convenient approximation of the empirical formula * of Churchill et al. for the reaeration coefficient of the oxygen sag formula [4]:

$$k_2 = \frac{5V}{H^{1.67}}$$

where

$k_2$ = reaeration coefficient, per day, at 20°C using common (base 10) logarithms.

V = mean velocity in feet per second.

H = mean depth in feet.

The very nearly direct relationship of velocity to reaeration is indicated by the numerator 5V, the reaeration coefficient increasing in nearly direct proportion to the velocity for a constant depth.

The exponential effect of the more important depth factor is illustrated by the results of a few calculations. With a velocity of one foot per second and a depth of four feet, the reaeration coefficient, $k_2$, equals about 0.45 per day. At the same velocity and a depth of two feet $k_2$ equals about 1.57, and at one foot $k_2$ equals about 5.0. With these coefficients and no biochemical oxygen demand (BOD), times required for dissolved oxygen (DO) to recover from total depletion to 99 percent of saturation at 20°C. would be about 2.1, 0.61, and 0.19 days, respectively.† Thus a reduction in depth from four feet to one foot would increase the reaeration rate by a factor of 11. By contrast, a 4-fold increase in velocity would increase the reaeration rate by a factor of only four, or only a little more than one-third as much as an equivalent factor of reduction in depth.

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* The exact formula is: $k_2 = \frac{5\ V^{0.969}}{H^{1.673}}$

† Infinite time would be required for DO to recover to 100 percent saturation in all three cases, and this would provide no basis for comparison of recovery times.

## SLUDGE DEPOSITS

Slope of a stream and roughness of its channel exert important effects on velocity and depth of flow. The latter two factors, as noted previously, control turbulence. Turbulence, in turn, influences sedimentation of suspended solids and scour of deposited solids. Both sedimentation and scour of organic solids can impose heavy loads of oxygen demand on the DO of a stream.

A common rule-of-thumb is that sedimentation of suspended sewage solids may be expected in stream reaches where velocity of flow is below about 0.6 feet per second.[5] This applies particularly to raw sewage or industrial wastes with settleable solids, but may apply to primary effluents also. Some settleable solids escape primary tanks, and colloidal solids frequently are coagulated and made settleable by chemical and biological action in streams.

The settled solids, or sludge, continue to exert an oxygen demand on the water flowing over them. During the initial period of deposition, the solids exert less daily demand on the DO of the stream than they would if they remained in suspension. Ultimately, with stable conditions of stream flow and temperature, the deposits accumulate to the extent that they exert a daily oxygen demand on the flowing water that is approximately equal to the oxygen demand deposited daily.[6] This is the maximum daily demand that can be exerted by the accumulated sludge so long as it is not resuspended by increased stream flow or temperature does not increase the rate of decomposition of the sludge mass.

At first thought it might appear that sludge deposits should not reduce DO to lower levels than would the same solids in suspension, but this is not the case. The sludge exerts its oxygen demand in the relatively short reach of the stream in which it settles, compared to the distance over which it would exert the equivalent demand if it remained in suspension. The reaeration in the short reach is less than it would be in the greater distance. The demand of the sludge may, in fact, be considered almost a point source of oxygen demand in many cases. This almost instantaneous oxygen demand, unbalanced by the reaeration that occurs in the greater distance, may reduce DO to excessively low levels.

Sludge deposits pose another potential hazard to the DO of the stream. The deposits can be scoured from the bottom and resuspended in the water of a stream by an increase in velocity of flow. The scouring velocity for compacted sludge is nearly double the maximum settling velocity of 0.6 feet per second[5]. A sudden moderate increase in stream flow that increases velocity of flow above the scouring rate, but does not provide compensating dilution, may reduce DO dangerously, or even totally deplete it, by the drastically increased oxygen demand due to the resuspended sludge. There are documented cases of fish kills that resulted from such occurrences.

## BIOLOGICAL ACCUMULATION

An entirely different, yet somewhat analogous, accumulation of organic matter may occur in certain streams. Here depth and possibly velocity of flow, and the nature of the stream bed are the important factors. Shallow, turbulent streams, with bed materials that provide abundant surfaces suitable for attachment of biological slimes, rid their water rapidly of heavy organic and bacterial loads in unbelievably short distances. Reductions of BOD in the range of 68 to 96 percent and of coliform bacteria between 43 and 99.8 percent in distances of 0.3 to 5.1 miles and in times of travel of three to 12 hours have occurred in such streams. Flow velocities ranged from 0.1 to 1.5 feet per second.

Brink[7], for example, reported 95 percent reduction in BOD and 99.8 percent coliform bacteria in a septic tank effluent discharged into a ditch with water depths of inches and a velocity of about 0.1 feet per second, in 0.3 of a mile and about 4.5 hours times of travel. The bacterial reductions might be expected to require six to eight days in most streams. The reduction in BOD is equivalent to a $k_1$ coefficient in the oxygen sag formula of 6.8 compared to values in the range of 0.1 to 0.3 in most streams. The extremely high $k_1$ does not represent the actual rate of exertion of oxygen demand as do the lower $k_1$ values in most streams. It represents primarily the rate of removal of oxygen-demanding material from the flowing water by absorption and adsorption in and on the biological slimes on the streambed. While stored in the slimes, the material presumably exerts an oxygen demand at the more nearly normal rate.

Streams with such high natural purification rates have been called "horizontal trickling filters." The analogy is quite apt. The principal controlling factor in rates of removal of the pollutants from the flowing water presumably is the frequency with which a given particle of water contacts the bottom slimes. This frequency is controlled by turbulence which, as previously noted, is a product of depth and velocity. Depth appears to be the more important of the two factors, as it is in reaeration. It would not be surprising if the types of formulas for calculating reaeration coefficients, $k_2$, should be found to apply in the calculation of similar coefficients defining the rates of removal of bacteria and BOD from the flowing water in streams of this type. There undoubtedly is minor removal of these polluting materials from deep streams also by biological bottom slimes. Contact of any particular particle of water with the bottom slimes in deep streams is so infrequent, however, that the effect of this type of removal is obscured by the greater reductions through organic decomposition and bacterial die-away.

# 4

# SAMPLING STATIONS

MANY factors are involved in the proper selection of sampling stations. The factors include: objectives of the stream study; water uses; access to desirable sampling points; entrance and mixing of wastes and tributaries; flow velocities and times of water travel; marked changes in characteristics of the stream channel; types of stream bed, depth and turbulence; artificial physical structures such as dams, weirs and wing walls; and personnel and facilities available for the study.

## IDEAL STATION

The ideal sampling station would be a cross section of a stream at which samples from all points on the cross section would yield the same concentrations of all constituents, and a sample taken at any time would yield the same concentrations as one taken at any other time. The former situation occurs when vertical and lateral mixing of any upstream wastes or tributaries are complete at the sampling station. This is not uncommon. The latter situation occurs only if there is no variation in upstream waste discharges or there is complete mixing longitudinally of any variable waste discharge, and if there are no upstream variations in stream flow, time-of-water travel, temperature, biological activity or other factors that contribute to variation in water quality. This situation never persists in nature for any appreciable period of time. Variations in water quality with time require that samples be collected at the proper frequencies and times of day to ensure results representative of the variations. This will be discussed in a subsequent chapter.

## INVESTIGATION OF MIXING

Only rarely is it necessary, as noted earlier, to sample at several depths in a stream because of incomplete vertical mixing.

On the other hand, incomplete lateral mixing frequently occurs at one or more stations below a major waste source or tributary stream.

Any uncertainty regarding completeness of lateral mixing at a station may be resolved by analysis of samples taken at various points on the cross section for dye or salt added to the waste or tributary inflow, or for some distinctive constituent of the inflow. The samples should be taken at stream flows reasonably comparable to those anticipated during the study. If mixing is not adequate, either the station location should be shifted downstream or multipoint sampling across the section must be employed.

## SAMPLING POINTS AT STATIONS

The most nearly accurate method of multipoint sampling involves measurement of stream velocities at numerous points on the cross section and dividing the cross section into several subsections of equal flow. The individual sampling points are then spotted at the centers of mass in the subsections. This is a complex procedure, and can be complicated still further by changes in subsections of equal flow as river stage changes. Determining centers of mass for subsections of equal flow over a wide range of river stages and subsequently locating the exact sampling points at different river stages can become hopelessly complex.

An alternate method was used during the original research on pollution and natural purification of the Ohio River.[8] This consisted of dividing the river cross section at an "average" river stage into three subsections of equal area, and establishing fixed sampling points at the mid-points of the subsections.

Even this refinement rarely is attempted in most routine stream studies. Sampling points usually are established at approximate quarter points, or other equal intervals, across the width of the stream when multipoint sampling is necessary. The equal intervals should be across the main current rather than across the entire width of the stream if there are quiescent or eddy areas on one or both sides of the stream. Restricted cross sections are preferred locations. Good flow distribution throughout them usually prevents still water areas, and vertical and lateral mixing are intensified. Flow distribution also is apt to be good in straight stream reaches of relatively uniform cross sections.

Even when vertical and lateral mixing are complete in large, wide streams such as the Mississippi, Columbia, Detroit, St. Lawrence, Missouri, Ohio and Tennessee rivers, it is good practice to sample at quarter points. If this proves to be too time consuming however, a single sample at midpoint of the main current may be adequate in even such large streams. A single midcurrent sampling point is adequate for most streams where lateral mixing is complete.

Sampling the edge of a stream from the bank should be avoided if at all possible. If unavoidable, sampling should be on the outside of a bend where the current flows along the bank. This will avoid collection of quiet or even stagnant water of a quality that does not represent that of the main flow. DO may be slightly higher in the shallow water along the bank than in the deeper current.

Sampling usually is at either five-feet or mid-depth, whichever is less. Exceptions are samples taken just below the surface for bacteria, at about one foot for plankton and from the stream bed for bottom organisms.

## TRIBUTARY AND WASTE STREAMS

Representative measurement of a pollution load at a point on the main stream that is close below a source of waste or a tributary stream is highly impractical. The inflow frequently hugs the stream bank with very little lateral mixing for some distance. Samples from quarter points in this reach might miss the wastes altogether and reflect only the quality of water above the waste source. Samples taken directly in the portion of the cross section containing the wastes would indicate excessive effects of the wastes with respect to the river as a whole. Recognition of this fact is reflected by the mixing zones allowed by some water pollution control agencies. Within these mixing zones water quality standards do not apply at present. This problem could be eliminated by a requirement that wastes, adequately treated, be diffused across the entire width of the stream.

Two types of data frequently are needed at points in streams immediately below waste or tributary inflows to calculate pollutional patterns. One is the total loads of constituents in pounds per day. The other is the computed average concentrations of constituents that would result if the waste or tributary inflows were completely mixed with the receiving streams at the points of inflow. These data cannot be obtained by direct measurement, but may be developed indirectly by two methods.

The more common method consists of gaging flow and sampling and analyzing the main stream just above the inflow, and the inflowing waste or tributary just above its point of entry. The constituent loads immediately below the inflow are the sums of the measured loads. The average constituent concentrations are the sums of constituent concentrations of the two streams weighted by their flows, divided by the sum of the two flows, or,

$$C_B = \frac{(C_A \times Q_A) + (C_T \times Q_T)}{Q_A + Q_T}$$

where:

$C_B$ = hypothetical average concentration of constituent in main stream below inflow.
$C_A$ = concentration of constituent in main stream above inflow.
$C_T$ = concentration of constituent in tributary or waste.
$Q_A$ = flow of main stream above inflow.
$Q_T$ = flow of tributary or waste.

The other method involves gaging, sampling and analyzing the main stream downstream from the inflow, where adequate lateral mixing has occurred, at two or more points for unstable constituents or at one for stable constituents. The rates of change of unstable constituents are established from data at the downstream stations. The concentrations or loads of constituents are projected upstream from these stations to the point of inflow at the rates established. Stable constituent concentrations or loads at the point of inflow are those measured at the downstream station without projection.

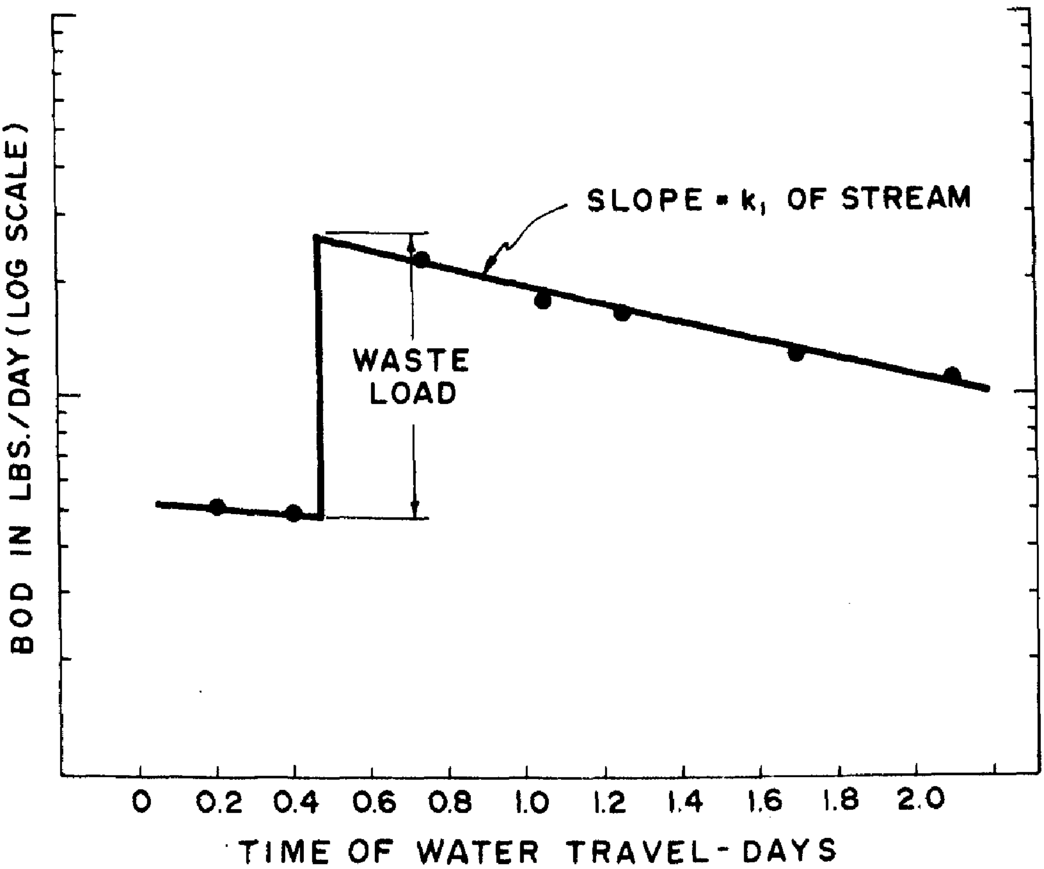
An adaptation of these two methods may be used to obtain loads of constituents contributed by wastes or tributaries if their direct sampling or gaging is not practicable. For example, a tributary may be inaccessible within a reasonable distance above its mouth or a waste may be discharged through so many sewers that sampling and gaging would require excessive time and effort.

In such a situation the receiving stream may be sampled and gaged just above the inflow and at an appropriate distance or distances downstream. The loads of stable constituents of the waste are the direct differences between those measured below and above the inflow. Those of unstable constituents are the differences between the downstream loads projected upstream to the point of inflow and the upstream loads projected downstream to the inflow point (Figure 3).

## POINTS OF WATER USE

Water quality at a point or a limited area of water use is of concern in some situations. For example, water quality at a specific point of water supply intake or at a limited area such as a swimming beach is of interest, rather than the representative average quality of the adjacent cross section or the total pollution loads passing through the cross section. Lack of mixing is of no concern in measuring water quality in these situations

FIGURE 3
MEASURE OF WASTE LOAD IN STREAM
BY PROJECTION FROM UP-AND DOWNSTREAM




and the sampling station is located at the points or areas of actual use to measure quality as used.

Use of the raw water tap in a water plant laboratory is convenient when an existing intake is used as a sampling station. However, the actual source of the sample must be determined to make certain that it represents the stream. The water may be from the outlet of a pre-settling basin with a day or so of storage. Pre-chlorination may have been applied ahead of the point from which the sample is drawn.

Raw water taps usually are connected by small pipes, frequently of considerable length, to raw water mains. Sometimes the connecting pipes are copper, which is highly toxic to bacteria and has been known to reduce bacteria to densities considerably below those in the stream. The zinc of new galvanized pipe may have a similar effect. Biological slimes may develop in galvanized, iron or plastic pipes. These slimes on the interior walls of the pipes can reduce bacteria, turbidity, plankton and other suspended matter, and may change even such soluble constituents as BOD, DO, alkalinity and hydrogen ion concentration. Comparison should be made of constituents in simultaneous samples from the tap and the raw water main if the tap is served by more than a few feet of pipe. The same precaution should be exercised in sampling at an established monitoring station where the water is pumped from some distance out in the stream through a pipe to a convenient point on the bank or on a bridge.

## ACCESSIBILITY

Accessibility of any sampling station is an obvious requirement. Bridges are popular with sanitary engineers for this reason. Where there is a bridge, there is a road that provides ready access to the stream. Another virtue of bridges is that they permit sampling at any point or points across the width of the stream. They are not, however, without their shortcomings as sampling stations. They are located by highway engineers on the basis of moving traffic from here to there and not in desirable relation to sources of wastes and tributaries, water uses, critical DO points and the other considerations so important to the sanitary engineer. More than one stream study has proved inadequate because of limitation of sampling stations to bridges only.

Station locations can be chosen without regard to other means of access if the stream is navigable by an available boat. Frequently, however, boat runs take more time than does travel by car between bridges.

A combination of bridges and boats may prove to be the best system in some situations. Boats left at fixed locations for the duration of the study may be used advantageously to reach the sampling point in the main current after traveling to the station by car.

Walking to collect samples may be feasible in a few cases, but this method usually will be chosen for only very small streams that purify themselves in short distances. A sample collector usually has to carry a considerable weight of sampling equipment, field kits and water samples. When it also is necessary to wear rubber boots to walk the stream or to wade out to the main current the physical effort involved often makes this method difficult.

Sampling by helicopter has advantages of ready access, speed and minimum of physical effort. Travel by helicopter is dependent on good weather, however, and its high cost usually limits its use by most traditionally tightly-budgeted pollution control agencies to the most compelling of situations.

## LOCATION OF STATIONS

Two general categories of sampling stations have been discussed in the chapter on objectives, the single station and the series of related stations. Many of the principles of selection discussed thus far apply to both categories.

### Single Stations

Choice of location of certain types of single stations may be reasonably flexible. For example, a monitoring station for a baseline record of water quality may be shifted up- or downstream several miles to permit use of a convenient bridge or to allow an upstream waste or tributary to be well mixed laterally when the stream arrives at the station.

On the other hand, single stations for monitoring water supply intakes, swimming beaches and waste discharges may be fixed within rather narrow limits. A waste discharge monitoring station usually is close downstream from the waste source, but beyond the limits of any mixing zone that is allowed. If, however, DO depletion is the principal problem, the station should be at or near the point of minimum, or critical, DO of the oxygen sag curve. If the critical point is not readily accessible, a study should be made at or near the design stream flow to correlate the DO at an accessible point with that at the critical point.

### Related Series Stations

The reason for using a series of related stations rather than a single station should be kept in mind in selecting the series of stations. The series is used to establish the course of pollution, or the water quality changes, throughout a reach of river. The pattern of changing quality reflected by the relationships among the several stations is more important than the isolated water quality at any one station. Development of the true relationship among the stations depends on data representative of the total flow of the stream past each station. Otherwise the apparent relationship may be distorted and misleading.

An advantage of a series of stations over a single station is that data from each station support and reinforce those from all other stations. For example, the BOD concentrations of a series of stations below an organic waste source should fall along a straight line of decrease when plotted against time-of-water travel on semilogarithmic graph paper unless the course of BOD reduction is altered by irregularities such as sludge deposition, tributary inflow or waste discharge. Probably not every point will fall exactly on the straight line. Almost inevitably some inaccuracies in measurement of the BOD or the time-of-water travel displace the data points to some extent. However, the slope of a straight line of best fit drawn among the plotted points, rather than from point to point, represents the best available approximation of the rate of BOD reduction, since BOD decreases with time at a constant proportionality rate. Thus, data from all stations are mutually supportive and those for each station contribute to the definition of the slope of the line.

The stations of a series should be spaced at intervals based on time-of-water travel rather than distance. As a general rule-of-thumb desirable intervals are about one-half day time-of-water travel for the first three days travel below a source of waste and about one day through any remaining distance.

An exception to the suggested spacing must be made for very shallow streams with abundant biological slimes on the stream beds. Natural purification in such streams can be so rapid that station spacing should be on the basis of hourly rather than daily intervals.

The suggested time intervals between stations are by no means inflexible. Other factors well may take precedence over exact spacing of stations in relation to time of travel. Adjustments in station locations for base-line data, because of lack of mixing of wastes and tributary streams, has been mentioned. Various factors associated with accessibility have been discussed. The fact that results from series stations are used to develop continuous patterns throughout reaches of streams indicates that the suggested intervals can be varied. Intervals of 0.4 or 0.6 days time of travel between stations are just as satisfactory as 0.5 days. When the data are plotted against actual times of travel satisfactory curves should result.

Similar reasoning applies to the use of stations sampled in a previous study or to location of a station at an exact point of water use. The water quality at any point within a stream reach may be ascertained from the pattern developed from a series of stations even though no station was at that particular point during the current study. Thus, the results at any station used in a previous study can be compared with results of the current study at the corresponding point in the pattern. The water quality at a point of water use likewise can be derived from the pattern even though no station was at that exact point.

Establishment of stations at marked changes in physical characteristics of the stream channel is desirable. For example, a stream reach between two adjacent stations should not include both a long rapids section of swift, shallow water with a rocky bottom, and a long section of deep, slow-moving water with a muddy bottom. Stations at each end of the combined reach would yield data on certain rates of change, such as reaeration, that would be an unrealistic average of two widely different rates. Much more would be learned of the actual natural purification characteristics of the stream by insertion of a third station within the reach between the rapids and the quiet water sections.

Dams and weirs cause changes in physical characteristics of a stream that may be similar to the above rapids-quiet water situation. They usually create quiet, deep pools in river reaches that, by comparison, formerly were swift and shallow. Such impoundments should be bracketed, at least. When times-of-water travel through them are long, stations should be established within the impoundments.

Some stream structures, such as dams, permit overflow that accomplishes significant reaeration of oxygen deficient water. In such cases stations should be located short distances above and below the structures to measure the rapid, artificial increase in DO, which is not a true portion of the natural reaeration.

A minimum of three stations located between any two points of major change in a stream is a desirable precaution, when feasible, even when the time of travel between the points of change is short. Major changes may consist of a waste discharge, a tributary inflow or a significant difference in channel characteristics. The use of three stations is especially important when rates of change of unstable constituents are being determined. If results from one of only two stations in a subreach are in error for some unforseen reason, it may not be possible to judge which of the two sets of results indicate the actual rate of change. Results from at least two of three stations, on the other hand, very probably will support each other and indicate the true pattern of water quality in the subreach.

## CONTROL STATIONS

The majority of stream studies involves determination of the effects of one or more waste discharges. This implies the need of a basis for comparison of water quality above and below the waste inflow. A control station above the source of waste is fully as important as are stations below, and should be chosen with equal care to ensure representative results. At times it may be desirable to project the concentration or load of some unstable constituent from the control station to the point of waste inflow. In such cases it may be desirable to locate two or three stations above the waste inflow to establish the rate at which the unstable material is changing. The time of travel between the stations should be sufficient to permit accurate measurement of the change in the constituent under consideration.

## TRIBUTARY STATIONS

Usually sampling of every tributary stream that enters the reach of the main stream being studied is not feasible. A tributary with a flow that is less than 10 to 20 percent of that of the main stream need not be sampled unless it is badly polluted at its mouth, or has some natural characteristic markedly different from that of the main stream.

The station on a tributary should be as near the mouth as is feasible. This frequently is a bridge some distance upstream from the mouth. Two or three stations on the tributary to establish the rates of change of unstable constituents may be desirable when projection of data on unstable constituents from the tributary station to the main stream is necessary.

Frequently the mouths of tributaries may be entered from the main stream for sampling when collection in the main stream is by boat. Care should be exercised to avoid collecting water from the main stream that may flow into the mouth of the tributary on either the surface or bottom because of differences in density resulting from temperature, dissolved salts, or turbidity differences.

## BIOLOGICAL STATIONS

Considerations in station selection discussed thus far have been directed principally toward sampling for chemical and bacterial constituents. Some of the same factors apply in biological sampling, but others must be considered. Chemical characteristics of the water have an impact on the aquatic organisms in a stream and biological reactions in turn affect chemical characteristics. The full interpretation of both biological and chemical findings requires understanding and consideration of these mutual interactions. Thus, biological and chemical samples should be collected at or near the same stream locations.

Plankton samples should be collected at the same stations and in essentially the same way as samples for chemical analyses. They should be collected within a foot of the surface, since some organisms tend to congregate near the surface. Samples of bottom and attached organisms, on the other hand, frequently should not be collected at the same stations. Contrary to the engineers' preference, biologists avoid bridges for bottom organism sampling. The bottom population may have been destroyed or altered by activities involved in construction of new bridges. Passing motorists and pedestrians are prone to toss cans, bottles and other objects that may injure the sample collector into the water near bridges. Bridges frequently shade the stream beneath them and reduce light exposure and penetration. Finally, the types of dredges used by biologists are not water tight, and the water leaking from the dredges as they are hauled up to bridges carries away many organisms with it.

### Channel Characteristics

The series of stations from which biological samples are collected should have as nearly uniform physical characteristics as practical. For example, attached organisms recovered from shallow, swift riffle areas, with gravel beds usually consist of a wealth of different kinds. Obviously the abundant kinds of organisms on the riffle were not reduced by pollution to the few kinds in the adjacent pool. The difference is a reflection, rather, of differences in physical environment of the two areas. Important differences are depth, light exposure and penetration, velocity, sedimentation, and attachment surfaces provided by the stream bed. These two extremes in types of environment cause marked differences in organisms living in them, but even less extreme differences in environment can cause subtle differences in abundance and kinds of organisms.

Riffle areas constitute the preferred type of sampling station for bottom organisms. The life on riffles, more abundant than that in pools, provides more information on which to base interpretation of conditions. But areas less productive of biological organisms may have to be used to achieve reasonable physical uniformity of biological sampling stations if riffle areas do not occur in the vicinity of most of the chemical stations.

Pools, shallow enough for wading and direct hand sampling, constitute the next most desirable type of bottom organism station. Here again there should be good light exposure and penetration and adequate attachment surfaces.

Many streams consist of alternate pools and riffles. In such a case two series of samples may be desirable, one from riffles and the other from pools. The results of all riffle stations would be comparable and so would those of all pool stations, but the two series would not be comparable with each other.

Deep streams in which samples must be collected from boats by use of dredges and ropes are still less desirable but are acceptable if shallow pools and riffles are not available. Again good light exposure and penetration and attachment surfaces are important. Areas with these characteristics may occur near the banks of even the deeper streams.

## Attachment Surfaces

Hard materials such as rocks, gravel, waterlogged wood and similar objects provide preferred attachment surfaces. A limited number of kinds of organisms can live in mud and sediment that is soft but firm enough to withstand the velocity of the current and remain in place.

Sand, and especially shifting sand, is a very poor material for attached and burrowing bottom organisms. Hard packed, slick clay bottoms are entirely unsuitable. The only surfaces to which organisms can attach successfully in some streams may be twigs and branches submerged along the water's edge. Provision of artificial attachment surfaces to determine what organisms the streams can support may be necessary in others.

## Points on Cross Sections

The number of bottom sampling points on a cross section is varied with the width of the stream. Generally one point is adequate for a stream up to 20 feet wide, two points between 20 and 150 feet, and three points over 150 feet.

Location of bottom organism sampling stations where vertical mixing of wastes is complete is essential, since the wastes must reach the bottom of the stream if their effects are to be detected. Vertical mixing, as noted earlier, usually occurs in such short distances that lack of vertical mixing only rarely constitutes a problem in biological station location.

Multipoint sampling of bottom organisms is necessary on a cross section where lateral mixing is incomplete, just as it frequently is for chemical and bacterial data. Bottom organism data on a cross section are not averaged as they usually are for chemical and bacterial data. Rather the biological data for each point on the cross section are reported and discussed separately with emphasis on the point that reflects the greatest effects of the wastes. Organisms may be collected deliberately in some situations in the portion of the cross section where the wastes have received little of the total available dilution. Such a collection may be made, for example, between two points of waste discharge on the same side of a stream, to distinguish the effects of the upstream waste from those of the downstream waste. Also, a waste with negligible biological effect after complete lateral mixing may be sampled at a station farther upstream where mixing is incomplete, to reveal the types of effects exerted by the less dilute wastes.

## ORGANISM EXPOSURE

Bottom organisms are exposed to the entire range of variable concentrations of constituents that result from irregular waste discharges before mixing longitudinally is complete. The populations of these organisms have been said to reflect the integrated effect of the variable concentrations. Actually, however, they reflect the effects of the maximum concentrations rather than the integrated or average effects. The organisms cannot be made to reflect the mean effects of the wastes as can chemical constituents and bacteria by proper selection of times and frequency of sampling.

## REDUCTION OF STATIONS

Personnel and facility limitations may prevent the collection of samples from all desirable stations or points, or the examination of the desirable daily number of samples. The least detrimental cut usually can be made in the number of stations when reduction of the sampling or analytical program below the optimum level is necessary. Decreasing the number of stations in a stream reach by increasing the spacing between them usually is preferable to reducing the length of the reach, the number of points on station cross sections where lateral mixing is incomplete, or the frequency or total number of sampling runs.

# 5

# SAMPLING PROCEDURES

THE collection of representative samples is the first step toward accurate measurement of water quality. Improper collection can nullify the most careful and accurate work of the rest of the field crew. The frequent assignment of this duty to nonprofessional personnel might indicate the attitude that this is a simple procedure that does not require particular knowledge or skill. Yet the sample collector sees the stream under investigation more than anyone else in the field party. An experienced, intelligent, observant and conscientous sampler can contribute a great deal to the fullest understanding of the results of a stream study and what is occurring in the stream.

## THE COLLECTOR

Any implication that samples should be collected by professional personnel only is not intended. Nonprofessionals can and do become very proficient sample collectors. However, the professional who wishes to achieve the greatest proficiency in the conduct of stream studies will be well-advised to spend a reasonable apprenticeship in the not unpleasant job of sample collection. He will gain an understanding of the sample collector's work and problems that will serve him well in his supervision of samplers. He will gain far more than this in a "feel" for and an understanding of streams and stream pollution that he will achieve in no other way.

The aquatic biologist is an outstanding exponent of this philosophy. He obtains his own samples of bottom organisms, although he often allows others to collect his plankton samples. He knows that he can fully understand the environment from which the samples come only by being there and seeing for himself. His interpretation of the bottom organism data is severely handicapped if he lacks this firsthand understanding. In addition, his observations during sample collection may indicate the need for adjustments in the procedure or even in the station location that would not be recognized by a nonprofessional.

Some, possibly many, of the following suggestions may appear so elementary that it is difficult to believe that they have been ignored or violated in stream sampling. The fact is that most, if not all, of them have been.

Sampling instructions given in "Standard Methods for the Examination of Water and Wastewater"[1] generally will not be repeated here. However, there is some duplication for special emphasis and even some contradiction where there is thought to be justification.

## IDENTIFICATION OF POINTS

Sampling stations should be shown on an up-to-date, detailed map of the area. Usually county highway department maps are available and adequate. U.S. Geological Survey quadrangle maps are excellent, especially when they have been revised in recent years. River development agencies have good maps of the streams with which they work.

The selected point, or points, of sampling at a station should be marked if feasible. This is relatively simple on a bridge, where chalk or even paint may be used to mark the station identification, with an arrow for the sampling point. Boat sampling points may be marked with an anchored float unless this will interfere with navigation or regulations. It may be possible to line up two objects on shore in each of two directions so that the two lines sighted past the four objects will intersect at the sampling point if a float is not permissible. A tree or other object marked on one or each bank of the stream may be adequate.

Sampling at exactly the same point each time is not essential unless there are water quality differences vertically or laterally at the sampling station. Variation of the sampling point by a few yards will introduce no error in results unless upstream waste discharges or tributary inflows are not mixed at the station. Great care should be exercised, however, to sample always at the same points if there are variations in water quality throughout the cross section.

The most satisfactory designation for sampling stations is the stream mileage measured from the mouth, usually combined with one or two of the first letters of the stream's name. The common practice of assigning numbers or letters, more or less at random, to identify stations leaves much to be desired. Identification by random number or letter is in no way distinctive of or specific to the stream or the station involved. On the other hand, the abbreviated name of the stream on which the station is located and the stream mile specifies its location.

This system is useful in reports, especially when combined with location by stream mileages of various features such as points of waste discharge, water use and tributary inflow. It provides the readers of reports with a ready method of relating various features to each other, including stream distances separating them.

River development agencies usually prepare maps with official stream miles spotted on them at regular intervals. The mileage for any feature can be obtained from these maps by interpolation. Stream mileages can be measured with an instrument known as a map measure on any accurate map when official mileages are not available.

Station locations also may be identified for permanent reference by latitude and longitude where accurate maps are available, or by land surveying procedures in the absence of adequate maps. These identifications are not so suitable for station designations in reports as are stream mileages.

Multiple sampling points across the width of the stream at a station usually are designated as L (left), M (middle) and R (right). Most agencies dealing with streams apply these designations as they would be for an individual facing downstream. The U.S. Public Health Service, on the other hand, considers the individual to be facing upstream. This difference understandably has led to confusion on occasion.

## PRELIMINARY PREPARATION

The supervisor should visit each station with the sample collector and give any necessary instructions on the spot. Instructions may include the points and depths of sampling, desirable approximate times of collection, reading of river stage gage, and pointers on any special precautions that should be followed or visual observations that should be recorded.

Any obstructions to easy access to stations should be adjusted in advance of routine sampling. For example. there is no serious objection to climbing into and out of a deep ditch, jumping a small stream, or breaking trail through thick weeds to reach a station on a one-time reconnaissance of the stream. The same physical exertion each day, or more often, for 15 to 25 days when loaded down with sampling equipment and water samples can become intolerable. Small bridges and paths cut through weeds can save time, and wear and tear on the sample collector.

The sample collector should make all preparations possible before starting on each daily round. There usually is time to do this soon after delivery of the day's samples to the laboratory. Equipment, including car and outboard motor, if any, should be serviced, repaired or adjusted if necessary, portable meters checked and calibrated, reagents for any field kit or sample preservation checked and replaced, sample bottles assembled with tags for the next day's run filled out as fully as possible in advance, and any miscellaneous odds and ends completed.

## TIMING

Sampling should be started at one end of the stream reach every other day and at the opposite end on alternate days when samples are collected once daily. This practice avoids sampling the same portion each day of any cycle in upstream waste discharge that has not been mixed longitudinally at any of the sampling stations. This will be discussed more fully in the chapter on "Sampling Frequency."

## THE ROPE

The sampler rope should be tied to a bridge railing, or to a seat or other object in a boat to avoid loss of the sampler if the rope should slip.

Cotton sash cord may be used for the sampler rope, but nylon is preferred. Nylon does not absorb water, as does cotton, and therefore stays drier and does not rot and weaken as the cotton eventually does.

Marks of ink, paint or fingernail polish encircling the rope at five foot intervals are useful, especially in depth sampling. Every 10-foot interval may be specially marked with a different color, or with an additional band for each 10 feet of length. Braided nylon rope does not change length, and therefore the measures marked on it, so much as does cotton rope through shrinking or stretching. Depth measurements are best made with a steel cable, however, when accurate depth sampling is important. Steel cables with winches are available commercially and they may be equipped with counters that automatically indicate depths.

Rope may conveniently be wrapped into a ball, or looped by winding around the extended hand and upper arm. Tangling and knotting of the rope may be avoided or minimized by starting the first loop near the armpit and bringing successive loops forward toward the elbow. A reel may be used, but this increases the equipment that must be carried.

## DISSOLVED OXYGEN

Determination of the DO of a stream sample is reliable only if the sample is collected with a special device that will avoid aeration of the water. One design of an acceptable Ohio-type sampler is illustrated in "Standard Methods"[1]. The Juday bottle, or one of its modifications (e.g., Kemmerer, Van Dorn), also is acceptable. This type consists of a cylinder with stoppers that leave the ends open while being lowered to allow free passage of water through the cylinder. A messenger is sent down the rope at the designated depth to cause the stoppers to close the cylinder, which is then raised. Water is drawn through a valve and rubber tube in the bottom stopper to fill and overflow the DO bottle.

The Ohio type sampler is suitable for most bridge sampling and in moderate depths of water. The air in the sampler can be compressed and allow water to enter the sampler on the way down when used at depths where pressure is great, even when the air vent tube is valved to permit opening at the desired depth. This gives a partial composite through the depth traversed rather than a sample from the designated depth only. The Juday bottle is ideal for sampling at depths. It may be used from bridges also, but the messenger dropped from the height of the bridge will batter and ultimately ruin the triggers that release the stoppers unless special precautions are taken. The messenger may be supported a few feet above the sampler by an attached string and then dropped after the sampler is in place. Either the Ohio or Juday bottle type is suitable for use from a boat.

Water may enter around the top of the Ohio type sampler rather than through the inlet tube to the bottom of the DO bottle if the lid is not tightly closed or the gasket is leaking. There is aeration of the DO sample when this occurs. A similar error may result from an air outlet tube that is too large. Water gurgles in, with air escaping alternately, through the oversize air outlet. Evidence of both of these problems can be detected by watching the air bubbles from the sampler as they rise to the surface. There is a stream of small bubbles at regular, very short intervals when the sampler is working properly. The air rises to the surface intermittently, frequently in large, irregular blobs when the sampler is leaking air, and water is not flowing into and overflowing the DO bottle.

A hole in which an Ohio type sampler can be submerged may be scooped out of the bed of a very shallow stream or a small dam may be raised across a narrow stream. As an alternate, a bicycle or other small hand pump with valves reversed may be used to pull a vacuum on a quart, or larger, bottle. This bottle in turn is connected by a rubber tube and glass nipple through a rubber stopper in a DO bottle. An open end of a second tube is placed in the shallow water and the other end of this tube is attached to a glass tube extending to within a fraction of an inch of the bottom of the DO bottle. The DO bottle is overflowed as usual, into the larger vacuum bottle.

DO should be determined as soon as feasible after collection, preferably by the sampler at the point of collection. "Standard Methods" [1] recommends preservation, if immediate determination is not feasible, for as long as four to eight hours with 0.7 ml of concentrated sulfuric acid and 1 ml of 2 percent sodium azide solution, and storage at 10 to 20° C. with the bottle submerged. The instructions do not specify icing to near 0° C. and storage of the preserved DO sample in the dark, which have been found to increase precision of the determination.

"Standard Methods"[1] describes several alternative procedures to counteract interferences with the DO determination. One alternative particularly worthy of note is that only a polarographic instrument is suitable for the determination of DO in paper mill effluents. Swamp waters must be included in the same category. The polarographic instruments include the dropping mercury electrode and the galvanic cell oxygen analyzer. The latter is available as a field instrument. There is a problem even with the polarographic instruments. The most precise calibration requires comparison with the DO in samples of the water under examination in which the DO has been determined by iodometric titration. But the iodometric titration is not feasible for swamp water or water containing paper mill wastes. Somewhat less precise calibration may be accomplished by using 0.01 N potassium chloride solution.

## TEMPERATURE

It may appear absurd to say that temperature should be taken immediately after sample collection with the thermometer bulb submerged in the water, but some inexperienced samplers have been known to withdraw the thermometer from the water to read. It is much easier that way.

## pH

Often pH is determined in the laboratory after samples have been in transit and on the laboratory bench several hours. Descriptions of procedures in subsequent reports rarely indicate that the pH was determined hours after sample collection. Such data may vary by 0.3 to 0.5 units or more from the values in the stream. Algae can cause an increase in pH on standing by using free carbon dioxide and converting bicarbonate to carbonate. Active decomposition can lower pH on standing by producing additional carbon dioxide. pH should be determined in the field by the sampler at the point of collection. "Standard Methods"[1] does not mention this precaution, nor does it discuss the changes that can take place nor methods of preservation of samples. Both electrometric and colorimetric pH sets are available for field use.

## SAMPLES FOR OTHER DETERMINATIONS

Samples for transport to the laboratory may be obtained from the water in the Ohio type sampler that overflowed the DO bottle. When the Juday bottle is used there usually is enough water left for other samples after the DO sample is withdrawn.

## BACTERIA

Samples for bacteriological examination must be collected in bottles properly sterilized and protected against contamination. The preferable method is to scoop up the water with the open bottle just below the surface. This method usually is used when sampling by boat. While the bottle is open both bottle and stopper must be protected against contamination. A small amount of water should be poured from the bottle after filling, to leave an air space for subsequent shaking in the laboratory. The bottle should be closed at once.

When sampling from a bridge the sterilized sample bottle should be placed in a weighted frame that holds the bottle securely. The bottle should then be opened and lowered to the water with a string or rope. Care should be taken not to dislodge dirt or other material from the bridge that will fall into the open bottle. The mouth of the bottle may be faced upstream by swinging the sampler downstream under the bridge and dropping it quickly but without excessive slack in the rope. The sampler then is pulled upstream and out of the water, thus simulating the scooping motion of sampling by hand.

Special Ohio type samplers have been used to collect bacterial samples [8]. It was customary to insert a sterile glass tube through a one-hole rubber stopper in the cover of the sampler, with the lower end extending inside and near the bottom of the sample bottle. The bottle filled through this tube, and a fresh sterile tube was used for each sample. The air relief tube extended through the cover into the bucket far enough to reach below the top of the bacteriological sample bottle so that the sampler stopped filling before the neck of the bottle was submerged. These precautions are not generally followed any longer, although they probably are desirable when the maximum in sterile techniques is necessary.

The Juday (or Kemmerer) type sampler, as well as the Ohio type, has been used without special sterile precautions for bacteriological sampling in deep water. This practice probably is acceptable in most water quality studies. Cross contamination between stations that would significantly alter bacteriological densities or conclusions based on them probably would occur in only the most extreme situations.

A sample collected from a station with a very low coliform density immediately following collection of one from a very high density area conceivably might yield a bacterial density that was unduly increased by contamination from the high density area sampling. A juxtaposition of waters with such different coliform densities is not apt to occur. Even if it did occur the station with the low density usually could be sampled first. If a nonsterile sampling technique is used the sequence should be from low density to higher density stations to the maximum extent feasible.

Special equipment for sterile sampling at depths, when essential, is available. The ZoBell sampler, for example, includes a metal frame to hold the sample bottle, two sterile glass tubes connected by a ruber tube and inserted through the sterile bottle stopper, and a messenger. One of the glass tubes is bent so that the upper portion is horizontal, with this portion positioned next to the rope. The messenger breaks this tube, which allows the bottle to fill.

## PRESERVATION AND TIME LAPSE

Ideally bacteriological samples should be innoculated at the point of collection for most reliable results, and this can be done in a few situations. It is routine at sampling stations that are intakes of water plants with laboratories. It is practical with a sampling boat that is equipped with a bacteriological laboratory, which is rare. Otherwise there are problems of transporting the necessary equipment and media, and maintaining sterile techniques in the field. These problems can be met but the improved accuracy rarely is worth the extra effort required.

Samples thoroughly iced and delivered to the laboratory in the shortest time feasible, but not to exceed four to six hours, generally yield results within a few percent of true values.

The twelfth edition of "Standard Methods" [1] does not recommend icing of samples but rather storage at the temperature of collection until examination can be started. It recommends that examination be started as soon after collection as possible, preferably within an hour, but in no case exceeding 30 hours. This recommendation undoubtedly is based on consideration of treated water supply samples, only. Anyone who has collected and interpreted bacterial data from polluted streams cannot accept results on samples held uniced or for 30 hours. It is understood that the thirteenth edition of "Standard Methods" will recommend immediate icing and start of examination within six to eight hours for stream samples.

BOD dilutions have been made in the field at the point of sample collection in a few cases, but this is a cumbersome procedure at best. Well iced samples delivered to the laboratory in four to six hours give satisfactory results.

"Standard Methods" [1] should be consulted for preservation of samples for all other determinations of unstable constituents. Much research is needed, however, to develop the most reliable preservation methods for many constituents. Very little has been published on this subject that would allow the individual to judge for himself the adequacy of recommended methods.

The best all-around preservation method, when in doubt, probably is rapid reduction in temperature to near the freezing point by icing, and the starting of analysis within a few hours.

## FIELD NOTES

The sample collector should label all samples and complete all field analyses and necessary records before leaving a sampling station. Any attempt to depend on memory from one station to the next or until the end of the sampling run is certain to end in disaster. Also, another sample can be obtained to correct any error in a field determination without time lost in backtracking if the collector remains at each station until all procedures are completed.

Records should include date, station identification, time of collection, temperature and pH (if determined) of samples, condition of sky (sunny, cloudy, light rain), appearance of stream (clear, turbid, oil, scum), gage reading (if any), and any special observations that may be considered useful.

## CLEANING EQUIPMENT

Contamination of the sampling equipment by water from a badly polluted station should be remedied by rinsing with the water at the next station before the sample is taken. The same practice should be followed with sample tubes of field testing kits, such as those for pH. This applies also to the sampler or field kit glassware if contaminated by field kit reagents.

## BIOLOGICAL SAMPLING

The biologist considers the type of environment in selecting sampling equipment and method. A qualitative reconnaissance of types of attached organisms is undertaken first. Rocks and driftwood in riffles and shallow pools are lifted from the water and examined. Submerged branches and leaves of bushes and trees along the bank are inspected. Organisms are scraped from these solid surfaces and preserved for identification. The branches may be agitated by a fine mesh net, which catches the detached organisms.

Only the shallow water and submerged branches along the banks can be examined in this manner at stations where the water is deep. Soundings are made with a weighted rope in deep water to determine the types of stream bed so that each type may be sampled quantitatively subsequently. The sounding weight may include a small conical cup with lid, known as a reconnaissance sampler. This cup picks up samples of any bottom sediments that indicate the nature of the bottom.

When the population of aquatic organisms at a station has been established qualitatively and the type of stream bottom has been evaluated, the biologist proceeds with quantitative sampling that ensures inclusion of most of the representative types of organisms in the samples.

The Surber square foot sampler is used on most riffles and in shallow pools where flow velocity is adequate. Rocks and gravel to a depth of about two inches are lifted from the square foot area within the sampler, and scrubbed under water to remove the attached organisms. The current sweeps the detached organisms into the sampler net, from which they are transferred to a sample bottle and preserved for identification.

The Surber sampler is not satisfactory where there are significant organic deposits that support sludge worms and small midges. These small organisms pass through the Surber net and are lost.

The Petersen dredge generally is the sampler of choice in these cases and in most deeper water. One precaution in using this dredge is especially worthy of note. It should be lowered very slowly as it approaches the bottom. It can displace, force out and miss some of the lighter organisms and other materials, such as fluffy sludge and biological slimes if allowed to drop of its own weight.

The Ekman dredge has only limited usefulness. It does well where bottom material is unusually soft, as when covered with organic sludge or light mud. It is unsuitable, however, for sandy, rocky and hard bottoms, and is too light for use in streams with high flow velocities.

The stream bed may be unsuitable for all attached organisms, especially where it consists of shifting sand or hard packed clay. Artificial attachment surfaces, left in place for two to four weeks, may be necessary to evaluate the kind of attached organisms the stream with hard clay or shifting sand bottom can support.

# 6

# SAMPLING FREQUENCIES AND DURATIONS

Rules for frequency and duration of sampling cannot be hard and fast. The purpose of frequency and duration combined is to obtain enough samples at the proper times to yield results representative of the conditions under observation. The result sought usually is that elusive value known as a representative mean for a selected, limited and relatively stable portion of the range of possible variations in stream conditions. Maximum and minimum values frequently are desired also, especially in connection with monitoring for compliance with stream standards and substantiating biological data.

The problems of selection of proper frequencies and durations of sampling result from the variations in conditions that occur during the period of study. The major basic variations occur in volume and strength of sewage and industrial waste discharge, stream flow and temperature, light intensity from day to night, and rainfall and runoff, if any.

## NUMBERS OF SAMPLES

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

There is no fixed number of samples that will yield results within selected limits of precision in all situations. The number of samples needed for any point on a stream varies with the variability in water quality at that point. A preliminary estimate of the variability can be calculated after a limited number of analytical results has been obtained. A preliminary prediction of the number of samples needed to ensure final results within selected confidence limits can be based on the preliminary estimate of variability. The prediction can be refined as the number of analytical results is increased until the point is reached at which a firm prediction of the number of samples required becomes possible. Data from a previous study under comparable conditions may be used to determine variability and predict the number of samples required [9].

The principle that precision of measurement is increased in proportion to the square root, only, of the number of measurements indicates the diminishing returns from increasing the number of samples beyond a reasonable base. For example, the precision yielded by 16 samples will be increased only 20 percent by increasing the number of samples to 25, or 56 percent [9].

Experience has shown that, as a rule-of-thumb, 20 to 25 samples collected at a station during a period of relatively stable waste discharge, stream flow and temperature yield reasonably representative mean MPN values for coliform bacteria. Fewer samples may yield acceptable mean values of other constituents, since the method of MPN estimation is relatively imprecise.

An average of results from samples taken over a wide range of stream flows usually is relatively meaningless. Likewise, results on samples taken during summer and winter, or other periods of large temperature differences, should not be included in a common average. Data collected throughout the year or for several years, may be presented in terms of averages, and perhaps maximums and minimums, for each month or for three periods—summer, winter, and a combination of spring and fall.

More samples are required for a selected degree of precision close below a waste discharge than farther downstream. As longitudinal mixing smooths out the peaks and valleys of irregular waste discharges, fewer samples are necessary to obtain comparable precision. This suggests a possible means of savings in cost and effort in the study of a reach of stream. For example, samples might be collected every day at the first several stations below a source of irregular waste, but only every other day at the remaining stations farther downstream. There is a possible objection to this method, however, that may render it unworkable. The two sets of data may fail to match unless stream flow, waste discharge, light intensities and other variables that affect stream conditions are approximately the same on the days of limited sampling downstream as they are for the days of more frequent sampling upstream. Such a failure might invalidate an entire study. It cannot be known whether uniform conditions persisted during a study until the study is completed and all data are assembled. Efforts to match data obtained from a stream on different days or during different periods generally are something less than successful.

## DURATION

The objective of a study is a prime factor in decisions regarding frequency and duration of sampling.

A single point station most often is operated for a long-term purpose, such as maintenance of a record of water quality at a water supply intake or at a point on a stream below a waste source. The duration of sampling at such a station is indefinite, usually for so long as the use involved is continued.

Most monitoring stations are operated routinely throughout the year. Careful thought should be devoted to the real need for sampling during all periods of the year. A knowledge of raw water quality throughout the year is essential for a water supply. A monitoring station for a record of water quality should be operated year-round. On the other hand, sampling at a bathing beach is not necessary except during the bathing season. Monitoring below a waste treatment plant designed to protect the stream during low flows may be rather meaningless during high flow periods. Considerable economy might be achieved by limiting the operation of waste monitoring stations to periods of potential damage. The savings might be invested in more frequent monitoring during the more critical periods.

The duration of studies involving a series of stations, by nature of their objectives, usually is much shorter than that involving single stations. As a concomitant, sampling frequencies usually are much greater. The accurate measurement of natural purification rates, such as deoxygenation, reaeration and bacterial death rates, require reasonable stability of stream flow and temperature. The probability that acceptable stability will persist increases as the duration of the study is decreased. An ideal schedule in many ways would be hourly sampling for one twenty-four hour period. This would provide 24 samples at each station, which should ensure an adequate quantity of data. It also would cover any diurnal variations in waste discharge or regulated stream flow. Equally important it would cover the diurnal variation in DO that results from photosynthesis if DO depletion were a problem.

This method, however, is not without its disadvantages. Such intensive sampling requires a large field crew of sampling and laboratory personnel, and generous laboratory facilities. Not many organizations have staffs or facilities large enough to conduct such an intensive study if many stations and numerous constituents are involved.

Another disadvantage is that the waste discharges during the

24 hours may not be representative of those for other days. The relationship among downstream stations may be distorted if the waste varies from day-to-day. The waste concentrations at each, or at least some, stations may reflect a different waste discharge at the point of origin. This condition can be countered only by following the waste for a 24-hour period downstream and sampling it as it passes each station. Natural purification rates can be established by this procedure. However, neither the day-to-day variation in wastes and their effects nor the needed reduction in the maximum waste load will be determined by this method. Finally, sampling at night, especially by boat on a navigable stream, may involve hazards to which sampling personnel should not be exposed.

The sampling schedule must be adapted to the available personnel and facilities. Sampling every two hours for two days, every three hours for three days, and so on to every six hours for six days would provide the same number of samples. The possibility that an excessive change in stream flow may occur increases as the sampling period is increased. Temperature is not as apt to vary as greatly as stream flow.

Intensive measurement of water quality for 24 hours at a station below a waste source, following the same body of water downstream and measuring its quality at successive stations would appear to be the most accurate method for determining natural purification rates. This method has been used a number of times, but not always with the outstanding success that might be expected of it. Probably the fault is not with the method but with the difficulty of its execution. A large field crew, round-the-clock sampling, and almost military precision in coordination are required. Tracking the water past successive stations, sampling at proper times, and early analysis of samples that are brought in at all hours of the day and night is not a job for an amateur crew.

As a practical matter, relatively few stream studies involving a series of stations are conducted on a round-the-clock basis. As a result, the most critical effects of pollution sometimes are not detected. The sampling frequency for most studies is once daily for the work days of the week. The duration commonly is two to three weeks because of budgetary and personnel limitations. Thus a total of 10 to 15 samples is obtained at each station.

## FREQUENCY

Frequency of sampling varies with the water use, the urgency of developing a representative record of quality, and the capacity of the responsible agency for sample collection and analysis.

Sampling usually is at least daily for an operating water supply. One sample a day should be adequate to evaluate water quality on a monthly average basis unless quality changes rapidly because of variable stream flow or waste discharge. The single daily sample should not be collected at a fixed time each day but rather at systematically alternated or at completely random times throughout the operating day. This variation in time of collection ensures measurement of the effects of any diurnal changes in quality.

Sampling of raw water may be as often as once a shift or even every hour at larger water plants with substantial laboratory facilities. Continuous records may be maintained for a few constituents for which reliable automatic monitors are available. The more frequent analyses generally are useful for guidance in hour-to-hour control of treatment processes rather than for over-all evaluation of raw water quality, and are conducted primarily for that purpose.

Daily or more frequent sampling of the raw water at a water plant presents no problem because the sampling point is readily available to the laboratory. Sampling to monitor the effects of a waste discharge on a stream usually is less convenient. The sampling point may be some distance from the waste treatment plant laboratory. In addition, the most desirable sampling point may be relatively inaccessible. As a result, sampling frequency rarely is more often than once daily and is apt to be less.

The waste monitoring stations operated by pollution control agencies are still farther from the agency's laboratory than they are from the waste treatment plant laboratories. Control agencies rarely sample such stations more than once weekly and many are sampled only monthly. A few are sampled only two to four times yearly. A great many violations of standards can occur undetected during the long intervals between such infrequent samplings.

Many considerations involved in monitoring a waste source are applicable to single stations for developing a record of water quality. There are two principal differences. Sampling for a record of quality need not be so frequent if a station is not close below a source of waste. The flexibility possible in location of quality record stations, noted previously, may permit placing the station either above or well below the waste source. The same flexibility also may permit locating the station at a point of water use, such as a water plant or a power house. Here operating personnel are available to collect samples and to perform some of the necessary analyses. The frequency of sampling in this case may be as often as needed.

Frequently, the principal interest in water quality is for some limited period, such as the month of September, for example. In this month stream flows are low, temperatures are relatively high and both usually are reasonably stable throughout the month in most areas of the country. The frequency of sampling may be governed by the time available before a representative mean value or the range of values is required. It would be desirable to sample at least every work day during September, if the quality must be known within a year. This would provide 20 to 22 samples, based on the distribution of week-ends in the particular September involved. If the value is not required before five years, sampling once weekly would provide 20 to 21 samples by the end of that time.

At the extreme, one sample could be taken in September of each year, if the value is not needed before 20 years. Of course, the water quality probably would change during that length of time and the 20-year average would not be representative of the existing quality at the end of that time.

The monthly sampling frequencies cited above could be halved to provide the necessary number of samples if stream flows and temperatures should be sufficiently stable for two consecutive months of each year, to permit spreading the frequency over two months annually.

## CONTINUOUS MONITORING

The limitations imposed on desirable frequency of sampling by available budget, personnel and facilities are most obvious in schedules for monitoring below waste discharges. Sampling as frequently as is desirable only rarely is possible. Daily monitoring for critical constituents is a desirable minimum, at least during periods when stream flows are low and water quality damage is most apt to occur. The ideal is continuous sampling during such periods. Continuous monitoring is feasible only for the limited number of constituents for which reliable automatic recording equipment is available. Principal water quality characteristics for which such equipment is commonly used are temperature, DO, pH, conductivity and turbidity.

Many wastes have important constituents, such as BOD and coliform bacteria, for which continuous monitoring equipment is not available. Monitoring for these constituents still must depend on less frequent hand sampling. In addition, the automatic equipment is expensive. It must be housed and have a power source, which rarely is close to the desired location of the waste monitoring station.

# 7

# SAMPLE EXAMINATION

"STANDARD Methods for the Examination of Water and Waste-Water"[1] gives instructions for most of the biological, bacterial, physical, and chemical methods of examination that are necessary in a water quality study. This chapter will not infringe on that territory, but rather will attempt to suggest practical bases for deciding what types of examinations should be made.

Here again the objectives of the study influence the choice of determinations to be made. The whole "laundry list" of examinations described in "Standard Methods"[1] could be chosen if the objective is to establish a broad base-line record of water quality, for example. Practicality must be considered, however, and sound judgment exercised to hold the list to manageable and useful proportions.

## WATER QUALITY STANDARDS

Analyses should be made for those constituents for which water quality standards have been adopted. Constituents for which numerical standards commonly are adopted include temperature, DO, pH, gross radioactivity and coliform bacteria. Less common are limits for such heavy metals as lead, iron, manganese, silver, and selenium, and especially those used in metal plating, such as chromium, copper, zinc, nickel, and cadmium. Still other limits are for phenol, threshold odor, detergents, filterable residue, chloride, phosphate, ammonia, nitrate, sulfate, fluoride, arsenic, barium, boron, and cyanide.

There may be standards for almost anything that may be added to water. Many of these are neither specified nor limited numerically, but rather are covered by general statements, such as "not in concentrations or combinations that will be toxic (or detrimental) to humans, fish and other aquatic life." This applies not only to heavy metals, but also to organic toxic materials, such as pesticides.

The general prohibition designed to protect aquatic life appears in practically all water quality standards in one form or another. Judgment of compliance with this requirement necessitates biological sampling and examination.

Examination of plankton samples may or may not be necessary. Plankton populations vary so drastically, rapidly, and widely that practical interpretation of their significance often is quite difficult. If there is a potential use of the stream as a source of municipal water supply, plankton data may reveal the possibility of taste and odor problems, and of difficulties in treatment, such as rapid clogging of filters. The certainty that bottom organism examination definitely is a useful determination contrasts with some doubt of the value of plankton data.

## BASE-LINE RECORD OF QUALITY

Proximate mineral analysis for anions and cations commonly present in water might well be included along with standards constituents in the base-line list of determinations. Proximate analyses include calcium, magnesium, sodium, potassium, bicarbonate and carbonate, chloride, nitrate and sulfate. So-called mineral analyses often include, in addition to the above, silicate, ammonia, conductivity, pH, filterable residue, turbidity, aluminum, iron, manganese, and fluoride. Data on many of these constituents are useful in judging suitability of water for municipal supply, and especially for many kinds of industrial supply. They are a must in design of treatment for water to be used for high pressure boilers.

Lists of constituents that may be involved in standards and those determined in the usual mineral analysis include some duplication. Appropriate constituents for base-line data may be selected from these lists, and others may be needed to detect materials or effects of materials that result from industrial wastes. Any attempt to list even a portion of the infinite variety of materials in industrial wastes would be useless. They should be determined in each case by review of the industrial processes involved.

## MUNICIPAL WATER SUPPLY

Routine monitoring of a source of municipal water supply normally includes determinations of temperature, alkalinity, pH, hardness, turbidity, color and coliform bacteria, and chlorine, coagulant and other chemical treatment requirements. Less common or less frequent determinations may include threshold odor, phenol, ammonia, proximate mineral analyses, iron, manganese, and other heavy metals, total dissolved solids, gross radioactivity, bacterial plate counts, and plankton.

## WASTE MONITORING

Examinations of samples from a single station for monitoring the effects of a waste discharge are selected on the basis of the constituents of the waste and their effects on water quality. Any standards that may be violated are included. The determinations normally include total and fecal coliform bacteria, temperature, BOD, and DO if the waste is municipal sewage with no industrial waste complications. Ammonia, nitrates, COD, chloride, pH, turbidity, color, filterable residue, settleable solids, and phosphate may be determined in some situations. When industrial wastes are involved, determinations are selected on the basis of the constituents of the industrial wastes and their effects on water quality.

## EFFECTS OF WASTES

Most studies involving a series of related stations are designed to trace the effects of one or more wastes on water quality. Temperature, BOD and DO are the determinations most frequently made, when sewage and many organic industrial wastes are involved, to evaluate rates of deoxygenation and reaeration and the assimilation capacities of streams for oxygen demanding wastes. Coliform bacteria are determined when sewage and some industrial wastes, such as those from meat-packing, beet sugar production, and pulp and paper manufacture are involved. Nitrogen compounds and phosphate may be of concern. Supplemental examinations for pH, alkalinity and turbidity often are made to determine whether these factors are normal and on occasion to aid in interpreting the principal data.

Here again determinations of constituents characteristic of specific industrial wastes and of their effect on water quality are tailored to knowledge of the types of wastes involved. Any attempt to name all possibilities would be endless.

Examination of bottom organisms at a series of related stations is particularly useful in following the course and determining the limits of degradation and recovery from pollution. Bottom organisms examination may be supplemented by examination of attached algae and fish populations. A biological investigation should be an integral part of essentially all stream pollution studies.

## LIMIT ANALYSES TO ESSENTIALS

Decisions regarding determinations to be omitted can be almost as important as those regarding determinations to be made. Unnecessary determinations not only add nothing of value to the study but waste laboratory staff time and effort that might profitably be used on more significant constituents or on a greater number of samples. Data on pH, alkalinity and turbidity, for example, probably will be useless when they are requested for no better reason than "they are easy to run" or "they don't take much time." The appendices of all too many reports are filled with tables of such data, to which no reference is made in the texts of the reports. The tables increase the thickness of the reports and may appear impressive to the uninitiated. They impress the "old pro" as evidence of poor judgment and wasted effort. The determinations should be worth a page or two of interpretation in the text if they were worth making.

There may be borderline cases, in which one or more constituents may or may not prove to be important. Some expected constituents may be absent. The importance of some constituent may not be possible to evaluate definitely in advance in some situations. Analyses for those constituents on two or three early sets of samples will provide a basis for judging whether to include or omit their regular determination. Continuation of determinations once the insignificance or absence of the constituents has been established by preliminary examination is wasteful unless there is reason to believe the constituent may increase or appear irregularly.

## JUDGMENT

Suggestion of a specific list of determinations that should be made for each type of study obviously is impossible. In selection of determinations to be made, sound judgment must be exercised in tailoring the list of analyses to the particular situation. Probably no other single feature of a study requires better judgment. Decisions must be based on objectives of the study, present and probable future uses of the water, natural quality characteristics of the water, constituents of waste, if any, and their potential effects on water quality, and personnel and facilities available for the job.

# 8

# STREAM FLOWS

STREAM flow is one of the primary factors in water quality. Both natural water quality and the effects of wastes in a stream vary as stream flow changes.

## EFFECTS OF FLOW VARIATION

Concentrations of natural constituents, such as alkalinity, hardness and minerals, generally vary inversely with stream flows in uncontrolled streams. Most of the water in a stream at low flows has spent much time underground in intimate contact with the minerals of the soil and has dissolved maximum concentrations of these minerals. At least some of the water at high flows has run off directly over the surface of the ground, and some of it has been underground a relatively short time, with less opportunity to dissolve minerals.

Total loads, or quantities, of natural constituents carried by a stream, on the other hand, increase as flow increases. The increasing water carried by the stream more than balances the decreasing concentration to yield a greater load in terms of a unit of total quantity, such as pounds per day.

Concentrations of wastes also vary inversely with stream flow when completely mixed with the stream immediately below the point of discharge. Negligible adverse effects of wastes may occur at high flows, whereas the stream may be polluted seriously at low flows.

The minimum flow for which a stream is to be protected and desirable water quality maintained is a critical factor in design of waste treatment plants. The seven-consecutive-day minimum flow that occurs once in 10 years commonly is used as the basis for plant design.

The inverse relationship of stable waste constituents to stream flow continues downstream until additional dilution by tributary inflow occurs. Other factors come into play with unstable constituents. Time-of-water travel increases as flow decreases to accomplish natural purification in shorter distances. Higher densities of bacteria, for example, occur just below the point of discharge at lower flows, but they die off in shorter distances because of the longer time of travel. Likewise, BOD's are higher near the point of discharge but stabilize in less distances at low discharges. DO concentrations drop to lower minimums but recover in shorter distances. Other factors, in addition to time-of-travel, contribute to the DO recovery. The stream surface, through which oxygen enters the water from the atmosphere, usually decreases only slightly as stream stage and flow decrease. Approximately the same quantity of oxygen enters decreasing quantities of water in a given stream reach as flow decreases, other things being equal. Therefore, the concentrations of DO in the smaller quantities of water increase as the flow decreases. The decrease in depth with decreasing flow generally increases the reaeration coefficient. The reverse of this variation may occur, however, in deep pools with relative low velocities at minimum flows. These factors, together with stabilization of BOD in shorter distances, combine to accomplish recovery of DO in shorter distances at lower stream flows.

## NATURAL ANNUAL CYCLE

The natural flow of uncontrolled streams usually varies over a wide range. Stream flows follow precipitation patterns except in the colder areas of the country, where precipitation falls as snow in winter and much of the surface water is frozen. There can be wide differences in stream flow throughout the year and in the annual flow cycle from year to year. Flow in most areas tends to be high in winter, especially in January and February, and to taper off subsequently to minimum quantities in September and October and, on occasion, into November. October is the minimum flow month as a general rule. High flows usually occur in colder areas when relatively warm spring rains melt the winter accumulation of ice and snow.

## CONTROLLED FLOWS

The natural cycle may be altered to a considerable extent in streams controlled by impoundments. The objective of control for power production is to maintain reasonably uniform average monthly flow throughout the year. This does not result in uniform daily flow, however. The daily flows are governed by power demands, being low at night and on weekends, and high during daylight hours of Mondays through Fridays.

Flow control for power production presents special problems in the collection of representative stream samples. The flow just below a power dam may drop within a few minutes from several thousand to a few hundred cfs (Figure 4). Round-the-clock sampling at frequent intervals is essential to obtain representative data in such situations. Continuous records of stream flow at each sampling station must be maintained. All samples preferably should be analyzed separately but, if compositing is necessary, the composites should be proportioned to flow. The stream sampling procedure may be similar to that of sampling an industrial waste with highly irregular flow.

The main objective of flood control is to reduce the peaks of floods. Reservoirs are kept as low as feasible, consistent with maintenance of conservation pools, in advance of floods. All water possible is stored during flood periods and, when flood flows cease, is released as rapidly as possible without causing downstream flooding.

Maintenance of a selected constant water depth is the objective of control for navigation. This may be accomplished by dams on navigable streams, in which case relatively little control of flow may be necessary. It may be accomplished also without dams by relatively steady, continuous release of water from upstream impoundments. The resulting steady flow is ideal for stream studies.

Control of stream flow for irrigation presents special problems to anyone concerned with stream flow at some downstream point or reach. As much flood water as possible is stored for later release during the planting and growing season. Generally fairly steady, continuous releases are made from irrigation impoundments during the growing season. Almost anything may happen to the flow from there on downstream. The flow of irrigation streams often decreases downstream as water is diverted to irrigate crops. This is contrary to the continuous increase in flow downstream that is typical of uncontrolled streams. A portion of the water is consumed and the unconsumed portion is returned farther downstream. The result is a bewildering series of suddenly decreasing and increasing flows on proceeding downstream. No general principles can be applied to such a system, but each must be investigated to determine the pattern peculiar to that system.

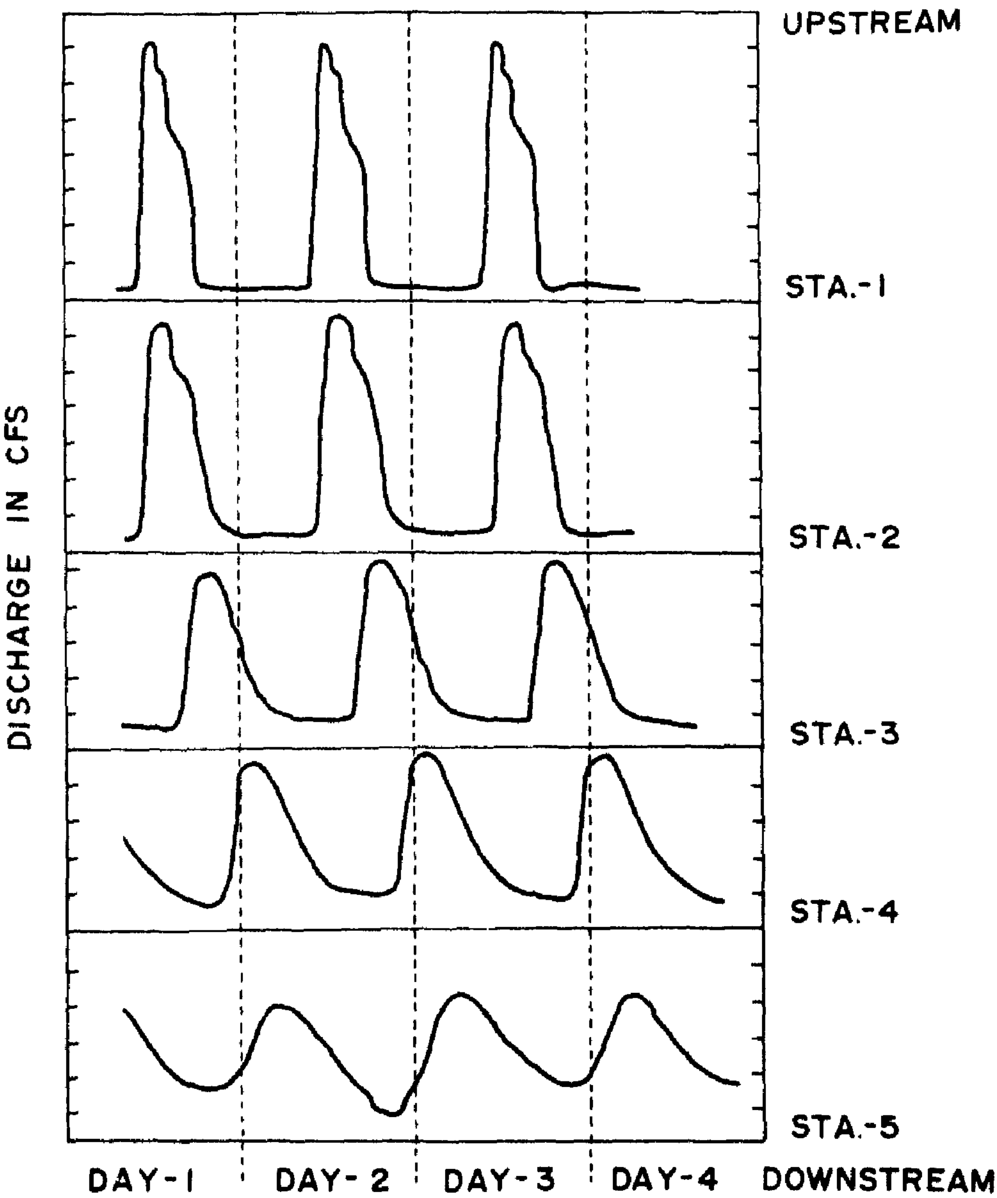
## SELECTION OF SAMPLING PERIOD

Stream flows must be considered in selecting periods for stream study because of the considerable variations in water quality that accompany changes in flow. The objectives of the study are important in this selection as they are in other decisions.

Meeting the objectives for most single, isolated station studies generally requires knowledge of water quality under all conditions of flow, since most water uses are year-round. The period of study is usually year-round, for several or many years.

The objective of a study involving a series of related stations usually is to determine the course of pollution and recovery for a limited, stable combination of stream conditions. The combination of low flow, high temperature that is most adverse for DO depletion often is selected. The warm weather month of minimum flow most often is October, as noted previously. The month of Septem-

FIGURE 4
EFFECT OF HYDROPOWER PRODUCTION ON STREAM FLOW




ber may be a better choice, however, for a study of maximum DO depletion. Although stream flows usually are not quite so low in September as in October, they usually are relatively low and temperatures are higher than in October. The effect of the combination of flow and temperature in September may be such that lower DO occurs in that month than in October. The lowest DO may occur in winter months in northern areas where ice cover occurs. Of course, not all stream studies can be made in the months of most adverse conditions. Fortunately, studies can be made under other conditions than the most adverse and the results can be projected to more adverse conditions of low flow and high temperature.

The combination of stream flow and temperature that is most adverse for DO may not be most adverse for bacterial contamination. Bacteria die off very rapidly in the first day or so below their source. A relatively small reduction in time-of-travel, caused by a moderate increase in flow, can allow a much higher density of bacteria to reach a downstream point within the first day's time-of-travel, in spite of the greater dilution. Also, the bacterial death rate is lower in colder water and they persist farther downstream in cold weather. This combination of conditions can over-balance the lower density immediately below the source that results from both moderately higher flow and lower per capita contributions of coliform bacteria in cold weather. As a result, the water supply intake within a day's time-of-travel below a source of bacteria may receive water with the highest bacterial densities at moderate flows and cold weather temperatures.

## EFFECTS OF PEAK FLOWS

A period of reasonably stable stream flow during a study involving a series of stations is highly desirable, regardless of the objectives of the study. A study should not be started soon after a marked rise in flow caused by rainfall and runoff. A convenient rule-of-thumb is that flows in medium to large streams decrease from their peaks at rates of about 10 percent per day. Thus, in one week the flow could fall to less than one-half of the peak and in two weeks to less than one-quarter of the peak.

Data obtained during such a range in stream flow can not be expected to yield valid averages. Initial concentrations of wastes immediately below the source and times-of-travel to downstream stations vary greatly during such a period. These variations cause changes in unstable constituents that occur between the source and each downstream station to differ for each increment of flow. Moderate changes of 10 to 20 percent in flow normally are unavoidable during a study, but the differences in dilution and time of travel they cause are relatively minor and are acceptable.

An abrupt rise in stream flow following a heavy rainfall and runoff during a study involving a series of related stations can totally disrupt the reasonably stable conditions needed for study. The study may as well be suspended until the stream settles down again, unless data on a period of high runoff would be useful. The variable flow causes the problem described above and, in addition, the surface runoff can add loads of polluting materials that may equal or even exceed those from the sources of waste under study. High coliform densities are almost certain to occur. BOD can increase sufficiently to cause DO depletion down to the range of 4 to 5 mg/1, in even the largest of rivers, such as the Mississippi and the Missouri. Oxygen depletion from man-made wastes is very minor in these two streams. Flood flows can dislodge bottom organisms and sweep them from the reach under investigation in many streams. Several weeks may elapse before organisms drift into and repopulate the reach sufficiently to serve as indicators of water quality.

## SOURCES OF FLOW DATA

The U.S. Geological Survey is the official agency for stream flow measurement and recording in the United States. Their program depends heavily on the cooperation and budgetary support of the states. The U.S. Corps of Engineers and the U.S. Bureau of Reclamation maintain stream flow records on streams for which they have especial responsibilities.

Stream pollution control agencies only rarely make stream flow measurements on any but the smallest streams. They traditionally depend on the Geological Survey, or occassionally the Corps of Engineers, the Bureau of Reclamation, or the Environmental Sciences Services Administration (Weather Bureau) for the necessary flow records.

Usually only one, or at the most two, stream gaging stations are situated in a stream reach being studied. Occasionally there are none. Stream flow data should be available at every sampling station and on all major tributaries during a sampling period to provide a sound basis for interpretation of results. The Geological Survey contracts to provide flow records, either by establishing flow measurement stations at the necessary points or by extrapolation from existing stations. Their official flow records normally are published annually several months to a year after the end of the water year, which ends September 30. Under special contract they undertake to furnish the records for the period of a stream study as soon as the stream stage data can be converted to flow. The records may be designated as "tentative," but are adequate for all but the strictest legal uses.

The Geological Survey should be notified as far in advance of a stream study as possible, especially if establishment of new gaging stations is necessary. Flow measurements must be made at several river stages to develop rating curves. The probability that the necessary range in stream stages will occur is greater, of course, as the time available is increased.

# 9

# TIME-OF-WATER TRAVEL

## IMPORTANCE IN RATE STUDIES

Determination of times-of-water travel between stations is essential when the objective of a stream study involving a series of related stations is to determine rates of change of unstable constituents, such as bacteria, BOD and DO. These time-dependent constituents have been subjected to mathematical analysis and formulation for projection to other combinations of stream flow, temperature and waste load than those examined. Many other unstable constituents could, and probably should, be treated in a similar manner. The oxidation of ammonia, the decomposition of phenol, and the decay of radionuclides having relatively short half-lives are only a few examples of the many unstable constituents for which rates of change in streams might profitably be formulated and used in projections of data.

## OTHER USES

Time-of-travel data can be useful for purposes other than determination of unstable constituent rate changes. A pollution control agency rarely receives notice of a fish kill, for example, in time to reach the area and detect the responsible materials in the reach where the fish died. When the time of the kill can be established and time-of-water travel data are available, the downstream location of the slug of water in which the fish died can be estimated. Examination of the slug increases the possibility of identifying the probable cause of the kill.

The times of arrival of a spill of a material that would cause difficulty in water treatment at downstream water plant intakes can be estimated with time-of-travel information. The water plant operators can then take steps to stop pumping raw water during passage of the material, or to adjust the water treatment processes to compensate for its effects.

Time-of-travel data are especially useful in planning a stream study, and may be useful in its conduct. The information provides one basis for judgment in selection of sampling stations, and in deciding the length of reach to be examined. It can be used to estimate the subsequent downstream position of a mass of water in which some abnormal result was obtained at one or more sampling stations. This allows additional sampling of the water mass to confirm or revise any idea or conclusion based on the abnormal result.

Determination of time-of-water travel is one of the most neglected of the factors involved in stream studies, even though it is essential for complete interpretation of data on unstable constituents and is useful in other ways. Its determination is not particularly difficult and does not require more than a small fraction of the personnel time and effort usually devoted to the collection and analysis of water samples. Furthermore, once determined, the data are permanently useful unless some major change in physical characteristics of the river occurs. An example of such a change would be the elimination of an oxbow either by natural establishment of a new channel, or by a man-made cutoff. Repeat studies of pollution frequently are necessary as waste loads or types change, in contrast to the permanence of time-of-travel data.

## METHODS OF DETERMINATION

Time-of-water travel can be determined by several different methods. The three principal methods involve use of surface floats, use of a tracer such as a dye or radionuclide, and measurement of cross-sectional areas.

A word of caution must be inserted regarding the fallacy of using times of travel that are derived from changing stage heights as rises in surface levels, accompanying increased flows, advance downstream. The Corps of Engineers and others concerned with flood control frequently develop and use such curves. They are properly used in flood predictions or control but are not usable in determining rates of change of unstable constituents. They are measures of the times-of-energy-wave travel that occur with increases in stream flow. Energy waves move much faster than do the water masses involved, and therefore require much less time to traverse any particular stream reach.

### Approximations

A very rough method for preliminary estimates of time-of-water travel consists of dropping sticks or other floatable objects from bridges in the current of the stream reach under observation, and noting the time required for them to float an estimated 10 feet, or some other convenient distance. The velocity estimates are too inaccurate for use in interpretation of data or final reporting, but can be useful in preliminary planning of studies and in subsequent more precise measurements of time-of-water travel.

Stream velocities at gaging stations, measured by the Geological Survey in developing rating curves, may be applied to the entire reach under observation to estimate times-of-water travel. This is somewhat more refined than the floating objects estimates, but still can be far from accurate. There rarely are more than one or two gaging stations in even a lengthy stream reach. Stream channels generally are restricted at gaging stations and velocities there generally are higher than average velocities throughout the reach.

## Floats

Surface floats may be followed downstream and timed for known distances to determine times-of-water travel. This requires exercise of considerable judgment, for floats tend to travel into quiet or eddy areas, or to become stuck on tree limbs, the stream bank, or other obstacles. The floats must frequently be retrieved and returned to the current of the stream. The principal judgment factors are how long the floats should be left in quiet areas before retrieval and where they should be placed in the current.

The surface water velocity is greater than the average for the entire stream, and a correction factor must be applied to the surface velocity. An average velocity of about 85 percent of that of the surface velocity is a reasonable rule-of-thumb value.

Oranges make very satisfactory floats. Their density is such that they float with only a small portion of their tops exposed to wind action. Their yellow color is easily detected and followed in the water. They tend to rotate around obstacles rather than to hang up on them because of their spherical shape. They are easily thrown back into the current when picked up in quiet areas.

Dumping a number of oranges into a stream at a bridge, traveling to another bridge downstream by car, and timing the oranges as they arrive would appear to be a simple procedure. This does not work because of a little appreciated self-purification ability of streams, that of ridding themselves of floating litter. Floating objects tend to move towards the banks of a stream fairly quickly and to be deposited there. On one occasion an entire crate of oranges was thrown into a stream at one bridge and their arrival awaited at another bridge a few miles downstream. Not a single orange was detected at the downstream bridge.

## Cross Sections

Measurement of cross sections at frequent longitudinal intervals and calculation of average velocity from the average cross section and stream flow at the time of measurement constitute a time-consuming method of obtaining times-of-water travel. This method does, however, produce information that is useful for other purposes. It affords a detailed appreciation of channel characteristics that can be obtained in no other way. Reaeration coefficients may be calculated by one of the formulas based on average depths and velocities.

The necessary field measurements of cross sections may be made by a combination of land surveying and depth sounding methods. Water surface elevations and stream widths must be measured at the selected cross sections. Soundings may be made with a weight on a rope, a pole, or sonar. The resulting data for each cross section are plotted to scale and planimitered to obtain cross-sectional areas. The stream flow at which the measurements are made must be obtained from available gaging stations or by special measurement. Depth soundings and stream widths on some navigable streams are available from the Corps of Engineers.

The longitudinal intervals at which cross sections should be measured vary with the characteristics of the stream channel. One cross section per mile may be adequate for streams with reasonably uniform channels. Cross sections at every tenth of a mile may be desirable for streams with quite irregular channels.

## Tracers

The most nearly accurate method of measuring time-of-water travel involves following a tracer downsteam. An industrial waste may include an occasional discharge of some constituent that can serve as a tracer. Salt may be used in small streams, but handling the large quantities needed for large streams is a problem. Radioisotopes have given good results, but their safe handling can present problems and their use must be approved in advance by the Atomic Energy Commission. Public reaction to their use may be adverse, especially if a municipal water supply is involved. Their detection is more complicated than is that of dye. Several kinds of dyes have been used, with the trend in recent years toward use of Rhodamine WT. This dye can be detected in concentrations as low as 0.05 part per billion by a fluorometer.

The dye, or other tracer, is distributed across the stream at the upstream point, as nearly instantaneously as possible. The ideal distribution produces a narrow band of tracer in uniform concentration across the stream. The band of tracer mixes with water ahead of and behind it by diffusion, or longitudinal mixing, as it moves downstream to produce an increasingly wider band. The peak concentration remains near, but somewhat downstream of, the center line of the band and decreases as longitudinal mixing proceeds. The times-of-water travel to downstream points are the differences between the time the dye was added to the stream and the times the centroid of the dye mass arrives at downstream points.

Peak concentrations of Rhodamine WT dye at downstream points in the range of one to 10 ppb allow satisfactory definition of the downstream dye concentration curve when this dye is the tracer used. Several empirical methods of calculating the dosage of dye needed at the upstream point have been proposed.[10, 11] All of them involve estimates of one or more stream characteristics, such as flow, velocity, length of reach, volume in the reach, cross-sectional area, average depth, and the roughness coefficient, "n" of Manning's formula. The simplest method is calculation of the weight of dye required to produce a concentration of one ppb in the estimated total volume of water in the reach between the two points where time-of-travel is being determined. The calculated dosage produces concentrations in excess of one ppb at the downstream point, since the dye is not actually mixed with the total volume of water in the reach.

The stream should be sampled frequently as the dye arrives at the downstream point to define the curve of concentration versus time, with especial emphasis on the peak. The frequency may be varied from once each minute to once every 10 to 15 minutes, depending on how wide the band of dye has become at the sampling point. Available equipment pumps water from the stream and measures and records dye concentrations continuously.

The dye may be missed altogether by overestimating the time required for it to travel downstream. Much time may be wasted, on the other hand, waiting for it to arrive if the time-of-travel is underestimated. All information that will contribute to the best possible preliminary estimate of the time required should be used.

## PROJECTION OF DATA

Projection of data obtained at one stream flow to some other flow requires determination of time-of-travel for the other flow. The probability that the other flow will be available for measurement of time-of-travel when needed is very slight. Measurements should be made at three different flows as appropriate flows occur. The measurements preferably should be made in advance of the stream study, if possible. The resulting travel times plotted against the corresponding stream discharges for each stream section provides curves from which other travel times may be obtained by interpolation or extrapolation. Times of travel for the stream flows of both the study and the projection may be obtained in this way.

If cross sections are measured to determine time of travel, longitudinal profiles of the stream's water surface at three or more flows can be determined from available flow gaging stations or from staff gages established at the time of the cross-sectional measurements. The profile at the desired flow can be interpolated or extrapolated from these profiles, and cross sections determined for this flow by interpolation or extrapolation. This method requires measurement of the cross sections up to the level of the highest profile used. This involves surveying methods above water level if cross-sectional measurements are made at a stream profile below the highest one examined.

# 10

# THE FIELD LABORATORY

Most stream studies involving a series of related stations and more than three to four hours driving time from the headquarters laboratory require a mobile laboratory for examination of unstable constituents, such as bacteria and BOD.

## MOBILE LABORATORIES

Two types of mobile laboratories commonly are used. The trailer type requires a separate tractor, while the van type is self-propelled. The trailer laboratory provides more space than the van laboratory with the same outside dimensions, but its transportation is more of a problem. Pollution control agencies rarely own a tractor for hauling trailer laboratories, for they are expensive and are used only occasionally. It usually is more economical to rent a commercial tractor when a trailer must be moved. A commercial tractor may not always be available at just the time that it is needed. The van laboratory can be moved as needed by members of the field crew, but the trailer only when a tractor is available. Two vans or trailers may be used, one for chemical and one for bacteriological examinations.

When a large body of water is to be sampled for a long period, equipping a boat as a laboratory may be justified. A boat large enough to serve as a complete laboratory, however, requires an experienced pilot and usually at least one crew member.

Biological studies rarely require a field laboratory, since most biological samples are preserved for examination in the headquarters laboratory. A small van-type truck or station wagon may be used for transporting sampling equipment, boots and waders, and supplies such as bottles, simple chemical kits and preservatives. A small bench with a microscope light and sink may be set up in the small truck, or the work may be done in one of the larger chemical or bacteriological mobile laboratories when examination of live specimens in the field is desirable. The biologist frequently has occasion to use analytical kits for simple field determinations such as DO, pH and temperature, or to prepare samples for the light-dark bottle tests of photosynthesis.

## FIXED LABORATORIES

Space in a permanent local laboratory of a water or sewage treatment plant, an industrial plant, a university, or even a high school may be used on occasion in place of a mobile laboratory. This is not always as advantageous as it may appear. Supplies and special equipment must be packed and shipped, unpacked at their destination, and set up in a strange laboratory. This requires a great deal more effort and time than does preparation of a mobile laboratory once it has been equipped and used on previous studies. Frequently the space in the local laboratory must be shared with others, which can lead to conflict with regular employees of the laboratory. Access to the laboratory may be restricted, especially at night and on weekends. All of these factors should be considered in any decision to use a local laboratory if a mobile laboratory also is available.

## ADJUSTMENT OF WORK LOAD

A common failing in many stream studies is an overload imposed on the field laboratory facilities and personnel. The individual planning a study, especially if he is an engineer, cannot understand how a few apparently simple determinations can take so long unless he has worked in a laboratory himself. He does not appreciate the time-consuming housekeeping duties of the laboratory, such as washing glassware, preparation of stock and standard solutions and bacterial media, and calculation and tabulation of results of analyses. As a result, the initial plan frequently calls for something like twice as many determinations as the laboratory crew can make. This can lead to an overworked and disgruntled crew, and to sloppy analytical results if the workload is not adjusted.

Of course, all of this can be avoided. The supervisor of the study and the laboratory chief, or other individuals of the laboratory crew, should cooperate closely in the initial phase of the planning. The length of the study period may be increased to reduce the daily number of determinations, sampling stations may be dropped, or the laboratory crew may be increased, if the plan calls for more determinations than the laboratory crew can handle comfortably and efficiently. Most field crews away from home do not mind a reasonable amount of overtime, but excessive overtime can cause weariness and poor quality of analytical data.

## PREPARATION

The mobile laboratory should be in first-rate operating condition with all equipment in order and a plentiful supply of laboratory supplies and reagents before it leaves headquarters. Any preparation postponed until the laboratory arrives in the field can take several times as long to accomplish there as at headquarters. Laboratory suppliers, mechanics, electricians, and similar supply and service agencies, and the quality of their supplies and services are known at headquarters from past experience. Time is consumed in locating such supplies and services in the field and, in addition, their quality and reliability are unknown. Every day lost in the field making preparations that should have been made at headquarters increases the cost of the study by that much.

Arrangements for location of the mobile laboratory in the field should be made in advance of its arrival there. Permission should be obtained for parking at a suitable location. Preparations for connecting to water and current sources, including meters if necessary, should be completed. The location should include a place for discharge of the laboratory drain where it will not cause a nuisance or pollution.

The mobile laboratory should arrive at the field location at least a couple of days before sampling starts to allow time for unpacking, starting up and checking out equipment, such as incubators and refrigerators, and otherwise preparing to receive samples.

The interest of the laboratory crew in the study can be increased by taking them on a tour of the principal features of the study area. Their work can be performed more intelligently when they have a knowledge of the field situation. A day's time devoted to this orientation can be well worthwhile.

## DATA TABULATION

The results of all determinations should be tabulated soon after they are completed. This may be done at the end of each day, or at the beginning of the next day, before samples are delivered to the laboratory. This helps to prevent possible misplacement of data, which might occur if they are not assembled until the end of the study. More importantly, it facilitates review and comparison of data as they are accumulated and permits detection of any need for revision of study plans or details as soon as possible.

## CHANGES IN SCHEDULE

The laboratory should be notified as far as possible in advance of any change in plans, such as collection of special samples or performance of additional determinations. The laboratory personnel and facilities are used to the limit in most field studies. Time is needed to revise the work schedule or to prepare new solutions and equipment. Unanticipated additions to numbers of daily samples or changes in constituent determinations can upset and disorganize a smoothly functioning laboratory.

The first two to three days of a field laboratory operation, before the work is well organized, usually are rather hectic. Collection of any special samples should be delayed, if possible, until the laboratory crew has settled down to a routine schedule. They can handle additional work more easily after a basic routine has been established.

## WINDUP

A skeleton crew must stay another five days after sampling has ended to complete BOD determinations or as much as four days to complete bacteriological examinations. The laboratory can be prepared for return to headquarters while completing these examinations.

## SAMPLES TO HEADQUARTERS

Samples for determinations of stable constituents, or of constituents that can be preserved for the necessary lengths of time, should be shipped to the headquarters laboratory for examination. Examinations can be performed more economically in that laboratory, and equipment and surroundings are more conducive to careful, exacting analyses. Of course, reliable work can be performed in the mobile laboratory, but the speed, convenience, and economy of working in the headquarters laboratory make it advantageous to perform all examinations possible there.

Favorable air express schedules sometimes may make it feasible to ship samples for all determinations, including unstable constitutents, to the headquarters laboratories. Only the supervisor and a sampling crew need be maintained in the field when this is possible, and a saving may be realized in the overall cost of the study. One or more sets of samples, however, probably will be delayed longer than desirable in reaching the laboratory if air express is used. The sample collector may be delayed and fail to get the samples on the scheduled flight. A flight may be cancelled or diverted because of bad weather. A shipment may go to the wrong destination through error. The sample containers may be misplaced temporarily at the sending or receiving airport express room. The necessity for an uninterrupted series of samples must be weighed against the saving in cost if use of air express is considered for a stream study.

# 11

# WASTE SOURCES

Municipal sewage and industrial wastes, commonly designated as point sources, are the two types of wastes that are most often considered in water quality studies. This does not imply that other sources, such as surface runoff and agricultural drainage, are not important but rather that pollution control agencies have taken the practical approach that the other sources are so diffuse that no feasible method of treating them has been developed to date. Much thought is being devoted to the problems of the diffuse wastes and sooner or later techniques for minimizing their effects will be evolved.

A detailed knowledge of sewage and industrial waste sources, their locations, characteristics, quantities, and treatment, if any, is essential in the planning and conduct of a stream study. There are several ways to obtain necessary information.

State stream pollution control agencies usually have lists of domestic sewerage systems and industrial waste sources.

## MUNICIPAL SEWAGE

### Control Agency Lists

The sewerage system lists of the control agencies usually include data on sewered populations and sewage flows, the types of treatment, if any, and loads discharged to receiving streams in terms of population equivalents based on BOD. The lists rarely include information on industrial wastes discharged to the municipal sewerage system. It is desirable to determine whether the data listed on sewered population, flow and load to the stream are estimates, mean values derived from treatment plant operating records, or the results of spot sampling and analysis by the state agency. Knowledge of the source of the data is necessary for judging their reliability and whether the sewage should be sampled and analyzed for the study of stream water quality.

## Estimation

The necessary information on sewage sometimes can be obtained from the municipalities if the state has no data or if they are inadequate. City departments responsible for sewage disposal usually have information on either sewered populations or numbers of home connections to the collection systems, especially where the systems are financed by sewer rental fees. The number of connected homes multiplied by 3.7 persons per family gives a reasonable estimate of sewered population. The sewered population multiplied by 0.17 pounds of 5-day BOD per person per day provides an estimate of the BOD load of raw domestic sewage. The sewered population multiplied by 0.2 pounds of suspended solids per capita per day gives an estimate of the suspended solids load of the raw sewage. The total coliform bacteria load in the receiving stream, if no treatment is provided, may be estimated by multiplying the sewered population by 400 billion per capita per day for temperatures above 15° C. and 125 billion for temperatures below 15° C. These and other factors useful in making estimates are given in the appendix.

A city sewer department usually has data from spot checks on flow, BOD and suspended solids of industrial wastes when sewer rental charges are proportioned to these characteristics of the wastes. The total loads of the industrial wastes connected to a municipal system may be calculated from these data and added to the totals of the domestic sewage loads for estimates of the total loads of the raw municipal sewage.

It may be feasible to obtain necessary information by interviewing industrial plant personnel if no analytical data on industrial wastes discharged to the sewer system are available. Knowledge of manufacturing processes and of production quantities thus obtained may be adequate to permit reasonable estimates of waste characteristics by application of conventional unit waste values to units of production. This method should be applied by an individual experienced in industrial wastes for best results.

An estimate of the treated sewage BOD load may be made by applying conventional percentage reductions in BOD for various types of treatment if an estimate of raw sewage load has been made as outlined above. Values commonly used are 33 percent for primary treatment, 65 percent for chemical precipitation, and for secondary treatment, 85 percent for trickling filter plants, and 90 percent for activated sludge plants. Reductions in suspended solids by conventional treatment may be estimated as 55 percent for primary, 80 percent for chemical precipitation, 80 percent for trickling filter plants, and 90 percent for activated sludge plants. Bacterial reductions may be estimated as 50 percent for primary, 60 percent for chemical precipitation, 92.5 percent for trickling filter plants, 94 percent for activated sludge plants, and 99 percent for chlorination following secondary treatment (see Appendix).

Estimates made in this manner are no better than the judgment used in arriving at them. The sewage flow must be measured, sampled and analyzed, if accurate evaluation of sewage load to the receiving stream is required.

## Treatment Plant Records

Plant operating records for most municipal sewage treatment plants include data on sewage flow, BOD and suspended solids as a minimum, on both raw and treated sewage. Methods used in procuring these data should be evaluated.

## Gaging, Sampling, and Analysis

Some, but relatively few, sewage treatment plants have flow meters on their effluent lines. Most have meters for the incoming sewage. The meters at some plants may not have been calibrated recently and may require calibration before they can be trusted. Flow measurements usually require installation of weirs or Parshall flumes, or use of current meters if flow meters are not available. The choice of method depends on local circumstances. Usually weirs or flumes are used with low to moderate flows in restricted channels. Parshall flumes are required for wastes with large suspended solids, such as those in raw sewage. Large flows in relatively large channels may more readily be measured with current meters. Staff gauges may be installed and calibrated for instantaneous water level readings for conversion to flows, but continuous recorders for permanent records of flow levels are preferable.

A reliable measurement of sewage load to the receiving stream can be achieved only by round-the-clock sampling because of the wide variations in flow and sewage constituents from the mid-morning maximum to the minimum of early morning hours. Raw sewage should be sampled frequently, possibly every 10 to 15 minutes, because of its variability. Large cities and long collecting sewers produce fluctuations in sewage that are neither so rapid nor so wide as are those of small towns and short collecting sewers. Passage through treatment plans reduces fluctuations, and plant effluents may be sampled less frequently than raw sewage, possibly once every 30 minutes to one hour.

The lag period in passage of sewage through the plant may be considered when sampling to determine treatment efficiency. The same sewage entering and leaving the plant should be sampled for the most precise measure of efficiency. The daily sewage for all workdays of the week may be assumed to be sufficiently similar, however, so that no unacceptable error in efficiency is introduced by 24-hour sampling of influent and effluent during the same period if a somewhat less precise measurement is adequate. Theoretical detention times, based on total volume displacement, are two to three hours in primary plants, four to six hours in conventional trickling filter plants, and 10 to 12 hours in conventional activated sludge plants, if it is decided to be necessary to sample the same inflow and outflow. There are many variations in sewage treatment processes and departures from these conventional theoretical detentions. In addition, actual average detention time may be as little as 50 percent of the theoretical detention for sedimentation tanks. Average detention in aeration tanks approaches theoretical detention more closely than in sedimentation tanks. Only a tracer can define actual passage time of sewage through a plant.

Samples should be iced as collected if unstable constituents are involved. Each sample preferably should be analyzed separately, but this rarely is practical. Samples collected at selected intervals are composited for the full 24 hours in many sewage studies. A portion of such a composite is at least 23 hours old when compositing is completed and the average age of the composite is nearly 12 hours. At least three, and preferably four, composites should be prepared each 24 hours, so that no portion of a composite is more than seven, and preferably not more than five, hours old when the composite is completed.

At least seven consecutive days of round-the-clock sampling is desirable for maximum reliability of sewage measurement. An acceptable measure that will satisfy most needs may be obtained in three to four days. One preferably should be a week-end day.

## INDUSTRIAL WASTES

Much that has been said about sources of information on municipal sewage applies to industrial wastes discharged directly to the streams.

### Control Agency Lists

Information on industrial wastes in control agency lists frequently is much less comprehensive than is that on municipal sewage. Information on a manufacturing plant may be limited to the name of the company and its location, volume of water used, the product, the principal characteristic of the waste, and a brief designation of treatment, if any. Data on quantities of constituents are relatively rare, though some lists include population equivalents where organic wastes are involved.

### Estimation

The strength of industrial wastes discharged directly to streams may be estimated from process and production surveys by a competent industrial waste engineer, as suggested for industries discharging to municipal sewers.

## Treatment Plant Records

Plant operation records should include all necessary data on strength of wastes if treatment is provided. The reliability of methods of obtaining the data should be evaluated.

## Gaging, Sampling, and Analysis

Industrial wastes discharging directly to a stream under study must be measured, sampled, and analyzed, if data are not already available or an acceptable estimate cannot be made from process and production information. Many of the principles described for sewage measurement and sampling apply to industrial wastes, but there are exceptions that justify comment.

Variations in industrial waste discharges are in no way comparable to those of sewage discharges. A thorough knowledge of the process producing a given waste is essential in judging how the waste should be sampled. Some plants operate eight hours a day, some 16 and some 24. Some operate throughout the year, while others are strictly seasonal. Some produce relatively uniform wastes hour-after-hour, day-after-day, year-after-year. Others, especially those that use batch processes, may produce wastes that vary widely from one minute to the next. Some manufacture a single product, or the same combination of products simultaneously, throughout the year. Others manufacture one product with a particular type of waste for a day, a week, or a month, then switch to another product with an entirely different waste for some time before switching back to the initial product, or to still another product with still another waste.

Obviously, no fixed suggestions for frequency and duration of sampling can be propounded. At one extreme, adequate results may be obtained by sampling once hourly for six or eight hours per day for two or three days, even though the plant operates 24 hours a day. Samples need not be composited in proportion to flow if waste flow or content, or both, are reasonably uniform. At the other extreme, essentially continuous sampling, or at intervals of not more than five minutes round-the-clock for a week, with portions carefully composited to flow, may be necessary. Repetition of sampling several times as production changes may be required for full evaluation of some wastes.

Sound judgment applied to an intimate knowledge of the manufacturing process is essential to intelligent choice of laboratory examinations to be made on the wastes. The possible choices of constituents of industrial wastes that should be determined are practically limitless.

Many plants that discharge industrial wastes directly to streams dispose of domestic sewage from their employees to adjacent municipal sewerage systems. Information should be obtained on number of employees involved and on sewage treatment, if any, when the domestic sewage is discharged directly to a stream. The number of employees on duty may change from shift to shift in plants that operate more than one shift. The load of raw sewage may be estimated by assuming that each employee, working one shift, produces 15 to 20 percent of the normal daily per capita sewage load, if actual data on the sewage are not available. No data on sewage produced per employee per shift, other than a volume of 15 to 35 gallons, have been found in the literature, but the estimated probable range in constituent load suggested is judged to be a reasonable one. Appropriate reduction for the type of treatment may be made to estimate the load to the river if the sewage is treated.

## IN-STREAM MEASUREMENT

The discharge line from a sewage system or an industrial plant may be inaccessible, there may be too many discharge points to sample them all, or for some other reason sampling of wastes at their sources may not be practical. The waste load may be measured in such a case by measuring, sampling, and analyzing the receiving stream above and below the point or points of waste discharge. The upstream sampling may be omitted if no constituents of the wastes are carried by the stream. The success of this method depends on reasonably rapid vertical and lateral mixture of the wastes with the stream and the ability to measure accurately the difference in stream discharge above and below the waste discharges to obtain the flow of the wastes. Stream flow measurements within five percent of actual flows are about as close as can be expected. Flow of a waste discharge that is small in relation to flow of the receiving stream obviously cannot be determined with any high degree of accuracy by this method. Mixing of the waste in the stream is more rapid and flow can be determined more accurately when flow of the receiving stream is small in relation to waste flow.

## TIMING

Wastes should be examined at the same time that the receiving stream water quality is examined. Simultaneous study of both wastes and stream enhances the probability of obtaining a satisfactory check of the waste loads against their effects on the stream. Personnel available, however, rarely are adequate to conduct both waste and stream studies during the same period. They should be examined as closely together in time as feasible when necessary to study them separately. The wastes should be studied first in this case, so that knowledge of their characteristics can be used to advantage in the stream study.

# 12

# WATER USES

The uses of water constitute the prime reasons for water quality studies. If streams were used only for waste disposal, the only justification for stream studies and pollution control would be prevention of public nuisance in the form of unbearable odors that would evolve from anaerobic waters, and prevention of paint discoloration by hydrogen sulfide. A knowledge of existing and potential water uses is essential to the intelligent planning and conduct of a sound water quality study.

## RELATION OF USE TO STUDY METHOD

The location of a water quality station at a single or isolated point frequently is dictated by the water use at that point. The use may be a source of municipal, industrial, or agricultural water supply. Use may not yet be defined for base-line data stations, but one or several different uses may be anticipated. The use may be swimming or other water-contact recreation. It may be waste disposal that must be monitored to determine the effectiveness of waste treatment and the residual effects on water quality, to ensure adherence to standards of quality, or to supply a warning of waste spills or other excessive discharges to downstream water users.

Waste disposal is the use that most often necessitates stream studies that involve a series of related stations. The purposes of the studies include: determination of the pattern of pollution below waste sources; establishment of rates of natural purification for projection to minimum flow conditions and estimation of waste assimilative capacity of the stream; estimation of reductions in wastes needed to meet standards of water quality; determination of adherence to standards of quality; or revelation of standards violation. The role of wastes in the death of fish or other disaster may be investigated, or water quality may be assessed before a change in waste load. All of these purposes involve use of the stream for waste disposal, but the basic purpose is protection of one or more other water uses.

## CATEGORIES OF USE

Despite the tremendous quantities involved and essential nature of the uses of water, the types of use include a very limited number of categories:

1. Municipal water supply.
2. Industrial water supply.
3. Agricultural water supply.
   a. Domestic farm supply.
   b. Irrigation.
   c. Livestock watering.
4. Recreation.
   a. General.
   b. Swimming, wading, skiing.
   c. Boating.
   d. Esthetic enjoyment.
5. Propagation of fish and other aquatic life and wildlife.
   a. Sport fishing.
   b. Commercial fishing.
   c. Fur trapping.
6. Hydropower production.
7. Navigation.
8. Waste disposal.
   a. Low flow augmentation.

Selection of the categories, and more especially the sub-categories, is influenced by water quality characteristics desirable for each, as well as by the actual uses involved. Others may wish to add to, subtract from, or revise the list. It is, however, a rather generally used listing as it stands, with perhaps a greater breakdown of major categories into subcategories than usual.

## EXTENSIVE USES

Three of the uses listed may be assumed to be very nearly universal. These are general recreation, scenic enjoyment, and propagation of fish and other aquatic life and wildlife.

General recreation as used here is intended to include recreational uses of all kinds that are not formally organized or officially recognized, or for which water quality is not specifically protected. It may involve any or all of the other four types of recreation. The old swimming hole in the creek behind the barn is an example of what is meant by general recreation. A picnic at the edge of an isolated babbling brook, and the hot and weary bare feet of a mountain climber dangling in a cool stream, are other examples. Scenic enjoyment is quite similar to general recreation in many respects and, in fact, might well be included in that category rather than listed separately. It may be said unequivocally that where there are people and where there is access to water, general recreational use and scenic enjoyment of water will occur.

Fish and other aquatic life and wildlife propagation is not quite so universal a use as general recreation, but only because some waters are too badly polluted for this purpose. A greater percentage of the surface waters of this country are classified for this use than for any other. Fish and aquatic life are found everywhere water is suitable.

## POINT USES

Use of streams as sources of municipal, industrial, and agricultural water supply may be designated as point uses since water for any of these uses is withdrawn at a point on a stream or other body of water. The water quality at the point of withdrawal must be satisfactory for the use involved, after suitable treatment if necessary, and should be monitored at that point.

However, the quality cannot be controlled at that point alone regardless of upstream conditions. Protection of the point source requires control of wastes for many miles upstream. The characteristics of the upstream wastes, the effects they have on water quality, and changes in effects that occur between points of waste discharge and point of water withdrawal must be known to provide protection of water quality at the withdrawal point.

## LOW QUALITY USES

Water of very low quality generally is considered adequate for navigation and power production. Protection against corrosion of metals and maintenance of minimum aerobic conditions together with the general objectives for all waters, are the usual requirements. There is a trend, however, toward upgrading quality of all waters, including those classified for these two purposes.

## WASTE DISPOSAL

Waste disposal is a widespread use of streams and generally tends to conflict with other uses. This is what stream pollution control is all about. Wastes must be so treated and discharged that they will not interfere unduly with other uses and, in addition, they must not interfere unduly with disposal of other wastes. The capacity of a stream to assimilate wastes without harm must be allocated among existing sources of wastes with a portion retained in reserve for potential new sources.

Added capacity for assimilation may be achieved by low flow augmentation where impounded water is available. Use of impoundments financed by public funds for this purpose is permitted only if wastes are receiving the equivalent of secondary treatment as a minimum. This practice is not yet widespread.

## QUANTITATIVE INDICES OF USE

Information obtained on water uses should include type of use, location, and, if possible, some quantitative index of the importance or value of the use.

For example, the quantity of water withdrawn daily to supply municipal, industrial, or agricultural needs would be one measure of the importance of these supplies. Additional quantitative information might be the numbers of persons served by the municipal supply, the quantity or value of goods manufactured with the industrial supply, or the acres irrigated or the value of crops produced by the agricultural supply.

Many types of data may be available on recreational uses. These may include: the number of swimmers; the value of bathing facilities; the numbers of boat licenses; estimates of total numbers of boats and their value; the numbers of fish caught by sport fishermen and an estimate of the money spent for this sport; and numbers of duck hunting and fishing licenses.

Data on numbers of commercial fishing and trapping licenses, pounds and value of fish taken, and numbers of pelts and their value may be available.

The numbers and storage capacities of impoundments, installed power capacities and actual power produced, including its value, may be obtained for hydropower production.

Navigation use data most often are available in tons of materials or ton-miles transported. Total values of cargoes or savings by water transportation may be obtained.

Waste disposal may be described in terms of total numbers of municipal sewage and industrial waste discharges; numbers, types and capacities of treatment plants; total volumes of sewage and industrial waste discharged; and in population equivalents of BOD, coliform bacteria and suspended solids discharged. BOD and suspended solids may be described in pounds per day and coliform bacteria in billions per day, or more probably in millions of billions per day, rather than in population equivalents, if preferred.

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# SOURCES OF INFORMATION

Many sources may be tapped for information pertinent to a study of water quality.

## STATE POLLUTION CONTROL AGENCIES

The state pollution control agency, as would be expected, usually has the most complete collection of information and data on factors involved in water quality within a state. This agency may be a separate stream pollution control commission, or may be in the water resources commission, or in the sanitary engineering division of the department of public health.

The files of this agency may include all information needed for a complete study of water quality at the point or in the reach of the stream involved. A report of a previous study on water quality of the stream may be included. One or more employees of the agency are likely to have first-hand knowledge of the local situation.

## OTHER STATE AGENCIES

The state health department is responsible for supervision of public water supplies and has information, including treatment plant operation records, on the supplies.

The state fish and game department has information on fishing throughout the state, and frequently some information on water quality. Fish kills are most apt to be reported here and a record of kills maintained. Data on fishing licenses also are recorded in this department. Local game wardens, who usually are under supervision of the state agency, can provide much background information of a local nature.

State planning agencies assemble data of all kinds from other agencies but the information frequently is not selective or specific to the problem at hand.

The state geological survey usually is the agency that co-operates with the U.S. Geological Survey in the stream gaging program.

## INTERSTATE AGENCIES

Interstate pollution control agencies, such as the Interstate Commission on the Potomac River Basin, the Delaware River Basin Commission, and the Ohio River Valley Water Sanitation Commission, usually have information similar to that in state pollution control agency files. The interstate commission files may not be so detailed as those of the state agency, but the commission may have more information on an interstate river as a whole than any one state agency has.

## FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

The Federal Water Pollution Control Administration of the U.S. Department of the Interior has made many water quality studies similar to those made by the state control agencies. Some of these studies are detailed examinations of local situations, while others are less detailed comprehensive studies throughout a river basin or a geographical region. The Administration maintains a national pollution surveillance system of stations on interstate streams. Samples are collected and analyzed weekly and the data are stored in a central computer, from which printouts may be obtained. An inventory of municipal sewage and treatment also is stored in a computer, and there are plans for collecting information on industrial wastes. Data may be obtained from the Administration's regional offices or its Washington headquarters.

## RIVER DEVELOPMENT AGENCIES

Federal river development agencies, such as the U.S. Corps of Engineers, the Bureau of Reclamation of the U.S. Department of the Interior, and the Tennessee Valley Authority, are fertile sources of information on streams for which they have responsibilities. The former two agencies maintain relatively little water quality data, but they assemble much information on hydrology and a variety of background material. The TVA regularly makes water quality studies, especially as related to the effects of impounding and control of stream flow. All three agencies have especially good maps of streams. They can furnish data on uses of streams for purposes for which they are responsible, such as navigation, irrigation, and power production.

The interest of private river development agencies generally is limited to hydropower production. These agencies do not accumulate the range of information on streams that the federal agencies do. The private agencies can provide information on physical and operating characteristics of impoundments and on stream flow. Occasionally they assemble limited data on water quality and other water uses than power.

## OTHER FEDERAL AGENCIES

The U.S. Geological Survey operates stream gaging stations and reports daily stream discharges throughout the nation, usually in cooperation with the states. They also make mineral analyses and silt and temperature determinations at many of their discharge stations. Their topographic maps are among the most detailed of any available.

The U.S. Fish and Wildlife Service and the U.S. Bureau of Commercial Fisheries collect data on fish and fishing. They make studies of water quality as related to fisheries in some situations.

The U.S. Coast Guard licenses larger boats on interstate streams, and is generally responsible for boat safety and control of navigation. They gain intimate knowledge of the streams on which they operate, and can provide useful background information.

## WATER SUPPLIES

Operating records of municipal and some industrial water supplies withdrawn from streams are useful sources of data on water quality and of effects of wastes on water supply use. Generally duplicates of operating records from all water supplies in a state are maintained in the files of the state department of health. Interviews with water plant operators may yield information on water quality characteristics that cannot be obtained from operating records.

Municipal water department officials have information on numbers of customers served. Occasionally records of customers' complaints may reveal the effects of industrial wastes, especially those that cause taste and odor.

## WASTE TREATMENT PLANTS

Operating records of sewage and industrial waste treatment plants provide data on strength and characteristics of the wastes. Some plant operators also sample and analyze the receiving streams above and below their plants, but this practice is not nearly so widespread as would be desirable. This is surprising, since the purpose of the treatment plants is to protect the water quality of the receiving streams. Copies of operating records from all plants in a state are kept in the files of the state water pollution control agency.

Municipal sewerage departments can furnish information on numbers of persons served by the systems and in some cases have data on industrial wastes discharged to the systems.

## MISCELLANEOUS SOURCES

County highway department maps usually are the most recent available for laying out sampling routes and determining points of access to streams.

Pleasure boating club officials can provide information on use of streams for boating, and on visual and olfactory effects of pollution.

Isaac Walton League members have a particular interest in water quality as related to fish life, and each local section usually has a committee on water pollution that may have information of value.

Newspaper files may furnish otherwise unrecorded dates of unusual occurrences, such as fish kills and oil spills.

Individuals who have frequent contact with streams can be valuable sources of information. Fishermen, bathers, pleasure boaters, tug boat operators, water supply pump operators, lock and dam attendants and similar laymen frequently are sources of useful observations. Their conclusions regarding the scientific meaning of their observations may not always be reliable, but an experienced stream investigator with knowledge of the local situation usually can interpret their reports properly. Their observations should never be ignored simply because they are laymen.

Valuable data and information may be obtained from the various sources discussed above, and all should be investigated. However, the investigator will gain sound knowledge of and a feel for a stream only by detailed observations of his own in the field. The individual who depends on other sources, regardless of how reliable, and writes a report without visiting the area under consideration can miss the mark very badly. There is no substitute for personal observation.

# 14

# INTERPRETATION OF DATA

This chapter is not a treatise on details of calculations involved in the interpretation of stream data, such as the well known oxygen sag curve and the less well known bacterial die away curve. These calculations have been covered adequately in other publications, and references to selected publications are given where considered appropriate. An entire volume could be devoted to mathematics alone. It would completely overwhelm the other material if incorporated here. An attempt is made here, rather, to present practical suggestions that may help to resolve some of the puzzles inevitably encountered in the interpretation of stream data.

## ADVANCE PLANNING

The method of interpretation of data to be employed should be considered in planning the study, before samples are collected. What degree of statistical reliability of data is necessary? Is a computer to be used, or are calculations to be made by hand? Is the validity of the data to be checked by comparing waste loads measured in the stream with waste loads at their sources? Are rates of change in unstable constituents to be determined, or are concentrations of constituents at various sampling stations merely to be measured and reported without relation to each other? The data obtained may fail to meet the objectives of the study unless there is a clear understanding of anticipated methods of calculation and data interpretation.

## JUDGMENT vs MATHEMATICS

Reliance on the mathematics employed in data interpretation can be overdone, however. Some individuals undertake data interpretation as strictly an exercise in mathematics rather than an exercise in evaluation of an actual situation with mathematics used as a tool to assist in the formation of judgments. Those who believe they need not review a problem in the field, but can interpret adequately data collected by others, are prone to substitute mathematics for judgment. The increasing use of and reliance on computers tend in the same direction, for the computer inserts no judgment into the process of grinding out calculations exactly as programmed. The computer has its place, especially where large quantities of data are involved, but it must not be relied upon to the exclusion of judgment.

## ORGANIZATION OF DATA

Organization of data in some orderly form is the first step in their interpretation. Data produced by the laboratory usually are tabulated most conveniently for laboratory personnel by date of sample collection, with data for all stations combined under that date. The data must be reorganized by sampling stations for interpretation. A common basic table has the data for each station arranged chronologically by date of collection in the first column, followed by columns of time of collection, stream discharge, and the concentrations of various constituents.

Column headings must be explicit, specifying both the units and the chemical forms in which constituents are expressed. Much confusion can result from failure to designate the chemical form in which a constituent is calculated. For example, the column heading "nitrate," alone, could mean that the nitrate is expressed in either the more common form as the element, nitrogen (N), or as the radical nitrate ($NO^3$), which has a molecular weight that is 4.4 times the atomic weight of nitrogen. Phosphate, on the other hand, commonly is reported as the radical, phosphate ($PO_4$), but also may be reported, and is frequently discussed in texts, as the element, phosphorus (P). The element has an atomic weight less than one-third the molecular weight of the phosphate radical. Frequently it is not indicated whether the $PO_4$ is total, soluble, or what. Iron commonly is reported merely as Fe, without indicating whether it is in the ferrous ($Fe^{++}$) or the ferric ($Fe^{+++}$) form. The distinction is important in interpretation of the iron data, since ferrous iron uses DO and ferric iron does not. Failure to indicate whether the iron is total or dissolved is frequent. Total iron may include some indefinite portion of inert iron derived from silt in the water, which is dissolved by the acid used in analysis. This unidentified portion of the total iron has no more significance than the inert silt. So-called dissolved iron may include active ferrous iron, and colloidal iron, which does not settle by itself and can be difficult to remove from the water even by coagulation. Dissolved iron is much more significant with respect to water quality than total iron. It is even more significant when separated into dissolved ferrous and "dissolved" (mainly colloidal) ferric iron and so reported.

A few minutes spent in development of adequate column headings can save much subsequent time, uncertainty, confusion, and even serious error in interpretation of data.

The suggested form should be adequate for a basic tabulation if data for only a limited sampling period are available. Data for one or more years on a year-round basis, or for some other protracted period, should be separated into segments of similar flow and temperature combinations. Year-round data may be separated by seasons, such as summer, winter, and intermediate (a combination of spring and late fall). Data that are obtained daily or several times weekly may be separated by months or combinations of two or three months with similar stream flow and temperature characteristics. The discharge of a seasonal industrial waste may govern the separation of data. Data for the same month from two, three, or more years may be combined.

The important guiding principle is to include sufficient data for statistical reliability within relatively limited ranges of stream characteristics. The more important considerations are temperature, stream flow, and seasonal waste discharges, if any.

## DATA RELIABILITY

Evaluation of the reliability of the data is the second step in their interpretation. Inevitably the data at a given station will vary throughout some range, but the variations should be logical and within reasonable limits. Two factors inherent in the analytical procedures and a characteristic of the behavior of wastes in streams influence the validity and variability of the data. Judgment, aided by mathematics, may be applied to decide whether these features of the data are within reasonable bounds. All data should be presented in the tabulations, even though some may be omitted in obtaining averages, maximums, and minimums. Footnotes should explain any omissions.

### Precision and Accuracy of Analytical Methods

The two factors involving the analytical procedures are discussed in "Standard Methods for the Examination of Water and Wastewater."[1] Some analytical methods have inherent errors that are unavoidable. This in reflected in the degree of accuracy with which the methods measure the true concentrations of constituents. The most common unavoidable inaccuracy of the methods is failure to recover 100 percent of some constituents.

The other unavoidable analytical factor is the inherent variability of the results of replicate analyses of the same sample that is typical of any type of measurement. This involves the reproducibility of results on the same sample, and is designated as precision in "Standard Methods"[1], where it is discussed at some length.

Quantitative accuracy and precision of many methods have been determined and are included in "Standard Methods"[1].

Examination for the most probable number (MPN) of coliform bacteria is an outstanding example of a method with a very low degree of precision. The results vary so widely that they frequently appear useless to some individuals when examined for the first time. Ninety-five percent of the results of replicate examinations of the same sample, using five tubes each of three dilutions, normally vary within a range of about one to 9.4[9]. The other five percent of the results are outside of this wide range. The 95 percent confidence limits are even greater when only three tubes of each dilution are used, with a normal range of one to 17.5[9]. The wide range of values that result when the variations in coliform densities at a station are superimposed on the variability inherent in the method of examination explains why there are those who have little confidence in the quantitative values of coliform data. Despite this, the results on 20 to 25 samples at each station taken during a period of relatively stable sewage and stream flows and temperature can yield an average that is acceptable quantitatively. The average may be checked within acceptable limits against known factors of sewage discharge, dilution, bacterial death rate, and time-of-water travel.

The microfilter (MF) method for coliform bacteria generally yields more precise results than the MPN method does. Precision of the MF method varies in proportion to the densities of coliform organisms involved. Its precision may be two to five times greater than that of the 3-dilution 5-tube MPN method[12].

The MF method was developed originally for application to potable water supplies, but its application to stream samples has been accepted rather generally. The coliform densities obtained by the MF method may average about 70 percent of those by the MPN method. Adjustment of the MPN results for the bias inherent in the method of estimating the MPN's brings the results into better agreement, with the MF densities averaging about 87 percent of the adjusted MPN values[12]. This adjustment is rarely made in actual practice, however.

The MF method cannot be applied to highly turbid streams with low coliform densities. The microfilter becomes clogged with silt before sufficient water is filtered to yield the number of bacteria necessary for a reliable count.

## Concentration Variability

The variations in concentrations of constituents at a stream station constitute the third factor that influences variability of data. The effects of lack of analytical accuracy and precision should be minimized as much as possible by careful laboratory techniques, but it is essential that the actual variations in constituent concentrations at stream stations be determined throughout their range to the maximum extent feasible. This is accomplished by proper selection of sampling frequencies and times. The variations in concentrations may result from variations in waste discharge, in stream flow, dilution and time-of-water travel, in diurnal temperature, in sunlight, photosynthesis, and other biological activity, and in rainfall and surface runoff.

## Frequency Distribution

Evaluation of data at an individual station may be aided materially by arranging the values in sequence of magnitude and plotting them as a frequency distribution on probability graph paper [9]. Most data should produce a straight line on arithmetic probability graph paper. Coliform bacteria MPN's, however, should produce a straight line on logarithmic probability paper because of the nature of distributions of biological populations.

The data should plot as a reasonably straight line if they represent reliable measurement of the effects of a single set of conditions. There will be a break in the line and two or more straight lines may be required to fit the data if they represent a mixture of measurements of more than a single set of conditions [9]. The break may be the result, for example, of measurement of normal conditions for a portion of the sampling period, and of conditions resulting from rainfall and heavy runoff during another portion of the sampling period. A sampling station too close downstream from a tributary stream may cause a break in the line. Some of the samples may contain a preponderance of highly polluted main stream water and others an excess of cleaner tributary stream water. An unintentional change in laboratory procedure during the study may be still another cause.

Any major departure of the plotted data from a straight line is a cause for suspicion of reliability of the data, and for investigation to learn the cause. Once the cause has been determined, judgment may be used to decide whether some portion of the data is usable and how best to use it to obtain a representative mean.

Velz has described this and other applications of this graphical method in his clear and readily understandable series of articles on "Graphical Approach to Statistics"[9].

The frequency distribution plotting on probability paper may be used to determine the mean value graphically by taking the point at which the straight line fitted to the points crosses the 50 percent frequency line. The standard deviation of the data and selected confidence limits also may be taken directly from the plotting. The logarithmic probability plotting is especially useful for obtaining a mean of coliform density data. This method minimizes the influence on the mean of occasional extremely high values in much the same manner that the geometric mean does.

The slope of the line is proportional to the variability of the data. The data would, of course, plot as a straight line through the mean value and parallel to the X-axis if they did not vary. The slope is the result of a combination of inherent variability in the analytical method and the variation in concentrations at the sampling station.

The variation resulting from the analytical method may be separated graphically from the variation in concentrations by use of data on precision of methods from "Standard Methods"[1] or elsewhere. This permits determination of actual variation in concentrations at a station. A precaution should be noted in this connection. The data on accuracy and precision for a given constituent in "Standard Methods" are based on combined results from several laboratories. The precision of results produced by a single laboratory usually is considerably better than the combined results of several laboratories. The variability inherent in the analytical methods for most constituents is minor in relation to that in concentrations at most sampling stations. The variability in results of examinations for coliform MPN's, however, usually is much greater than that in densities at stream stations during stable flow periods.

Variability in concentrations of constituents decrease as longitudinal mixing occurs, as previously described. Therefore, the slopes of probability plottings of data should decrease relatively uniformly from station to station in the downstream direction. A marked reversal or abrupt change in the sequential decrease in slope at a sampling station is a cause for suspicion and calls for an investigation of the reason.

Poor distribution of times of sample collection is one cause for such an abnormality. Assume, for example, that the sampling schedule calls for starting at opposite ends of a stream reach on alternate days. Starting the sampling runs at approximately the same time each day ensures collection of samples at each end of the reach at two different times of day and thus on two points of any regular diurnal cycle in waste discharge. However, the tendency with such a schedule is to collect samples near the middle of the reach at approximately the same time of each day, which represents only one point on the diurnal waste discharge cycle. The results on samples collected at different times on alternate days throughout the sampling period are more apt to represent the variations in waste discharge and, therefore, exhibit a steeper frequency distribution slope than do the results on samples collected at approximately the same time each day.

The times of sample collection at a downstream station can be correlated with the times when the water sampled passed the point of waste discharge if times of travel are known. Thus, the daily results can be related to the diurnal cycle of the waste discharge to determine whether the samples represented the average, or a high or low point, of the waste cycle. This procedure assists in judgment of reliability of the data.

## Waste Loads Onshore and in Streams

Constituent loads onshore and in the stream can most conveniently be cross-checked if constituent concentrations and stream and waste flows are converted to pounds per day. This eliminates the changes in concentrations that occur with changes in flow, and puts all data on a readily comparable basis. The conversions may be made quite simply by the following formulas:

$$W = Q_c \times 5.39 \times C$$
$$W = Q_m \times 8.35 \times C$$

where:

$W$ = Weight of constituent load in pounds per day passing a given point.

$Q_c$ = Flow in cubic feet per second.

$Q_m$ = Flow in million gallons per day.

$C$ = Concentration of constituent in milligrams per liter.

These formulas can be memorized quite easily, and will be used many, many times in data interpretation. Their use may be reversed to express constituents in concentrations when load calculations are completed.

Suitable mean values for sampling stations are selected from the probability plottings, following any adjustments that are considered necessary. These means may be used for a check on reliability of the data where waste discharges are involved. A stable constituent of an on-shore waste load can be checked directly against the load measured in the stream. This requires a knowledge, of course, of any significant load of the stable constituent carried by the stream above as well as below the point of waste discharge.

The load at a downstream station must be projected upstream to the point of waste discharge at the rate of change and for the time-of-water travel that occurred during sampling for a check of an unstable on-shore waste load against the unstable waste load measured in the stream. The stream may carry a significant load of the unstable constituent above the point of waste discharge. The stream must be sampled above the point of discharge in this case, and the rate of change and time-of-water travel applied to project the stream load downstream to the discharge point. The most reliable measure of an unstable load added to the stream can be obtained only in this way. Generally insufficient information for this procedure is available if a single sampling station is used. Data should be adequate, however, when there is a series of related stations, including one or more above the waste discharge point.

The necessary projections of unstable constituents to the points of discharge may be calculated, or may be performed graphically for some constituents. For example, mean BOD values for a series of related stations define a straight line when plotted against time on semi-logarithmic paper, in the absence of interferences. The slope of the line represents the rate of BOD change. The difference between BOD values projected graphically at the indicated slope to the point of waste discharge from upstream and downstream stations represents the added waste load.

A precise check of the loads measured in the waste and in the stream cannot be expected because of the difficulties of achieving exact measurements. Agreement within 15 to 20 percent generally may be acceptable, and within 10 percent is rather exceptional. Once in a while, however, an investigator is surprised, and pleased, with a check within less than five percent.

## Relationships Among Stations

Another check on reliability of data may be applied to the results from sampling a series of related stations. The mean values for the stations plotted against time-of-water travel should form a straight line or smooth curve, depending on the nature of the particular constituent, without excessive scatter of the points in the absence of interference. Here again variations within the limits suggested for possible errors in a check of waste loads are not exceptional. Measurement of constituents carried by a stream is far from an exact science.

The plotted means for one or more stations may appear excessively far out of line. Projection of the data upstream from those stations to the point of waste discharge, based on time-of-water travel and rate of change for unstable constituents, may help to explain the apparent discrepancy. This procedure may reveal that the water sampled at the downstream stations passed the waste discharge point at times that were not representative of the waste discharge cycle, as described previously.

A similar discrepancy at a downstream station or stations may occur even though the waste discharge is uniform, if stream flow is regulated. Projection of the data from the downstream station to the waste discharge point may reveal that the water sampled had passed the waste discharge when the stream flow at that point was higher or lower than the daily average. The concentration of waste was fixed by the waste discharge and the stream flow when the stream passed the discharge point. The data from the downstream station under those circumstances would not represent the results of dilution of the wastes by the average daily flow. Actually they would represent only the portion of the day when the flow past the waste discharge point was higher or lower than the daily average.

A similar situation can occur if the downstream station is several days' time-of-water travel below the waste discharge and samples are collected from a rising or falling stream. Here again, the concentration of waste was fixed when the water sampled at the downstream station passed the waste discharge point as it was in the case of the controlled stream flow. Any comparison of the waste load at the discharge point with that measured at the downstream station is valid only if allowance is made for the difference in stream flows.

## BASES FOR INTERPRETATION

Sawyer's "Chemistry for Sanitary Engineers" [13] includes characteristics, effects on water quality and behavior of a number of the more common constituents of water. His book is useful to sanitary engineers, who frequently are a bit weak in chemistry, in interpreting stream data.

Interpretation of the significance of various levels of constituents at different points in streams in the past frequently has been guided by the investigator's knowledge of water uses at the different points and his personal opinion of appropriate limiting values under the circumstances. Occasionally there have been official standards to guide his interpretation.

With the advent of the federal program for adoption of standards of water quality on interstate streams, all of the states have classified their interstate streams on the basis of use and have proposed official standards for approval by the Secretary of the Interior. Some states have extended their standards programs to all intrastate streams. This program has simplified the investigator's evaluation of data, since the classifications and standards, approved by the Secretary, become the law of the land, and provide an official basis for evaluation. It is necessary only to be sure of the proper interpretation of the state document in which the classifications and standards appear. This may not always be simple.

The Secretary of the Interior appointed a National Technical Advisory Committee on Water Criteria, as one feature of the National Water Quality Standards Program, to recommend criteria for various water uses. The report of this committee contains excellent material for use in interpretation of water quality data [14]. It discusses effects of many of the constituents for which criteria are recommended and reasons for the limits selected.

Another publication of similar value, with even more extensive coverage of constituents, is "Water Quality Criteria" by McKee and Wolf, published by the California State Water Quality Control Board [15].

There would be no gain in attempting to incorporate here, or even summarize, the wealth of information in the three publications cited. Detailed comments on interpretations of three important features of the majority of stream studies, the BOD-DO relationship, bacterial contamination as measured by total and fecal coliform bacteria and *Salmonella*, and biological findings, is thought to be justified, however.

## BOD-DO RELATIONSHIP

The oxygen sag curve in the past appeared to hold more fascination for engineers and chemists engaged in stream sanitation than all other effects of pollution combined. The reason for this engrossment is not at all clear. A broader concept of stream pollution has been evolving in recent years, with serious consideration of its numerous other causes and effects, but it was not long ago that pollution was considered almost synonymous with oxygen depletion. In effect, it appeared that without serious oxygen depletion there was no pollution, even though the coliform densities may have been astronomical. The profession almost gave the impression that it was more interested in protecting fish life than human health. The efficiencies of sewage treatment plants were, and still are, cited in terms of BOD reductions, rather than bacterial or solids reductions—or something else equally neglected. The assimilative capacity of a stream meant, and still means to many, its ability to absorb a certain concentration of BOD without DO being depleted below a specified level. Streams do, however, assimilate other materials than organic matter. Reports on stream studies all too often speak of recovery from pollution when they actually are concerned with recovery from oxygen depletion only.

The fascination with the sag curve may stem in part from the beauty of the formula that so nicely balances the dynamics of two opposing forces, deoxygenation that reduces DO and reaeration that restores it. The fascination also may stem in part from the frustrations of trying to make the formula that works so beautifully with assumed data work equally well with actual data obtained from streams. The stream in which the BOD-DO relationship strictly follows the book is rare indeed. The simple truth is that, nearly a half-century after Streeter and Phelps [16] first published the method, there are still so many unknowns in the relationship and so many factors that are difficult to measure that its application in actual stream situations frequently is fraught with frustration, and even failure.

### Methods of Calculation

The mechanics of calculating the oxygen sag curve are explained by Streeter and Phelps in their original article [16], published by the Public Health Service in 1925. Streeter added new details in two articles in Sewage Works Journal in 1935 [6, 17]. The latter articles include sample calculations that are particularly helpful in understanding the procedure. There are several typographical errors in the formulas that, fortunately, are not difficult to detect.

There have been many adaptations of the method and some revisions in coefficients, but basically all changes are merely refinements of the Streeter and Phelps original concept.

The original Streeter-Phelps approach to determination of the reaeration coefficient ($k_2$) was to determine all other factors in the oxygen sag formula—ultimate first stage BOD ($L_A$), the deoxygenation coefficient ($k_1$), the initial and final oxygen deficits ($D_A$ and $D_t$), and time-of-water travel (t)—and calculate the reaeration coefficient by insertion of trial values of $k_2$ in the sag formula to obtain a calculated check on the observed $D_t$. This has the unfortunate result of combining all the errors of measurement and of ignorance in the reaeration coefficient, but the method still is used.

## Calculated Reaeration Coefficient

The major advance in technique has been the independent determination of the deoxygenation coefficient. O'Connor and Dobbins[18] developed a theoretical formula for calculation of the reaeration coefficient on the basis of diffusion, average stream depth and average stream velocity. Even this is not altogether new, for Streeter and Phelps[16] proposed a similar formulation based on physical characteristics of streams. They included several empirical coefficients that were derived from data of the original Ohio River research.

Churchill et al.[4] developed an empirical formula for calculation of the reaeration coefficient based on average stream velocity and depth from studies of oxygen depleted streams below storage reservoirs. Their formula gives generally lower values than does that of O'Connor and Dobbins. It has the inherent weakness that, being empirical, it cannot be extrapolated with assurance very far beyond the limits of the experimental observations.

## Direct Measurement of Reaeration

Tsivoglou et al. have published preliminary reports[19, 20] on a promising method for measuring reaeration coefficients directly in streams by use of a radioactive gas, krypton, a soluble radionuclide, tritium, and a dye, Rhodamine WT. This method has a definite advantage over detailed determination of average depths and velocities, which can be a monumental task in streams with irregular channels. The Tsivoglou et al. procedure measures the total effect of all depths and velocities in a stream reach. Calculations of $k_2$ based on average depth and velocity, on the other hand, depend on measurement of these factors at intervals that at best represent only a fraction of the total stream reach. The method includes time-of-travel measurement in the same operation.

The ability to determine the reaeration coefficient independently and accurately will contribute greatly to better understanding and application of the BOD-DO relationship by allowing reversal of the original approach. Determination of the reaeration coefficient no longer will be contingent on measurement of all oxygen demanding and depletion factors. Direct determination of the coefficient will permit its use to strike a balance with the measured oxygen demand factors with far more assurance than ever before.

## Revisions in Original Concepts

The profession has accepted revisions in a few items of Streeter and Phelps' original concept [16], and a few others are in question. This does not alter the soundness of their fundamental approach.

### Deoxygenation Coefficient

The deoxygenation coefficient, $k_1$, is not a constant. Streeter and Phelps [16] believed it always to be sufficiently close to 0.1 per day (base 10 logarithms) at 20° C. to be considered constant. Much investigation since that time has shown it to be variable, being lower than 0.1 for advanced stages of organic decomposition and frequently higher than that by as much as 50 to 100 percent, and occasionally even more, for initial stages of decomposition.

Tsivoglou has used an original and ingenious graphical method [21] for calculating $k_1$ to show that many time-series, or long-term, BOD curves exhibit two distinct coefficients of carbonaceous, or first stage, deoxygenation. The initial coefficient may be as high as 0.7 to 0.8 per day and persist for one to two days. This is followed by a much lower coefficient that usually is less than 0.1. Apparently the carbonaceous stage of the BOD frequently may consist of two stages, each with its own coefficient and each with its own ultimate demand. Streeter suggested a similar conclusion in his 1935 article [6], noting that there appeared to be an immediate oxygen demand, as well as the regular demand, at some stream stations. He based his conclusions, however, on interpretation of 1- and 5-day BOD results and the misconception of a constant deoxygenation coefficient of 0.1.

Streeter used the deoxygenation coefficient 0.1 per day both to extrapolate short-term BOD determinations (usually 1- or 5-day) to ultimate first stage demand, and as the basic coefficient of deoxygenation in streams [6]. This practice has been abandoned and the coefficient is determined when feasible in the laboratory for each sampling station by a BOD time series. The time series may involve determination of BOD on a series of incubated bottles daily for the first five days, for example, and every other day thereafter up to 11 to 21 days. All determinations should be made in duplicate, if possible. A limited time series of two- and five-day BOD's may be substituted and an approximate deoxygenation coefficient calculated from the two values if the full time series is impractical for all stations. In fact, all BOD determinations should preferably be made for at least two different time periods, such as two and five days, to approximate the deoxygenation coefficient on all samples rather than the few for which it is practical to run the complete time series.

The laboratory deoxygenation coefficients thus obtained preferably are used only to compute the first stage BOD at each station, and are not applied to the stream unless there is no alternative. The rate of BOD exertion in the laboratory bottle is not necessarily the same as that in the stream. The laboratory coefficient, however, may be the only one available for use in the stream if there is interference with the normal course of deoxygenation between stream stations. Such interferences may include: deposition of suspended solids as sludge, which reduces the BOD between two stations at a higher than normal rate; absorption of BOD by excessive attached biological growths, such as may occur in shallow, heavily polluted streams, with rapid reduction in BOD by absorption similar to that by settling; discharge of one or more wastes between two stations; or entrance of one or more major tributaries in a stream reach.

**Temperature Adjustments**

Streeter originally suggested a factor (theta) of 1.0159 for temperature adjustment of the reaeration coefficient[17]. Subsequently Streeter et al. revised this coefficient to 1.047, the same as that for temperature adjustment of the deoxygenation coefficient[22]. Other workers have reported other values that appear to center around 1.0241, and this probably is the better value[23].

Theriault originally concluded that the ultimate oxygen demand increased with increasing temperature[24]. Streeter repeated this conclusion in his 1935 article[6]. Subsequently Gottas[25], and later Zanoni[26], have concluded that there is no such increase. This disagreement has never been resolved by additional evidence. The adjustment suggested by Theriault (two percent change in ultimate BOD at 20° C. for each degree of temperature difference between 20° C. and the average stream temperature) appears, practically, to be an unnecessary refinement when the lack of precision of the calculated ultimate BOD is considered.

Gottas also disagreed with the use of a single theta coefficient of 1.047 for the temperature adjustment of the deoxygenation coefficient, $k_1$, throughout the normal range of stream temperatures[25]. He concluded that one adjustment should be used from about 5° to 15° C. and another from 15° to 30° C. Zanoni recently has reached similar conclusions[26]. These proposals for temperature adjustment of $k_1$ have not yet been accepted generally by the profession.

**Stream Deoxygenation Coefficients**

Streeter and Phelps recommended calculations of the deoxygenation coefficient between each pair of stream stations [16]. This may be necessary where any of the interferences described above occur in a stream reach. It is better practice to plot ultimate BOD's at all stations against time-of-water travel on semi-logarithmic paper and draw a straight line of best fit among the points when there is no intereference with normal deoxygenation. The slope of the line is the deoxygenation coefficient for the stream. The single value thus obtained probably is the best possible estimate of the stream deoxygenation coefficient.

It is possible that a straight line may not fit the plotted points in all cases. The reduction of BOD proceeds at a continuously decreasing rate in some streams. This has been observed especially in shallow, rapid streams with heavy biological growths and high natural purification rates, as described previously [27]. The reduction of BOD in such cases results from a combination of decomposition and absorption in biological slimes, rather than decomposition alone.

Fair et al. have suggested that the BOD curve in such cases may be fitted by a form of the biological purification retardant formula [28]:

$$Y=L[1-(1+nkt)^{-1/n}]$$

where:

$Y$=BOD exerted up to any time t.

$L$=Ultimate first-stage BOD.

$n$ =retardant coefficient.

$k$ =deoxygenation coefficient.

$t$ =time.

There is some evidence that a decreasing rate of deoxygenation, rather than a constant rate, may represent the normal course of organic decomposition in many, if not all, streams. Use of a constant rate, however, appears to be a satisfactory approximation in most cases, and especially in those with low to moderate BOD concentrations.

**Nitrification**

Streeter recognized, described, and formulated the nitrogenous, or second, stage of the BOD curve in his 1935 article [6]. However, he concluded, as have most investigators since then, that the second stage exhibits a lag in streams similar to that in laboratory bottles, where it usually starts only after five to 10 days. He illustrated this lag in a stream by data on the Illinois River. Therefore, the second stage was considered to be of no consequence in the reaches close downstream from sources of wastes, where the greatest oxygen depletion occurs.

Courchaine, however, found in a study of the Grand River below Lansing, Michigan, that nitrification of organic and ammonia nitrogen from the secondary treatment plant started immediately below the plant and accounted for over 75 percent of the downstream oxygen demand [29]. O'Connell et al. found a similar situation in the Truckee River below Reno [30]. Long-term BOD's were determined in the laboratory both with and without suppression of nitrification. Nitrification did not become well established in the bottles without nitrification suppression in less than three to eight days in most cases. Courchaine attributed the early nitrification of the stream to: nitrifying bacteria in the stream above Lansing from upstream pollution; a low carbonaceous BOD concentration; and an optimum stream temperature for nitrifying bacteria of about 30° C. There was, on the other hand, no significant sewage pollution above Reno.

The foregoing type of situation has not often been reported, but it is believed that it has gone unrecognized rather than that it is relatively rare. A reach of stream bed constantly exposed to organic nitrogen and ammonia in the flowing water might reasonably be expected to support a growth of nitrifying bacteria, starting immediately below the point of nitrogenous waste discharge and having densities sufficient to cause nitrification in that reach. This would be more apt to occur in a relatively shallow, rapid stream with biological slimes, including nitrifying bacteria, on its bed than in a deep, slow-moving stream with little slime growth. This factor, unrecognized, may have accounted for many BOD results that have puzzled and frustrated investigators by refusing to follow the book and yield smooth curves of uniform BOD reduction.

Nitrification in a stream may be revealed qualitatively by determination of nitrogen compounds at successive downstream stations. Each unit of organic and ammonia nitrogen, expressed as N, oxidized to nitrate requires 4.57 units of oxygen. Thus, a relatively small concentration of these constituents can cause an appreciable BOD.

Calculation of a mass balance representing conversion of organic and ammonia nitrogen to nitrate (the transitional nitrite stage in streams usually is insignificant quantitatively) in a stream reach would appear to be a simple method for determining oxygen used in the nitrogenous oxidation stage of the BOD. Unfortunately, as with so many other complex features of stream biochemistry, it is not always so simple as that.

It would be simple if the nitrogen cycle progressed directly from decomposition of organic nitrogen to ammonia, and through oxidation of ammonia to nitrite and then to nitrate with neither gain nor loss of the combined nitrogen content of the stream. Several short cuts and bypasses of this classical system render determination of a nitrogen mass balance extremely difficult, if not impossible.

Two of the difficulties involve oxygen used in oxidation of ammonia that cannot be balanced against the nitrates produced. The nitrates that are formed can be converted to nitrogen gas at DO concentrations below 1 mg/1. Pockets of water in contact with oxygen demanding bottom deposits may contain less than 1 mg/1 of DO even in streams in which the main flow has DO well above this concentration. The nitrogen gas formed from nitrates in these low DO pockets escapes from the stream, leaving no measurable evidence of the DO used when the nitrates were formed from ammonia.

Organic nitrogen converted to ammonia and oxidized to nitrate can be assimilated quickly by algae, which reconvert the nitrogen to the protein, or organic, form. Oxygen is used in the process, but nothing in the usual nitrogen compound analyses indicates the quantity of nitrate produced, and therefore the DO used, in this cyclical process.

Ammonia likewise can be assimilated by algae and converted to organic nitrogen by them. Oxygen is not used in this process. The nitrogen compound analyses make no distinction between the organic nitrogen formed in this manner from ammonia and that derived from nitrates, in the production of which DO is used.

Blue-green algae can fix nitrogen gas from the atmosphere and thus increase the organic nitrogen content of the stream. This organic nitrogen decomposes to ammonia when the algae die and then uses oxygen in going to nitrates.

These four examples of departures from orderly progression from the original organic nitrogen to the final nitrate illustrate the reasons why a mass balance of nitrogen compounds cannot be used as a quantitative index of the oxygen used in nitrification in a stream. Probably the closest approximation feasible is to follow the changes in organic and ammonia nitrogen from station to station and assume that any decrease in a unit of ammonia represents a use of 4.57 units of DO in the stream. This does not give a complete quantitative measure of the DO used by nitrogenous oxidation, but it is a useful indication of whether nitrification, or second stage BOD, is in progress in a given stream reach.

Two other causes of interference with the normal course of the oxygen sag curve are rather common. One is sludge deposits that concentrate oxygen demand in limited reaches of streams and impose heavy drafts on DO of the water passing over them. The other is the diurnal variation in DO caused by photosynthesis.

## Sludge Deposits

Several writers, including Streeter[6] and Velz[5], have proposed methods designed to make allowances for the concentrated oxygen demand of sludge deposits. These methods involve calculation, rather than direct measurement, of the sludge oxygen demand. The calculations include the assumption of certain coefficients, such as that defining the rate of decomposition of sludge, that have not been measured in place in streams. Fair et al.[31] made detailed studies of the characteristics, including oxygen demand, of sludge prepared and examined in the laboratory and of river mud collected from a stream and likewise examined in the laboratory. Others have collected sludge from streams and determined the oxygen demand. The demand of sludge thus disturbed cannot be assumed to be the same as that in place on a stream bed. Equipment, and its use, for measuring the oxygen demand of sludge in place in streams, only recently has been described by O'Connell and Weeks [32]. This direct method should be used either independently or for comparison with, and perhaps adjustment of, computed results.

## Photosynthesis

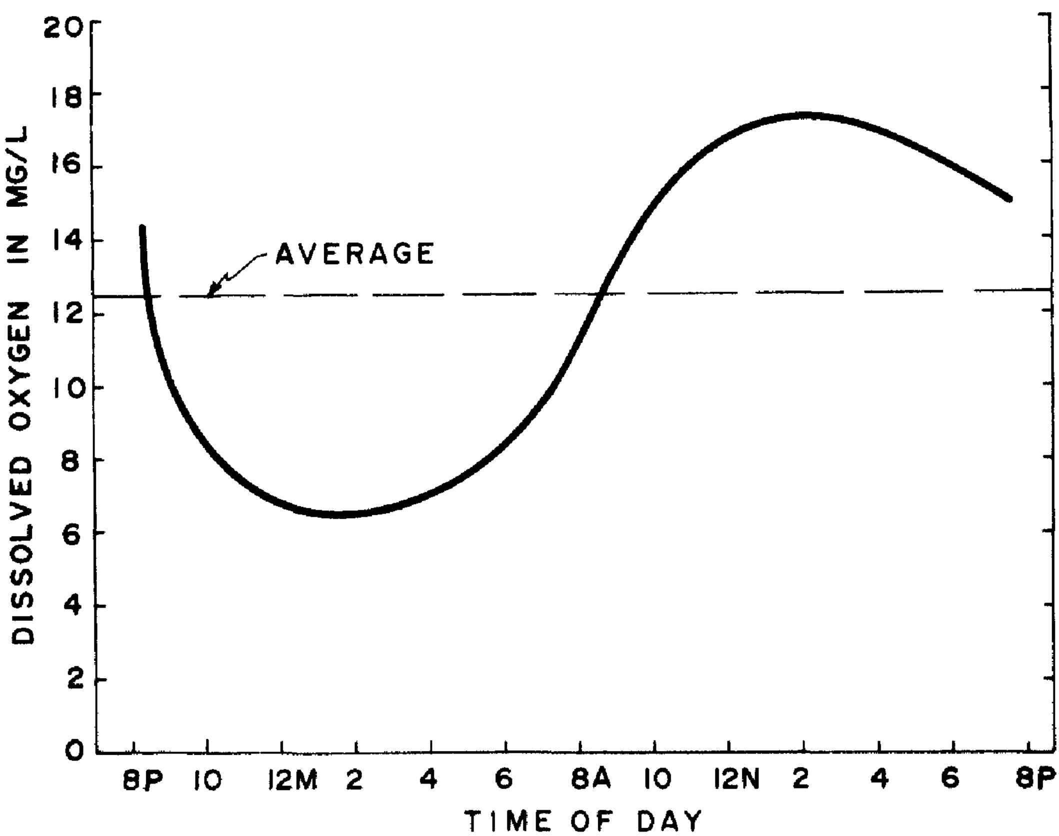
Algal photosynthesis and respiration by aquatic organisms can cause wide variations in DO from supersaturation in the day to very low, or even totally depleted, DO at night (Figure 5). Both attached and suspended algae may be involved. The wide fluctuations may completely obscure the effects of reaeration from the atmosphere. The photosynthetic supply of DO in streams is not dependable, for it varies not only from day to night but also from one period to another as algal growth fluctuates. Waste treatment plant design should be based on DO supplied in the water from upstream and by reaeration, and not on the undependable quantity added by photosynthesis.

Several methods for measuring the photosynthetic DO and separating it from the total carried by a stream have been used. Odum [33] has described use of both light-dark bottles and round-the-clock sampling of the stream. The light-dark bottle method measures only the oxygen added by suspended algae, while the round-the-clock sampling accounts for the increase by both suspended and attached algae.

More recently, O'Connell and Thomas [34] have described the use of light-dark algal chambers in which production and respiration of DO in streams by either attached or suspended algae, or both, can be measured. The measurements are performed in the stream, using stream water and attached algae from the stream reach under investigation.

Photosynthetic oxygen production and algal respiration should be measured if there is significant diurnal variation in DO. Otherwise evaluation of the BOD-DO relationship is incomplete.

FIGURE 5
EFFECT OF PHOTOSYNTHESIS
ON DISSOLVED OXYGEN CONCENTRATION




## Present Status of Method

This lengthy catalog of the complexities, the uncertainties, and the inadequacies in knowledge of the BOD-DO relationship has not touched on many of the details over which its practitioners have argued endlessly. It is not, however, intended to discourage use of the method. Some of the major problems have been discussed to warn that the beautiful, simple, straightforward method discussed in most textbooks is not so beautiful, simple, and straightforward in actual practice. This warning may, it is hoped, contribute to avoidance of pitfalls that others have found by falling into them.

The oxygen sag curve may be a poor thing in actual application, but it remains the best method available to simulate the reaction of organic pollution in streams and its effects on DO. "With all its faults, we love it still!"

This author realizes, at this point, that he is guilty of inconsistency. After haranguing against excessive emphasis on DO depletion by others, he has devoted excessive emphasis to the BOD-DO relationship. His only defense is that, despite its weaknesses, the method will continue to be an important feature of stream pollution studies. The length of the discussion here is more an index of the problems involved in the use of the method than it is an index of the importance of DO depletion in relation to other effects of pollution.

## BACTERIAL DIE-AWAY

The oxygen sag curve was not Streeter's only contribution to the interpretation of stream data. He and Frost[8] showed that the die-away characteristics of bacteria are just as susceptible of mathematical formulation as is the decrease of BOD in streams.

### Two Apparent Rates

The bacterial curve appears to have, as does the BOD curve, at least two distinct rates of decrease (Figure 6). Total bacteria determined by agar and gelatin plate counts as well as coliform bacteria exhibit this characteristic[8]. The coliform bacteria, for example, exhibit an initial extremely rapid decrease that results in 90 to 95 percent reduction of initial densities in two days in summer and 80 to 90 percent reduction in two days in winter. The reduction in five days may be 99 percent or more in summer and around 95 percent in winter. The two rates of decrease exhibited by individual curves resemble the two rates of decrease in the first stage BOD discovered by Tsivoglou[21] more than they do the carbonaceous and nitrogenous stages.

### Formulation

Frost and Streeter[8] suggested that the following formula adequately fitted the bacterial die-away curve:

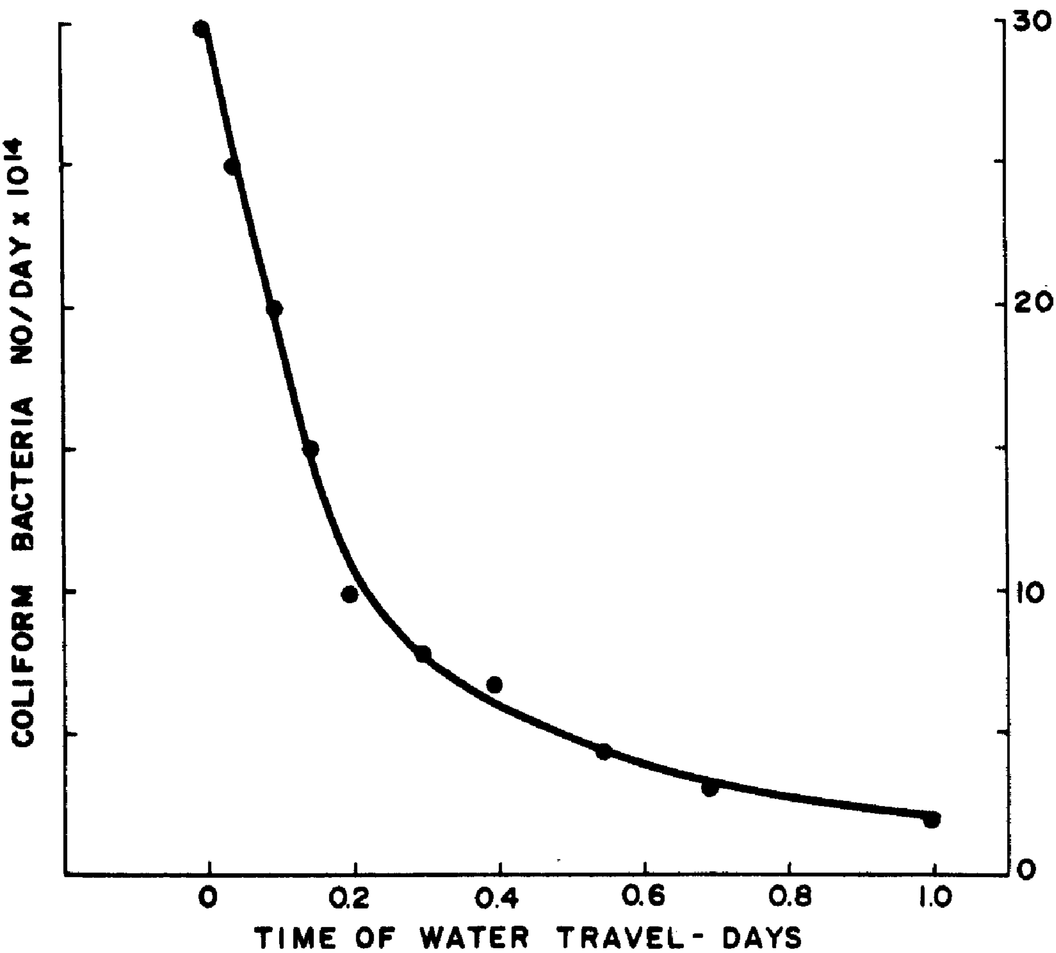
$$y = a(10^{-bx}) + c(10^{-dx})$$

where:

- y = portion of maximum bacterial density remaining after time, x.
- a = portion of initial bacteria decreasing at rate defined by coefficient, b.
- c = portion of initial bacteria decreasing at rate defined by coefficient, d.

Numerical values are given in the publication cited[8] for the factors in the formula for bacterial die-away curves in the Ohio River, but they were not proposed for general application to other streams.

FIGURE 6
PATTERN OF NATURAL PURIFICATION
OF COLIFORM BACTERIA




## TOTAL COLIFORM BACTERIA

Hoskins[35] summarized bacterial data from the Ohio River below Cincinnati and Louisville and from the Illinois River below Chicago and Peoria. He showed a reasonable consistency of daily per capita contributions measured in the streams (not in the sewage), with averages of about 400 billion in summer and 125 billion in winter.

Bacterial die-away rates of the four sets of data also exhibited reasonable consistency. He presented two series of idealized summer and winter die-away curves, with rates proportional to initial densities. He suggested that these rates might be applicable generally to other streams, and suggested methods of application.

Kittrell and Furfari[36] reviewed the earlier data and reports on coliform bacteria, especially those of Frost, Streeter, and Hoskins, and confirmed much of the material with data from recent stream studies. They also presented illustrative data with suggested methods of interpretation.

Bacterial data from a series of stations in a stream below a point of sewage discharge generally indicate an initial increase in densities before they start to decrease. There has been much discussion, but no authoritative conclusion, as to whether the increase is apparent as a result of sampling error or of disintegrating clumps of bacteria, or is an actual increase in numbers of coliform bacteria as a result of multiplication in streams. Streeter[37] believed there was an actual increase in numbers of bacteria and developed a formula to fit the increase as well as the subsequent decrease in densities. Phelps[3] appeared to question the possibility of multiplication in the adverse environment of streams.

## FECAL COLIFORM BACTERIA

The foregoing discussion of bacterial data interpretation has involved total coliform bacteria primarily. The same general principles apply to fecal coliform bacteria, but quantitatively the values of daily per capita contributions and die-away rates are different. The method for determination of fecal coliform bacteria has come into general use only in the last few years. There has been no systematic investigation of the pattern of fecal coliforms in streams such as that of Frost and Streeter[8] on total coliforms. Both factual data and discussions of the significance of the fecal coliform bacteria were presented at a symposium sponsored by the California State Department of Public Health.

One of the papers presented at the symposium by Ballentine and Kittrell[38] showed that fecal coliform bacteria in raw sewage constitute about one-third of the total coliforms. The fecal coliforms in streams die off more rapidly in summer than do the total coliforms. The winter data are less conclusive, indicating about the same rate of die-off for the first three days for both total and fecal coliforms, followed by a more rapid rate for the fecal coliforms by the fourth day. About 95 percent of the initial fecal coliforms die off in one day and 99 percent in two days in summer. Only about 0.06 percent of the initial densities remain at the end of four days. Comparable values were about 80, 90, and two percent in winter.

There is a general impression that the fecal coliforms in streams constitute about 20 percent of the total coliforms. This is correct close below the point of sewage discharge, but may not be farther downstream. Frequently the fecal coliforms are as little as 10 percent of the totals after a few days time-of-water travel, and occasionally drop as low as one to two percent of the totals.

Geldreich[39] has discussed the superiority of fecal coliform bacteria over total coliforms as indicators of possible pathogenic contamination of water. The latter group includes organisms, principally of the aerogenes group, that are not necessarily of fecal origin. The aerogenes may be a considerable portion of the total coliforms on occasion. They may have no sanitary significance since they can come from soils and vegetation, especially grains. Essentially all fecal coliforms, on the other hand, are of fecal origin and therefore potentially are accompanied by pathogens.

## Human vs. Animal Sources

Fecal coliform bacteria of themselves cannot indicate whether the feces from which they came were of human or some other warm-blooded animal origin. Differentiation is of little significance in most situations, for humans are susceptible to many intestinal diseases that are of animal origin. All fecal coliforms, therefore, indicate a health hazard.

The ratio of fecal coliform to fecal streptococci bacteria may be useful if it is important to differentiate between human and animal origin of bacteria.[30] If the ratio is about four to one, the source very probably is human, while a ratio of less than 0.7 indicates animal origin. Ratios between these values indicate mixtures of human and animal fecal coliforms. These ratios are dependable only if the samples that are examined are collected no more than 24 hours time of travel downstream from the source of the bacteria. This limitation frequently has been overlooked and the ratios applied indiscriminately, and probably erroneously.

Application of the 24-hour limitation in interpretation of the fecal coliform-fecal streptococci ratios requires a knowledge of the source or sources of wastes and of the stream that can come only from a sanitary survey. Such a survey is an essential part of any stream study, since intelligent interpretation of bacterial data is impossible without a sanitary survey. The survey, if complete, includes information on sources of waste that should permit interpretation of the fecal coliform bacteria as being of human or animal origin or both without resorting to the fecal coliform-fecal streptococci ratio.

# SALMONELLA BACTERIA

A method for isolating *Salmonella* bacteria qualitatively from stream water has been developed recently by Spino[40]. Positive evidence of the presence of this pathogen in streams below sewage discharges supports the evidence of a health hazard that is only indicated by the coliform bacteria. *Salmonella* have been found in the presence of even quite low total and fecal coliform densities.

## BIOLOGICAL DATA

### Unpolluted Streams

Without getting bogged down in the Latin names and the technical terms so dear to the biologist, it can be said quite simply that unpolluted streams normally support a variety of aquatic organisms with relatively few of any one kind. Any significant change in this normal balance usually indicates pollution. This holds true for all biological groups, whether they be fish, algae, plankton, attached forms or bottom-dwelling organisms. This discussion is primarily in terms of bottom-dwelling organisms, since their determination and evaluation constitute one of the most useful of the biologist's contributions, and the one most often included in stream studies.

### Importance of Total Environment

Interpretation of physical, chemical, and bacteriological data usually deals with one constituent at a time, or at most two or three that are interrelated in some way, such as BOD and DO, or the nitrogen compounds. Interpretation of biological data, on the other hand, involves the composition of the total group under examination and the type of the physical environment it inhabits as well. There have been attempts to judge the effects of pollution by concentrating on a single species, or a few species, but these have not been productive. The relationship of aquatic organisms from station to station also is important in interpretation.

Mackenthun and Ingram [41], and Keup [42], among others, have described the significance of various general types of biological findings. Of course, there are numerous gradations of the types of findings discussed, and combinations of two or more general types of reactions.

### Sensitivity to Pollution

In general, the larval stages of stoneflies, mayflies, caddisflies, and riffle beetles are bottom organisms most sensitive to organic pollution. Less sensitive are scuds, sowbugs, certain snails, and larvae of black flies, horseflies, and certain midges. Most tolerant are sludgeworms, bloodworms, and a single type of snail.

### Organic Constituents

The reaction to moderate organic pollution may be some reduction in the organisms most sensitive to pollution by organic matter, and a corresponding increase in the less sensitive organisms. Heavy organic pollution may eliminate all pollution-sensitive organisms, and leave large numbers of only one or two kinds of tolerant organisms.

### Toxic Materials

Toxic materials may reduce both kinds and numbers of organisms, with no corresponding increase in the numbers of the less sensitive kinds such as that which results from the nutrients of organic pollution. Highly toxic conditions may eliminate all bottom organisms.

### Organic and Toxic Constituents

The first biological reaction to a combination of toxic and organic pollution may be similar to that to toxic pollution only. The organisms are reduced by the toxicity with no corresponding increase in numbers of any kind in spite of the nutrients in the organic matter. Farther downstream, however, when the toxicity has been reduced by dilution, the organisms may show the typical reaction to organic pollution.

### Silt

Suspended silt that settles tends to cover and smother bottom organisms. The biological reaction, similar to that to toxic materials, is reductions in both kinds and numbers without corresponding increase in numbers of less sensitive kinds.

### Type of Bottom

The type of stream bed must be considered in the interpretation of biological data.

The scarcity or total absence of bottom organisms caused by toxicity may be approached or even duplicated by a stream bottom of fine shifting sand that provides an unsuitable attachment surface for organisms because of both instability and scouring action.

Deposited silt, on the other hand, tends to be more stable than fine sand, and may provide a suitable habitat for burrowing insect larvae. Hard clay bottoms are very poor attachment surfaces, while rubble bottoms are ideal.

## UNIQUE DATA

There are results in any set of stream data that are puzzling, even frustrating, because they do not respond to the usual methods of analysis and interpretation. The engineer is tempted to take the easy way out when faced with such data and dismiss them by blaming them on sampling or laboratory error. Such errors do occur, of course, and the possibility should be reviewed with the sampling and laboratory personnel. But the probability that something obscure occurred in the complex stream system or among the involved physical, chemical, and biological reactions of pollution in the stream that did not follow the usual pattern is greater than is the probability of sampling or laboratory error. The engineer should bring to bear every bit of originality and ingenuity at his command to attempt to determine whether something unusual did occur in the stream and, if so, what that something was, rather than dismiss such data as the fault of the sampler or the chemist. Frequently, when properly interpreted, both interesting and revealing information lies in those results that do not fit the pattern.

# 15

# REPORT PREPARATION

EVERY study that is worth making in the first place is worth reporting. The report should be prepared as soon as possible after completion of the field work, while the details are still fresh in the mind of the report writer. Details of the situation start to fade from the memory in a relatively short time, regardless of how complete the field notes may be.

A decision to file the data "until there is time to write the report" is a fatal decision. Files are crowded with data on which this decision was made. The "time to write the report" never comes, for other activities always intervene. Those data never attain their maximum usefulness, for they should be analyzed and interpreted, and conclusions drawn and recommendations made by those who conducted the study.

Anyone having occasion to dig into those musty files two, five, or 10 years later cannot possibly reconstruct the details known to those who conducted the study. The value of the data is diminished in proportion to the lost details.

## FAMILIARITY WITH STUDY

The individual responsible for preparation of the report on a stream study should be one who has had an active role in the field work. He should be thoroughly familiar with the stream, sampling stations, waste sources, water uses, and the details of the field operation. This knowledge is essential for the most intelligent and complete interpretation of the data. Reasons for apparent peculiarities of the data that would be totally baffling to one unfamiliar with the details of the situation and the study may be quite obvious to one who was involved in the work. The person who has been there and has participated can bring far more conviction to the writing of the report than can one to whom the stream is merely a wriggly line on a map and the study is an accumulation of numbers and a few brief notes obtained by someone else.

## TABLES

The basic data should be tabulated in full for use by anyone who wishes to check any detail of calculation or interpretation and for future reference. The tables may include all analytical data arranged by station and sampling date, and at least a portion of the field data, such as times of sample collection and notes on visual observations made during sampling. Stream flows may be tabulated with the analytical data or separately, by date and sampling station.

All data may be summarized by average, maximum and minimum, and perhaps in terms of standard deviation, below the individual values for each station, or in a separate summary table. The latter is best for ready reference.

Data on sources of wastes, including name of town or industry, location, point of waste discharge, waste flow, treatment, if any, and characteristics of the raw and treated wastes also may be tabulated.

A list of sampling stations, with descriptions, and other pertinent features such as flow gaging stations, tributary stream confluences, water plant intakes and other points of water use, and dams, if any, constitute a useful record. The locations of these items on the stream preferably should be designated by river miles above its mouth. Times-of-water travel may be both tabulated and shown on a graph. Other special tables are desirable in special situations.

These detailed tables should be in an appendix, where they will not disrupt the smooth flow of the text of the report. Occasionally brief summary tables in the text may be appropriate.

## GRAPHIC PRESENTATION

Both summaries of the basic data and results of calculations should be shown in graphic form where possible. Any trends in the data can be followed much more easily in charts than in tabulations.

The charts generally are plots of concentrations or pounds per day of constituents against river miles or times-of-water travel. Most data should be plotted on arithmetic graph paper to allow easy comparison of proportions and trends. However, semi-logarithmic paper usually is desirable for BOD, to show a straight line reduction of this constituent, and occasionally for data on coliform bacteria when a wide range of values must be shown. Occasionally a chart showing the frequency distribution of a constituent at a station may be desirable.

Pertinent information, such as points of waste discharge and tributary confluences, may be indicated at their proper locations on the graphs. They should be as uncluttered as possible, with no extraneous material. More than two, or at the most three, constituents or other plotted items on one graph can cause difficulty and confusion in interpretation of the several lines. Usually only one item to a chart is desirable unless the relationship of two or more items is being illustrated.

The appendix is an appropriate location for most charts, but those that require special discussion may best be placed in the text at the point of discussion for ready reference.

## MAPS

A basic map is essential in any report of a stream study. The map should show the stream reach and major tributaries involved in bold lines. Insignficant streams, highways, railroads, towns that are not involved, elevation contours, symbols for types of land use and similar features that are not pertinent to the study or to orientation of the reader should not clutter the base map.

On the other hand, any geographical feature that is mentioned in the text should be shown on the map. The reader can be extremely frustrated and irritated to find that "the coliform bacteria remained in excess of the standard until the river reached Tinytown," and then be unable to locate this crossroads town on the map. This type of oversight is not infrequent.

The base map may be in the form of a fold-out, having a blank sheet the size of the report on the left side. The entire map may be unfolded by this device to extend completely beyond the report where it can be referred to readily at any point in the text.

Usually more than one map is desirable. One may include locations of points of waste discharge. Another may indicate points or areas of water use. One showing locations of sampling stations is essential. Quantitative values of constituents found, or river reaches in which standards are violated, may be illustrated on a map.

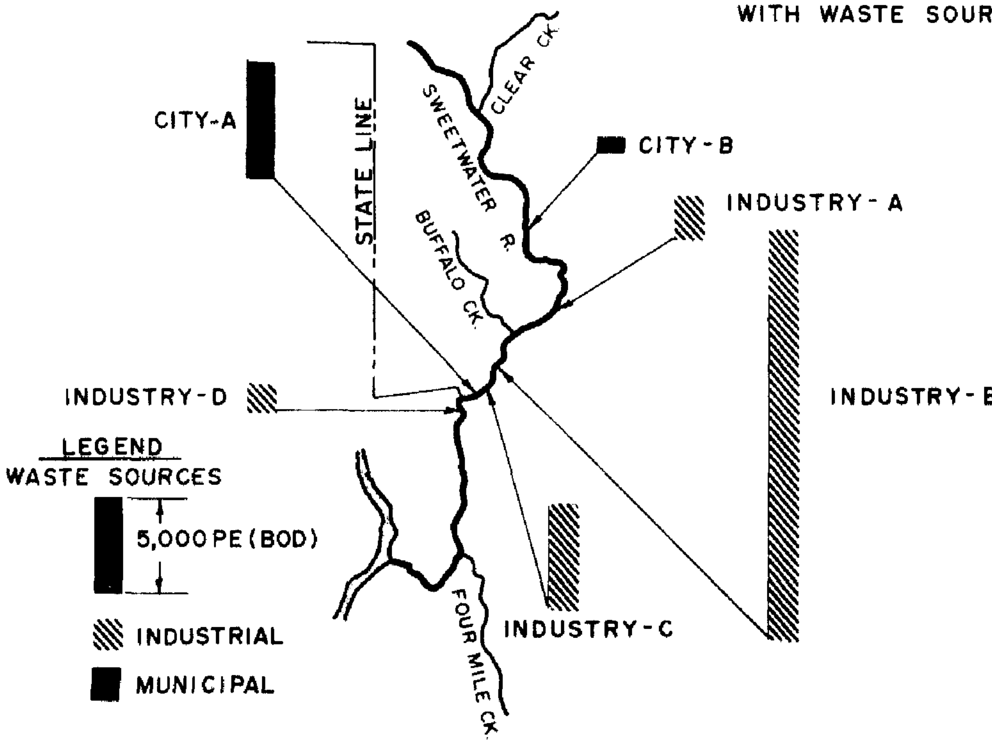
Imaginative use of both maps and charts can tell much of the story of the situation and the findings with a minimum of assistance from the text. For instance, the map of the sources of wastes gives a much clearer picture of the situation if each source is depicted by a symbol, such as a bar or circle, that is in proportion to the load of an important constituent of the wastes (Figure 7). Similarly, a map with the average concentrations of a constituent found at the stream stations may show them by proportioned symbols.

## PHOTOGRAPHS

Photographs may be used to furnish visual impressions of a limited number of features of a stream study that can be conveyed in no other way. Normally black and white reproductions are used because of the cost of color.

•he effects of pollution are difficult to catch by black and white

FIGURE 7
BASIC STREAM MAP
WITH WASTE SOURCES




photography with a few exceptions. Masses of dead fish, or waterfowl with feathers matted with oil, make dramatic pictures that produce maximum impact. Debris of any kind, floating or stranded, may be shown by photograph, but only rarely carries the impact of the actual situation. The plume of a waste discharge may appear in an aerial photograph, but this merely implies that the plume may indicate pollution. A photograph of bottom organisms from a series of stations in cylinders or bottles can provide a vivid impression of the changes from upstream clean water forms through downstream pollution tolerant forms and finally back to clean water forms again.

Color photography can be effective where wastes have colors that contrast with the natural color of the water. Even here, however, care must be exercised to take pictures from an angle that will ensure the proper light on the water surface. Reflection of the blue sky from the water surface can create the impression of clear, clean water although the actual water surface may be gray and murky with pollution.

The opposite side of the coin, of course, involves photographs of people enjoying the uses of clean water. Pictures of individuals enjoying fishing, swimming and boating, for example, are easy to obtain and illustrate the objectives of controlling pollution.

## TEXT

No hard and fast rules can be laid down for the content of the text of a report. This varies with the nature of the study, its objectives, its findings, the purpose of the study and report, and the audience to whom it is addressed.

Generally, the typical stream pollution study report includes the following sections:

1. A table of contents.
2. Acknowledgments of assistance.
3. An introduction, giving briefly the when, where and why of the study.
4. A summary and conclusions.
5. A concise recapitulation of recommendations that are discussed in more detail in the text.
6. A general description of the stream reach and area involved.
7. A discussion of water uses.
8. A description of waste sources.
9. An explanation of the method of study.
10. The presentation of the water quality data, and discussion of the effects of the wastes on water quality and uses.
11. Calculations of needed reductions in wastes.
12. Full discussion of recommendations for any action needed to correct adverse conditions.
13. An appendix.

## KNOW THE AUDIENCE

The audience at which the report is aimed is a first consideration in preparation of the text. A report written merely for the purpose of writing a report usually lacks direction and decisiveness. One addressed to a particular audience is apt to be much more direct and purposeful.

## TECHNICAL LANGUAGE

The report should avoid the use of technical language and technical detail as much as possible if it is designed to be read by and to influence laymen. Any unavoidable technical words should be defined in layman's language when first used. For example, when citing coliform data, it should be explained that tremendous numbers of coliform bacteria are contained in sewage, that results of their determination are used to trace the course of sewage pollution and their densities indicate the relative probabilities that they are accompanied by hazardous pathogens. Which, of course, leads to the necessity of defining pathogens in lay terms. The unit in which coliforms are reported also calls for definition. Laymen have no idea how much water 100 ml is, but they can visualize how much "about two-fifths of a glass," or "a little less than one-half of a glass" is. Illustration of densities by giving the numbers per drop as well as per 100 ml may be even more impressive. The U.S. Pharmacopoeia, which probably is as good an authority as any, states that one milliliter equals 15.5 minims ("about" one drop each), so 100 ml equals about 1,550 drops. As another example, one mg/l may be defined as "one pound per million pounds" or "a little more than eight pounds per million gallons."

There need not be so much concern over technical language in writing for a technical audience. Even here, however, judgment should be used. The primary purpose of writing should be communication and not pedantism. Several different sciences are involved in stream pollution control operations. A representative of any one of these sciences could completely confuse those of the other sciences by excessive use of some of his more obscure scientific jargon. Practitioneers of the several sciences can work together and support each other best only if they understand each other. For example, it is probable that others have been slow to accept the biologists' very valuable contributions to pollution control work because many biologists have expected others to learn their technical language rather than adapting their language to the understanding of others.

A new development in any field appears to call forth new words even for old familiar items. Until the computer came along who ever would have thought that formulas would grow up to be "mathematical models?" And who but a statistician involved with computers would know what an "undependable random component" is? A writer tempted to indulge in his professional lingo should remember that a word or sentence that the everyday person can understand certainly can be understood by even the most brilliant members of his own profession, but this does not apply in reverse.

## OMIT NONESSENTIALS

The text should get to the meat of the problem as quickly as possible. Some writers, for example, include lengthy descriptions of the area near the beginning of the report, giving facts that cannot be tied in directly with the pollution problem. What is the specific correlation of the problem with annual rainfall, annual temperature, population distribution, general industrial activities, economy of the area, terrain, geology, and land uses? Of course, several of these have a bearing on the problem, but only in a general way. Their inclusion contributes little if anything to the understanding of the problem or its solution. The delay in arrival at the real subject can divert the reader and cause a loss of interest.

Lengthy descriptions of methods of laboratory analysis, sampling, flow measurement, and calculation likewise can delay arrival at the heart of the report. Of course, these methods should be recorded for the information of those with particular interests and for future reference. However, their descriptions should be placed in the appendix unless the methods are standard procedures that can be designated by brief references.

## REPORT THE STREAM, NOT THE STUDY

Avoid continued reference to the fact that this is a report on a study. For example, do not say "A sample of water collected at Station No. 13 on August 19 was analyzed and found to contain 4.3 mg/1 of DO and a coliform MPN of 24,000 per 100 ml." This is, rather, a report on a stream. Say: "The river had 4.3 mg/1 of DO and a coliform density of 24,000 per 100 ml at the Lowertown water works intake."

Do not discuss data at individual stations and station-by-station unless there is a specific reason, such as a point of important water use. Consider the stream reach as a whole, rather, with a continuing pattern of water quality throughout the reach. Do not say: "The DO of Station No. 1 above town was 7.5 mg/1. At Station No. 2 below town it was 6.2 mg/1 and at Station No. 3 it was 0.9 mg/1. At Station No. 4 the DO was 4.3 mg/1 and at Station No. 5 it was 6.8 mg/1." Say, rather, "The DO of the stream, which was 7.5 mg/1 above town, dropped below the standard of 5.0 mg/1 about two miles below the sewage treatment plant. It continued to decrease to a low of 0.9 mg/1 at a point near Stinky Bend, four miles below the plant, after which it started to recover. At eight miles downstream it rose to the level of the standard and continued its increase to 6.8 mg/1 12 miles downstream."

## INCORPORATE BIOLOGICAL DATA

All too often biological findings are reported separately as though they were an adjunct to the other data instead of a part of the whole. Separate biological sections have even been placed in the appendices in some reports. The biological data should take their rightful place along with the coliform, the DO, and any other physical, chemical, or bacteriological data, and be woven right into the fabric of the report. They are indeed a part, an important part, of the total story and not a thing apart.

## WASTES ARE NOT POLLUTION

Some report writers appear to consider wastes and their constituents synonymous with pollution. They use the word, "pollution," when discussing sewage or industrial wastes and constituents such as coliform bacteria, BOD, or suspended solids. Sources of wastes have even been identified as "pollution" in the titles of tables. This practice appears to imply the foregone conclusion that wastes are "pollution." The writer could be accused of prejudice, because wastes are not actual pollution until they have caused an unacceptable degradation of water quality. In addition, writing is much better when specific with reference to sewage, packing house or pulp and paper mill wastes, coliform bacteria, BOD, suspended solids, or what have you, rather than calling everything "pollution."

## KEEP IT SIMPLE

This is not the place for a course in composition and style, nor is the author equipped to give such a course. In general, direct, simple, concise writing is the best writing. Both long sentences and long words should be avoided where feasible. Sentences of 15 to 20 words are followed by the reader much more easily than long, involved sentences of 40 to 50 words or more. And why utilize "utilization" when it is possible to use "use" with essentially the same meaning?

## WRITE AND REWRITE

Anyone who wants to write well must be willing to work at it. It is good practice to plan to write any publication at least three times. The three steps would be something like this:

1. Put the article on paper, paying more attention to what is said than how it is said.
2. Rewrite the entire article, rearranging, revising and editing for a smoother over-all product.
3. Polish, polish, polish, with especial emphasis on eliminating unnecessary words and substituting more appropriate wording where feasible.

Unfortunately, time rarely is available to allow the writer to do the best job he can.

## REVIEW

Finally, have several persons review the now nearly finished product after having done the best job possible. Do not impose on the reviewers by expecting them to overhaul a slipshod, half-baked effort. At least one reviewer should not be familiar with the situation covered by the report. If that reviewer has no problem understanding what the report is all about, it is a good report.

# 16

# CONDUCT OF STREAM STUDIES

PREVIOUS chapters have dealt with principles, problems, philosophies, prejudices, facts, figures, fancies, personal opinions, and intuitive conclusions regarding the major factors involved in stream studies. This chapter undertakes to describe an orderly sequence in the conduct of a stream study and the application of the factors already discussed. Inevitably some of the material in previous chapters will be repeated.

Kittrell and West [43] recently have presented a somewhat similar plan of stream study, using a case-history approach.

It is assumed that the study will involve a series of sampling stations rather than a single station. The former is the more complicated operation to conduct, since it includes factors not involved in the latter. Similar principles apply in both situations.

## DECISION

Consideration of the reasons for the proposed study and the budget, personnel, and facilities available to carry it out constitute the first step. The reasons should be examined critically, to make certain there is adequate justification for the study other than the mere fun of it or its substitution for some other less palatable action. So many stream studies have been unproductive of corrective action in the past that the profession has the reputation in some circles of preferring study to action. The best of all reasons for making a stream study, of course, is to determine what corrective measures are needed and to use the findings as tools to obtain correction.

A decision can be made to go ahead with the study when it has been determined that the reasons are valid and the prerequisites are available.

## AVAILABLE DATA COLLECTION

The first activity of the chief of the field party should be the collection and review of all readily available information on the stream. This assumes that he has not had previous experience with that particular stream and must start from scratch to acquire the background knowledge he needs.

The chief should not consider the proposed study an entirely original project or himself the pioneer investigator, even though the stream is strange to him. There are few important streams in this country without at least some record of past water quality. Many streams have been studied intensively. Usually a little digging, especially in the files of the state water pollution control agency, yields enough information on sources of wastes, water uses, and stream characteristics, including discharges and water quality, to serve as a basis for a preliminary study plan.

## PRELIMINARY PLAN

The chief should thoroughly digest all available material as the basis for a preliminary plan of study. A rough estimate of the length of stream reach to be examined can be made from theoretical calculations if bacterial die-away or oxygen sag curves are to be determined during the study. Other factors, of course, may determine the length of stream reach. The factors may include: the locations of water uses; geographical boundaries, such as state lines; and a marked change in stream characteristics, such as entry of a free-flowing stream into a reservoir or lake. Tentative selection of sampling stations can be made from any good map on which known sources of wastes and water uses have been spotted. A list of sources of wastes, and stream flow and water quality records provide a basis for a tentative list of analytical determinations.

The tentative lists of sampling stations and analytical determinations combined with numbers of samples needed for reliability of final results provide an indication of the probable length of time needed for the study. All of these factors must be balanced against the sampling and laboratory personnel and the capacities of laboratory facilities available. A shortage of samplers, chemists, or of bacteriological incubator space, for example, can limit the number of samples that can be handled daily. This, in turn, can determine the frequency of sampling and the length of time needed to process the desired number of samples from each station.

A preliminary cost estimate can be made at this stage, and it may be at this point that the first compromise of the ideal plan has to be made. The cost will have to be adjusted to the available budget. The compromise may be a reduction in the numbers of sampling stations, in the analytical determinations to be made, in the number of samples to be obtained at each station, or some combination of these three factors. Or perhaps the budget can be stretched a bit.

The chief of field party should have a good base of reference for a field reconnaissance of the study area when he has thus completed the written preliminary plan. This background will prevent overlooking some important feature of the situation and ensure coverage of essential features with a minimum of time and effort.

## FIELD RECONNAISSANCE

The field reconnaissance of the area is one of the most important phases in the conduct of a stream study. The information gathered at this time will form the basis for the completed plan of study. As much time as is necessary for a complete and detailed review of the problem in the field should be allowed.

### Reconnaissance Crew

The chief of the field crew should be accompanied by persons who supplement his own skills. Usually he is a sanitary engineer, and he may have with him, for example, a biologist, a chemist, or a sampler capable of making simple field determinations, and an industrial waste engineer if industrial waste discharges are involved. The engineer may make the reconnaissance alone if he has all these skills himself, which is unlikely.

### Biologist

The biologist is an especially important member of the reconnaissance team. An experienced aquatic biologist in a very short time can collect and examine bottom organisms that will reveal both the severity of pollution in a general way, and the length of stream affected by the wastes. His findings will reveal whether the effects of the wastes have extended farther downstream in the past than they do at the time of the reconnaissance. Most aquatic biologists are trained in making simple field analyses, and the biologist may substitute for a chemist or sample collector in this duty. His preliminary overall findings will have an important influence on the final planning of the study.

### Preliminary Tour

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

## Waste Sources

All sources of sewage and industrial wastes should be visited and evaluated. All treatment processes should be reviewed and recorded. Operating records may include all data on both raw and treated wastes needed for the study. The operating records should include data accumulated by monitoring the receiving stream above and below the treatment plant. There is no certainty that these data will be included, however, for this highly desirable practice frequently is neglected. The records should be reviewed, their reliability and adequacy evaluated, and needed information abstracted from them.

Plans should be developed for flow gaging, sampling, and analysis if there is no treatment and data on waste loads discharged to the stream are not available from some other reliable source. Data on sewered population and industrial wastes discharged to the sewerage system are desirable for municipal sewage.

A process survey of all industries discharging directly to the stream should be made, and data requested on raw materials, finished products, and water used. Information requested from an industry that will be provided only on a confidential basis usually should not be accepted. Knowledge that can be used only on a confidential basis frequently not only proves useless but actually may handicap freedom of investigation and reporting, or may even limit distribution of the report.

Grab samples for preliminary analysis of the wastes may be collected for submission to the control agency's laboratory. This will give the chemists an opportunity to determine whether the wastes contain substances that interfere with laboratory analyses, and to obtain an idea of concentrations of constituents that will be encountered when the final study is underway. Samples for this purpose usually will not require the care in preservation and prompt analysis necessary for most reliable results since the data will not be used in the report.

## Water Uses

Types, locations and magnitudes of water uses should be determined. Magnitude of water use may be stated in terms of dollar value, of number of people, or some other factor such as number of boats, pounds of fish, or quantity of water. The dollar value generally is the factor most readily understood by the layman, but this frequently cannot be determined.

All water plants taking water from the stream should be investigated. The operating records include direct data on stream water quality, and chemical dosages may indirectly reflect the effects of pollution on this priority water use. The operator, based on his experience in dealing with the water daily, can provide valuable information on effects of pollution.

## Time-of-Water Travel

Time-of-water travel preferably should be determined before final selection of sampling stations, and at least before the study starts. The determination may be made at the time of the field reconnaissance unless this period is so far in advance of the study that stream flows change too much by that time.

## Stream Characteristics

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

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

## Dry Sampling Run

A dry run of the sampling route or routes should be made and timed. This information will be needed in estimating the number of sample collectors that will be necessary. The routes should be marked on a map, and notes made of any check points that will assist in following the routes.

Stream samples for preliminary analysis may be collected for shipment to headquarters at this time to familiarize the laboratory personnel with what to anticipate when the study starts. Simple field determinations, such as those of temperature, DO and pH, may be made at the same time. The data obtained through preliminary sampling will be useful in preparing the final study plan.

## Laboratory Location

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

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

## Supplies and Services

Sources of needed supplies should be located. Supplies may include ice, distilled water, hardware, and laboratory reagents and minor equipment. Availability of repair services, such as automotive, outboard moter, electrical and plumbing should be determined. It may be desirable to arrange for purchases on charge account or government purchase order. Express, air or bus schedules for shipment of samples to the headquarters' laboratory should be investigated. All details settled in advance will save time when the field operation is underway. Arrangements should be made for any car or boat rentals that may be required.

## Room and Board

Convenient living quarters and eating places reasonably near the laboratory should be located. Special rates may be available for a sizeable field crew at a nearby motel.

## Local Help

Candidates should be interviewed and selections and commitments made at this time, if local help is to be employed for dishwashing, sampling, boat operation or car driving.

Contacts should be established with such persons as local municipal and industrial officials, the local game and fish warden, those who have frequent close contact with the stream, active representatives of conservation clubs, fishermen, and others who are interested in the stream. These individuals should be able to provide background information or even a bit of help, if needed, when the study is in progress.

### Importance of Reconnaissance

These suggested activities during the reconnaissance appear to involve a lot of work. They do just that. At least one or two weeks should be allowed for this purpose. It will be well worthwhile in the subsequent development of the final study plan and in the study itself. Anything necessary that can be completed in advance of the study reduces pressure during the study by just that much. A thorough reconnaissance provides the basis for the soundest possible study plan, ensures smoother operation of the study, and reduces confusion, time, effort and cost in the long run. The time and expense of most of the field crew will be wasted for about a week while the necessary orientation and planning are being accomplished if the crew is sent to a new stream on which a reconnaissance has not been made. The first couple of days of sampling usually are a period of considerable confusion, even when there has been the most thorough reconnaissance and advance planning. Without the preliminary procedure the situation is one of utter confusion.

## REVISED PLAN

The preliminary study plan can be revised and the final plan developed upon return to the office with information collected during the reconnaissance. Field findings may require some revision of details of the objectives. The study plan should be prepared with as much care as the objectives, and in greater detail.

Capacity of the laboratory usually controls the rate at which a study can be conducted. The chief of the field party must work closely with the chief of the field laboratory to determine how many samples for the specified analyses can be handled daily by the laboratory. Failure to consult the laboratory chief is almost certain to result in overloaded laboratory facilities and poor analytical results. At this point a compromise that will reduce the number of stations or the frequency of sample collection, or eliminate analysis for some constituents may be necessary.

## FINAL PLAN

The final plan can be put on paper when all necessary adjustments have been made. At this point the U.S. Geological Survey can be notified where and for how long stream flow data will be needed. Also, specific assignment of field personnel can be made. The assigned individuals should be notified as soon as possible so that they can wind up any assignments they are working on, prepare and equip the mobile laboratory, and make any personal arrangements necessary for their absence from home.

All personnel who will be involved in the study should be assembled for a briefiing on the study plan. This may include laboratory personnel who will remain at headquarters and be assigned to analyze samples transmitted to headquarters for stable constituents or those that can be preserved satisfactorily. In addition, experienced personnel not assigned to the study may attend the briefing to offer constructive comments on the plan of study.

At the briefing session definite assignments of responsibilities to specific individuals for various phases of the operation should be made. Copies of the study plan provided all personnel should be discussed both in terms of the entire operation and of individual responsibilities so there can be no misunderstanding and no oversight of pertinent items. Any suggested revisions of the plan should be discussed and accepted or rejected.

The plan for the field operation should include a liberal number of cars. It is better to have at least one more than necessary than to have one less than needed. This is not wasteful, as it might appear, but can prove to be economical. When an unexpected emergency arises or a car is put out of action by an accident or otherwise, some portion of the study may come to a halt if cars are not adequate. The usefulness of practically everyone in the field party except laboratory personnel is dependent on his mobility. The lost value of the salary and field subsistence alone of anyone grounded by a shortage of cars could easily be much more than the cost of the extra car. This does not include the cost of any loss of his contribution to the study. Extra cars may be obtained from a rental agency, if needed.

Timing of portions of the field operations may vary with the situation and the personnel and facilities available. For example, waste sources may be examined before the stream work starts, if they can be anticipated to remain reasonably constant from day to day and from week to week. Advance examination of the wastes may be necessary also if personnel and facilities are not adequate to handle both wastes and stream simultaneously. Obviously, it is preferable to acquire data on wastes discharged to the stream at the same time the stream is being sampled. Even a waste that normally is constant may change at times because of a problem in the manufacturing process, a treatment plant failure, a spill, or some other unforeseen circumstance. It may be essential to obtain data on both stream and wastes simultaneously even when available facilities are not adequate to examine the wastes separately. In this case, data from the stream stations above and below the waste sources must be relied upon to provide the measurements of the waste loads.

Time-of-water travel may be determined either just before the water quality study starts or while it is underway, if it is not determined during the reconnaissance. Generally, it is preferable that it be determined in advance. Knowledge of the rate at which the water moves downstream can be advantageous during the study.

A small crew may go to the field in advance of the main party if waste studies or time-of-travel measurements must be made in advance.

## FIELD OPERATIONS

### Preliminary Activities

The field crew should arrive at the study area two to three days before sampling is scheduled to start. The laboratory crew needs about two days to prepare the field laboratory for operation. The sample collectors must be taken over the sampling route, to familiarize them with the sampling stations and give them any necessary instructions on the spot. This period may be used to train individuals in any field techniques with which they are not familiar. Any last minute details not previously attended to may be completed.

### Communications

Arrangements for communication with all individuals should be established as soon as the field crew is settled. Telephone numbers at which individuals can be reached day or night should be listed at a central location, such as the laboratory. Those who travel around the area should leave information on their plans, including points where they can be reached. It may be advantageous for key personnel to call in from time to time. Inability to locate a key individual at times may seriously disrupt the study, or even bring portions of it to a halt until he can be found.

### Tour of Area

All of the crew, including laboratory personnel, should be taken on a tour of the stream, waste sources, and other items involved in the study. This pays dividends in increased understanding of and interest in the work. The crew is more alert to unusual occurrences that otherwise might pass without notice. Observation of such occurrences may provide an explanation for otherwise inexplicable details of the final data. A sample collector may note and record an unusual color or other appearance of a waste as he passes an industrial sewer. A chemist may observe the unusual appearance of that day's sample from a station below the industrial sewer, and provide additional dilutions in the determination of BOD. The DO of all bottles incubated would have been exhausted and a measure of excessively high BOD on that day would have been lost if the extra dilutions had not been made. The interest and alertness of the sample collector and the chemist make it possible to determine the source of the unusual slug of wastes and to measure its impact on the stream.

## Special Investigations

Any special investigations planned during the study that involve nonroutine samples for a few days should not be scheduled for the first couple of days of sample collection. There inevitably is considerable confusion and laboratory productivity is relatively low during the shakedown period while a routine is being established even with the best advance planning. The laboratory is in much better position to accept additional samples after this initial period. The laboratory personnel should always be informed as far as possible in advance of the collection of nonroutine samples or performance of nonroutine analyses.

## Calculation of Analytical Results

Calculation of analytical results should be made and tabulated at the end of the day, or by next morning at the latest, for all analyses completed during a day. Maintenance of current summaries of results, such as plottings of mean values to date against river miles, and of daily results at individual stations against dates of collection, is highly desirable. The main purpose of the summaries is to maintain a check on the course of the study, but the summaries can produce a bonus. The interest of the field crew can be increased as they see the results of their work developing.

## Continual Data Review

Regardless of how the data are maintained or shown, they should be reviewed each day. Continuing review of the data as they evolve is essential to judge whether the study plan is sound and the results are developing a true picture of conditions. Regular and prompt examination will ensure early detection of any need for revision of the study plan and of apparently abnormal results that should be rechecked.

## Unusual Observations

All personnel should be encouraged to watch for and record anything that may prove useful in the study or in interpretation of the data. Sample collectors may note both usual and unusual waste discharges or stream conditions. Laboratory personnel may note unusual appearance of samples or results that are markedly different from those previously obtained. The chief of the party should judge whether results are about as he expected from his knowledge of the situation or are quite different. The observations may indicate a need for rechecking some factor, may show that the study plan should be revised, or may be enlightening in subsequent interpretation of the data.

### Field Revision of Plan

Any necessary revision of the plan should be made as early in the study as possible. If a change found to be needed in a study scheduled for two weeks is not made until the end of the first week, half of the data may be useless, and extension of the study for another week may be necessary. On the other hand, no major change in the plan should be made unless there is a compelling reason for it. Even a minor change in procedure may render data obtained before and after the change incompatible.

### Runoff

Sampling should be suspended during and following periods of rainfall and runoff that significantly increase stream flow, until flow returns to its previous level. Data obtained during a dry period and one of appreciable surface runoff are not compatible.

Sampling may be continued, of course, if data on water quality during a surface runoff period are desired, but the data will not be pertinent to the original purpose of the study.

### Final Activities

When sampling is completed the laboratory crew, or some of its members, will have to remain for three to five additional days to complete bacterial examinations and BOD determinations. During this period the mobile laboratory can be prepared for return to headquarters.

## REPORT PROMPTLY

Analysis and interpretation of data and preparation of the report should start very shortly after return from the field. One or more persons who were members of the field crew should be relieved of all other duties and assigned to preparation of the report until it is ready for reproduction.

Sampling personnel frequently are used for tabulations of data, simple calculations, such as averages, and data plotting. Laboratory personnel, on the other hand, only rarely are involved in data analysis and interpretation. Many apparently have no interest in the data beyond meticulous manipulation of samples and production of the best possible analytical results. This is unfortunate, for knowledge of the methods of data interpretation should increase interest and proficiency in the laboratory work. The story that the data tell when properly interpreted is by far the most interesting feature of any stream study. All laboratory personnel who show a spark of interest in the handling of data for the report should be given encouragement and the opportunity to participate in report preparation.

## FOLLOW-UP

Finally, someone must get busy and supply the pressure necessary to obtain the needed correction if the report shows such a need. No report by itself will accomplish the necessary action no matter how sound technically and how beautifully written it may be. Some of the finest reports ever written are gathering dust, forgotten, in some file or on some shelf, while the pollution that they condemned goes on and on. No one followed up and sold the need detailed by the report or brought to bear the legal pressure that would have resulted in the needed action. Either the super-salesman or the hardboiled cop is needed to get results in the tough business of persuading towns and industries to spend money that appears primarily to benefit someone else.

## FINALE

So—that is the way to make a water quality study. Is that the way this author always does it? Well, no, not exactly, but it is the way it should be done.

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# APPENDIX

## USEFUL INFORMATION FOR STREAM SURVEYS AND EVALUATIONS *

CONVERSION FACTORS

1 cfs = 449 gpm = 0.646 mgd
1 mgd = 695 gpm = 1.547 cfs
1 cfs for 24 hours = 1.98 acre feet
1 ft/sec approximates 2/3 mph (0.682)
1 mph approximates 1½ ft/sec (1.47)

CONVERSION TO MASS OR TOTAL NUMBERS

Q in cfs x concentration in ppm x 5.4 = lbs/day
Q in mgd x concentration in ppm ÷ 0.12 = lbs/day
Q in cfs x MPN/100 ml x 24.6 x $10^6$ = No. of coli./day
Q in mgd x MPN/100 ml x 37.8 x $10^6$ = No. of coli./day

POPULATION EQUIVALENTS

| | |
|---|---|
| 1.0 $BOD_5$ Population Equivalent | = 1/6 lbs $BOD_5$/day |
| 1.0 Susp. Solids " " | = 1/5 lbs S.S./day |
| 1.0 Bacterial " " | = 400 billion coliforms/day |
| Total Phosphorous | = 3 lbs/cap/year |
| Total Nitrogen (Organic & Inorgan.) | = 9 lbs/cap/year |

ESTIMATED PERCENT $BOD_5$ REMOVALS BY SEWAGE TREATMENT

| | Probable Range | Use for Estimating |
|---|---|---|
| Primary Sedimentation | 30-40 | 33% |
| High Rate Trickling Filters | 60-90 | 80% |
| Standard Rate Trickling Filters | 80-90 | 85% |
| High Rate Activated Sludge | 65-85 | 75% |
| Standard Rate Activated Sludge | 85-95 + | 90% |

* Compiled by A. W. West, Chief, Pollution Evaluation Section, National Field Investigations Center, Federal Water Pollution Control Administration, Dept. of the Interior, Jan. 1966.

## TOTAL COLIFORM BACTERIA

Human feces may contain 2 billion coliform B./capita/day

SUMMER—(Water temperatures 15°C. or above)
Raw sewage—57 to 114 billion coli./cap./day
Raw sewage—15-30 million MPN/100 ml
Raw sewage—Use 21,000,000 MPN/100 ml for calcs.
Coliform bacteria multiply about 5 times
in about 12± hours, from sewer to peak.
1.0 BPE at peak = 400 billion coliform bacteria/day.
BPE = Q in cfs x MPN/100 ml x 61 x $10^{-6}$ (at peak)

$$\text{MPN/100 ml} = \frac{\text{BPE} \times 16{,}400}{\text{Q in cfs}} \quad \text{(at peak)}$$

WINTER—(Water temperature = 15°C. or below)
Raw Sewage — 19 to 38 billion coli./cap
Raw sewage — 5 to 10 million MPN/100 ml
1.0 BPE at peak = 125 billion coliform bacteria/day
BPE = Q in cfs x MPN/100 ml x 194 x $10^{-6}$ (at peak)

$$\text{MPN/100 ml} = \frac{\text{BPE} \times 5{,}150}{\text{Q in cfs}} \quad \text{(at peak)}$$

PROBABLE COLIFORM DIE OFF (after reaching peak)
Approximate % of coliform remaining after flow time
(from die-off curve with 2,000,000 MPN/100 ml at peak)

| | |
|---|---|
| ½ day = 40% | 5 days = 0.5% |
| 1 day = 17% | 6 days = 0.27% |
| 2 days = 5% | 7 days = 0.15% |
| 3 days = 2% | 8 days = 0.08% |
| 4 days = 1% | |

## ESTIMATED BACTERIAL REMOVAL EFFICIENCIES

(Imhoff & Fair pg. 6 used as a guide)

| | % Reduction Probable range according to Imhoff & Fair | % Remaining Use this value for calculating estimated bacterial loads |
|---|---|---|
| A. NOMINAL FACILITIES & CONTROL | | |
| Plain Sedimentation | 25-75 | 50% |
| Secondary Treatment (unspecified type) | — | 10% |
| Hi Rate Trickling Filter | 80-95 | 12½% |
| Hi Rate Activated Sludge | 80-95 | 12½% |
| Lo Rate Trickling Filter | 90-95 | 7½% |

| | | |
|---|---|---|
| Standard Rate Activated Sludge | 90-98 | 6% |
| Oxidation Ponds | — | 3% |
| Chlorinated raw sewage | 90-95 | 10% |
| Chlorinated settled sewage | 90-95 | 5% |
| Chlorinated biologically treated sewage | 98-99 | 1% |

B. WHERE EXCEPTIONALLY EFFECTIVE CHLORINATION CONTROL HAS BEEN DEMONSTRATED

| | | |
|---|---|---|
| Two stage (pre and post) chlorination of settled sewage | — | 0.01% |
| Prechlorination of settled sewage | — | 0.5% |
| Post-chlorination of biologically treated sewage | — | 0.01% |

## COLIFORM PROBABILITY PLOT EXAMPLE

| Observed Coliform Density MPN/100 ml | "Exact" Plotting Position N = 13 |
|---|---|
| 50,000 | 4.8 |
| 78,000 | 12.2 |
| 110,000 | 19.8 |
| 130,000 | 27.3 |
| 220,000 | 34.9 |
| 230,000 | 42.5 |
| 330,000 | 50.0 |
| 350,000 | 57.5 |
| 700,000 | 65.1 |
| 820,000 | 72.7 |
| 820,000 | 80.2 |
| 1,600,000 | 87.8 |
| > 1,600,000 | 95.2 |

Note:

541,000 = Arithmetic mean

330,000 = Probability mean (See example plot)

## BIOCHEMICAL OXYGEN DEMAND (BOD)

FUNDAMENTAL REACTION

The fraction of the total, or ultimate, carbonaceous BOD satisfied in the 5 day BOD test ($BOD_5$) depends upon the rate ($k_1$) at which the oxygen is depleted. The following formula is the basis of most BOD (carbonaceous) calculations:

$$\text{BOD at t in days} = \text{ultimate BOD} \times \left[1 - 10^{-k_1 t}\right]$$

Note: $BOD_t$ = amount satisfied

Note: $10^{-k_1 t}$ = percent remaining
$k_1 = 0.10$ - rate associated with river water
$k_1 = 0.15$ - rate presently associated with sewages
$k_1 = 0.20$ - rate for some industrial wastes
$k_1 > 0.20$ - rate for rapidly oxidized wastes like sugars, etc.

RELATIONSHIP BETWEEN 5 DAY BOD TEST AND ULTIMATE BOD

$BOD_5 = 0.44$ x ultimate BOD at $k_1 = 0.05$
$BOD_5 = 0.684$ x ultimate BOD at $k_1 = 0.10$
$BOD_5 = 0.82$ x ultimate BOD at $k_1 = 0.15$
$BOD_5 = 0.90$ x ultimate BOD at $k_1 = 0.20$

EXAMPLE of BOD satisfaction after varying periods of time at at $k_1 = 0.15$ from the equation

$$BOD_t = BOD_{ult.} \left[1 - 10^{-k_1 t}\right] \text{ (carbonaceous)}$$

| | | | |
|---|---|---|---|
| BOD satisfied in ½ day | = 0.19 x $BOD_5$ | = 0.16 x $BOD_{ult.}$ |
| BOD " " 1 " | = 0.37 x " | = 0.30 x " " |
| BOD " " 2 days | = 0.68 x " | = 0.50 x " " |
| BOD " " 3 " | = 0.78 x " | = 0.65 x " " |
| BOD " " 4 " | = 0.91 x " | = 0.75 x " " |
| BOD " " 5 " | = 1.00 x " | = 0.82 x " " |

NITROGENOUS BOD: Nitrogenous materials, such as ammonia, are also oxidized to the stable nitrate form. Some part of this reaction may occur simultaneously with the carbonaceous BOD reaction; but the major effect is exerted after the ultimate carbonaceous BOD reaction is completed. This additional nitrogenous BOD may equal the amount of the ultimate carbonaceous BOD. This concept is useful when considering BOD's some 10-30 days downstream, or in reservoirs. The nitrogenous reaction rate (k) may approximate 1/3 of the carbonaceous reaction rate ($k_1$).

EFFECT OF TEMPERATURE ON REACTION RATES

Laboratory measurement of $k_1$ rates are determined at 20°C. In streams, the actual rate increases approximately 4.7% for every 1.0°C temperature increase (and decreases an equivalent percentage for lower temperatures) according to the following equation:

$$k_1 (T°C) = k_1 (20°C) \times 1.047^{(T-20)}$$

## RIVER DISCHARGE AND TIME OF TRAVEL

RIVER VELOCITY CHARACTERISTICS

Velocity at 0.6 depth from surface approximates the mean velocity throughout the entire depth.

The average of velocities measured at the 0.2 and the 0.8 depth provides a slightly more precise measurement of mean velocity.

The mean vertical velocity varies from 80 to 95 percent (use 85%) of the surface velocity.

The maximum velocity occurs at 5 to 25 percent of depth; is nearer the surface in shallow streams, and farther from the surface in deep streams.

## TIME OF TRAVEL STUDIES

Time of travel in rivers (also threading, mixing and diffusion characteristics) can be measured by introducing Rhodamine B dye into the river and tracing it downstream with a fluorometer.

The fluorometer can measure Rhodamine concentrations as low as 1.0 part per billion (ppb). Concentrations in excess of 3.0 parts per million (ppm) may foul the meter cell.

Therefore, adjust Rhodamine B dosage to obtain from 1.0 ppm to 10.0 ppb along the river reach to be measured.

The amount of dye to be discharged can be estimated by calculating the amount necessary to provide a theoretical 1.0 ppb average concentration throughout the entire mass of river water contained in the overall reach to be studied. (Note commercial solutions contain about 45% dye in acetic acid solutions.)

Time of travel is determined by measuring the time required for the peak dye concentrations to reach the successive downstream sampling stations.

## SATURATION VALUES OF DISSOLVED OXYGEN

IN ppm

(UNDER NORMAL ATMOSPHERE AT 760 mm. PRESSURE)

Taken from Article "Stream Pollution" by H. W. Streeter,

Sewage Works Journal, Vol. 7, p. 535;
and Standard Methods, Ninth Edition

| Temp °C | 0.0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 14.62 | 14.58 | 14.54 | 14.50 | 14.46 | 14.42 | 14.39 | 14.36 | 14.31 | 14.27 |
| 1 | 14.23 | 14.19 | 14.15 | 14.11 | 14.07 | 14.03 | 14.00 | 13.96 | 13.92 | 13.88 |
| 2 | 13.84 | 13.80 | 13.77 | 13.73 | 13.70 | 13.66 | 13.62 | 13.59 | 13.55 | 13.52 |
| 3 | 13.48 | 13.44 | 13.41 | 13.38 | 13.34 | 13.30 | 13.27 | 13.24 | 13.20 | 13.16 |
| 4 | 13.13 | 13.10 | 13.06 | 13.03 | 13.00 | 12.97 | 12.93 | 12.90 | 12.87 | 12.83 |
| 5 | 12.80 | 12.77 | 12.74 | 12.70 | 12.67 | 12.64 | 12.61 | 12.58 | 12.54 | 12.51 |
| 6 | 12.48 | 12.45 | 12.42 | 12.39 | 12.36 | 12.32 | 12.29 | 12.26 | 12.23 | 12.20 |
| 7 | 12.17 | 12.14 | 12.11 | 12.08 | 12.05 | 12.02 | 11.99 | 11.96 | 11.93 | 11.90 |
| 8 | 11.87 | 11.84 | 11.81 | 11.79 | 11.76 | 11.73 | 11.70 | 11.67 | 11.65 | 11.62 |
| 9 | 11.59 | 11.56 | 11.54 | 11.51 | 11.49 | 11.46 | 11.43 | 11.41 | 11.38 | 11.36 |
| 10 | 11.33 | 11.31 | 11.28 | 11.25 | 11.23 | 11.21 | 11.18 | 11.15 | 11.13 | 11.11 |
| 11 | 11.08 | 11.06 | 11.03 | 11.00 | 10.98 | 10.96 | 10.93 | 10.90 | 10.88 | 10.86 |
| 12 | 10.83 | 10.81 | 10.78 | 10.76 | 10.74 | 10.71 | 10.69 | 10.67 | 10.65 | 10.62 |
| 13 | 10.60 | 10.58 | 10.55 | 10.53 | 10.51 | 10.48 | 10.46 | 10.44 | 10.42 | 10.39 |
| 14 | 10.37 | 10.35 | 10.33 | 10.30 | 10.28 | 10.26 | 10.24 | 10.22 | 10.19 | 10.17 |
| 15 | 10.15 | 10.13 | 10.11 | 10.09 | 10.07 | 10.05 | 10.03 | 10.01 | 9.99 | 9.97 |
| 16 | 9.95 | 9.93 | 9.91 | 9.89 | 9.87 | 9.85 | 9.82 | 9.80 | 9.78 | 9.76 |
| 17 | 9.74 | 9.72 | 9.70 | 9.68 | 9.66 | 9.64 | 9.62 | 9.60 | 9.58 | 9.56 |
| 18 | 9.54 | 9.52 | 9.50 | 9.48 | 9.46 | 9.44 | 9.43 | 9.41 | 9.39 | 9.37 |
| 19 | 9.35 | 9.33 | 9.31 | 9.30 | 9.28 | 9.26 | 9.24 | 9.22 | 9.21 | 9.19 |
| 20 | 9.17 | 9.15 | 9.13 | 9.12 | 9.10 | 9.08 | 9.06 | 9.04 | 9.03 | 9.01 |
| 21 | 8.99 | 8.98 | 8.96 | 8.94 | 8.93 | 8.91 | 8.89 | 8.88 | 8.86 | 8.85 |
| 22 | 8.83 | 8.81 | 8.80 | 8.78 | 8.77 | 8.75 | 8.74 | 8.72 | 8.71 | 8.69 |
| 23 | 8.68 | 8.66 | 8.65 | 8.63 | 8.62 | 8.60 | 8.59 | 8.57 | 8.56 | 8.54 |
| 24 | 8.53 | 8.51 | 8.50 | 8.48 | 8.47 | 8.45 | 8.44 | 8.42 | 8.41 | 8.39 |
| 25 | 8.38 | 8.36 | 8.35 | 8.33 | 8.32 | 8.30 | 8.28 | 8.27 | 8.25 | 8.24 |
| 26 | 8.22 | 8.20 | 8.19 | 8.17 | 8.16 | 8.14 | 8.13 | 8.11 | 8.10 | 8.08 |
| 27 | 8.07 | 8.05 | 8.04 | 8.02 | 8.01 | 7.99 | 7.98 | 7.96 | 7.95 | 7.93 |
| 28 | 7.92 | 7.90 | 7.89 | 7.87 | 7.86 | 7.84 | 7.83 | 7.81 | 7.80 | 7.78 |
| 29 | 7.77 | 7.75 | 7.74 | 7.73 | 7.71 | 7.70 | 7.69 | 7.67 | 7.66 | 7.64 |
| 30 | 7.63 | 7.61 | 7.60 | 7.59 | 7.57 | 7.56 | 7.55 | 7.54 | | |
| 31 | 7.5 | | | | | | | | | |
| 32 | 7.4 | | | | | | | | | |
| 33 | 7.3 | | | | | | | | | |
| 34 | 7.2 | | | | | | | | | |
| 35 | 7.1 | | | | | | | | | |
| 36 | 7.0 | | | | | | | | | |
| 37 | 6.9 | | | | | | | | | |
| 38 | 6.8 | | | | | | | | | |
| 39 | 6.7 | | | | | | | | | |
| 40 | 6.6 | | | | | | | | | |
| 41 | 6.5 | | | | | | | | | |
| 42 | 6.4 | | | | | | | | | |
| 43 | 6.3 | | | | | | | | | |
| 44 | 6.2 | | | | | | | | | |
| 45 | 6.1 | | | | | | | | | |
| 46 | 6.0 | | | | | | | | | |
| 47 | 5.9 | | | | | | | | | |
| 48 | 5.8 | | | | | | | | | |
| 49 | 5.7 | | | | | | | | | |
| 50 | 5.6 | | | | | | | | | |

# PLOTTING POSITIONS FOR NORMAL PROBABILITY PAPER

Sample Size

| Ordinal No. | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 28.6 | 19.9 | 15.2 | 12.2 | 10.3 | 8.8 | 7.7 | 6.9 | 6.2 | 5.6 | 5.2 | 4.8 | 4.4 | 4.1 | 3.9 |
| 2 | 71.4 | 50.0 | 38.3 | 31.0 | 26.0 | 22.5 | 19.7 | 17.6 | 15.8 | 14.4 | 13.2 | 12.2 | 11.4 | 10.6 | 9.9 |
| 3 | | 80.1 | 61.7 | 50.0 | 42.0 | 36.2 | 31.8 | 28.4 | 25.6 | 23.3 | 21.4 | 19.8 | 18.4 | 17.2 | 16.1 |
| 4 | | | 84.8 | 69.0 | 58.0 | 50.0 | 43.9 | 39.2 | 35.3 | 32.2 | 29.6 | 27.3 | 25.4 | 23.7 | 22.3 |
| 5 | | | | 87.8 | 74.0 | 63.8 | 56.1 | 50.0 | 45.1 | 41.1 | 37.8 | 34.9 | 32.4 | 30.3 | 28.4 |
| 6 | | | | | 89.7 | 77.5 | 68.2 | 60.8 | 54.9 | 50.0 | 45.9 | 42.5 | 39.5 | 36.9 | 34.6 |
| 7 | | | | | | 91.2 | 80.3 | 71.6 | 64.7 | 58.9 | 54.1 | 50.0 | 46.5 | 43.4 | 40.7 |
| 8 | | | | | | | 92.3 | 82.4 | 74.4 | 67.8 | 62.2 | 57.5 | 53.5 | 50.0 | 46.9 |
| 9 | | | | | | | | 93.1 | 84.2 | 76.7 | 70.4 | 65.1 | 60.5 | 56.6 | 53.1 |
| 10 | | | | | | | | | 93.8 | 85.6 | 78.6 | 72.7 | 67.6 | 63.1 | 59.3 |
| 11 | | | | | | | | | | 94.4 | 86.8 | 80.2 | 74.6 | 69.7 | 65.4 |
| 12 | | | | | | | | | | | 94.8 | 87.8 | 81.6 | 76.3 | 71.6 |
| 13 | | | | | | | | | | | | 95.2 | 88.6 | 82.8 | 77.7 |
| 14 | | | | | | | | | | | | | 95.6 | 89.4 | 83.9 |
| 15 | | | | | | | | | | | | | | 95.9 | 90.1 |
| 16 | | | | | | | | | | | | | | | 96.1 |

| 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | Ordinal No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.6 | 3.4 | 3.3 | 3.1 | 2.9 | 2.8 | 2.7 | 2.6 | 2.4 | 2.4 | 2.3 | 2.2 | 2.1 | 2.1 | 2.0 | 1 |
| 9.4 | 8.9 | 8.4 | 8.0 | 7.7 | 7.2 | 6.8 | 6.7 | 6.4 | 6.2 | 5.9 | 5.7 | 5.5 | 5.3 | 5.2 | 2 |
| 15.2 | 14.3 | 13.6 | 12.9 | 12.3 | 11.7 | 11.3 | 10.7 | 10.4 | 9.9 | 9.5 | 9.2 | 8.9 | 8.7 | 8.4 | 3 |
| 21.0 | 19.8 | 18.8 | 17.9 | 17.1 | 16.4 | 15.6 | 14.9 | 14.2 | 13.8 | 13.3 | 12.7 | 12.3 | 11.9 | 11.5 | 4 |
| 26.8 | 25.3 | 24.0 | 22.8 | 21.8 | 20.6 | 19.8 | 18.9 | 18.1 | 17.6 | 16.9 | 16.4 | 15.9 | 15.2 | 14.7 | 5 |
| 32.6 | 30.8 | 29.2 | 27.8 | 26.4 | 25.1 | 24.2 | 23.3 | 22.4 | 21.5 | 20.6 | 19.8 | 19.2 | 18.7 | 17.9 | 6 |
| 38.4 | 36.3 | 34.4 | 32.7 | 31.2 | 29.8 | 28.4 | 27.4 | 26.1 | 25.1 | 24.2 | 23.3 | 22.7 | 21.8 | 21.2 | 7 |
| 44.2 | 41.8 | 39.6 | 37.6 | 35.9 | 34.1 | 32.6 | 31.6 | 30.2 | 29.1 | 28.1 | 27.1 | 26.1 | 25.1 | 24.6 | 8 |
| 50.0 | 47.2 | 44.8 | 42.6 | 40.5 | 38.6 | 37.1 | 35.6 | 34.1 | 33.0 | 31.6 | 30.5 | 29.5 | 28.4 | 27.4 | 9 |
| 55.8 | 52.8 | 50.0 | 47.5 | 45.2 | 43.3 | 41.3 | 39.7 | 38.2 | 36.7 | 35.2 | 34.1 | 33.0 | 31.9 | 30.9 | 10 |
| 61.6 | 58.2 | 55.2 | 52.5 | 50.0 | 47.6 | 45.6 | 43.6 | 42.1 | 40.5 | 39.0 | 37.4 | 36.3 | 35.2 | 34.1 | 11 |
| 67.4 | 63.7 | 60.4 | 57.4 | 54.8 | 52.4 | 50.0 | 48.0 | 46.0 | 44.4 | 42.5 | 41.3 | 39.7 | 38.6 | 37.1 | 12 |
| 73.2 | 69.2 | 65.6 | 62.4 | 59.5 | 56.7 | 54.4 | 52.0 | 50.0 | 48.0 | 46.4 | 44.8 | 43.3 | 41.7 | 40.5 | 13 |
| 79.0 | 74.7 | 70.8 | 67.3 | 64.1 | 61.4 | 58.7 | 56.4 | 54.0 | 52.0 | 50.0 | 48.4 | 46.4 | 45.2 | 43.6 | 14 |
| 84.8 | 80.2 | 76.0 | 72.2 | 68.8 | 65.9 | 62.9 | 60.3 | 57.9 | 55.6 | 53.6 | 51.6 | 50.0 | 48.4 | 46.8 | 15 |
| 90.6 | 85.7 | 81.2 | 77.2 | 73.6 | 70.2 | 67.4 | 64.4 | 61.8 | 59.5 | 57.5 | 55.2 | 53.6 | 51.6 | 50.0 | 16 |
| 96.4 | 91.1 | 86.4 | 82.1 | 78.2 | 74.9 | 71.6 | 68.4 | 65.9 | 63.3 | 61.0 | 58.7 | 56.7 | 54.8 | 53.2 | 17 |
| | 96.6 | 91.6 | 87.1 | 82.9 | 79.4 | 75.8 | 72.6 | 69.8 | 67.0 | 64.8 | 62.6 | 60.3 | 58.3 | 56.4 | 18 |
| | | 96.7 | 92.0 | 87.7 | 83.6 | 80.2 | 76.7 | 73.9 | 70.9 | 68.4 | 65.9 | 63.7 | 61.4 | 59.5 | 19 |
| | | | 96.9 | 92.3 | 88.3 | 84.4 | 81.1 | 77.6 | 74.9 | 71.9 | 69.5 | 67.0 | 64.8 | 62.9 | 20 |
| | | | | 97.1 | 92.8 | 88.7 | 85.1 | 81.9 | 78.5 | 75.8 | 72.9 | 70.5 | 68.1 | 65.9 | 21 |
| | | | | | 97.2 | 93.2 | 89.3 | 85.8 | 82.4 | 79.4 | 76.7 | 73.9 | 71.6 | 69.1 | 22 |
| | | | | | | 97.3 | 93.3 | 89.6 | 86.2 | 83.1 | 80.2 | 77.3 | 74.9 | 72.6 | 23 |
| | | | | | | | 97.4 | 93.6 | 90.1 | 86.7 | 83.6 | 80.8 | 78.2 | 75.4 | 24 |
| | | | | | | | | 97.6 | 93.8 | 90.5 | 87.3 | 84.1 | 81.3 | 78.8 | 25 |
| | | | | | | | | | 97.6 | 94.1 | 90.8 | 87.7 | 84.8 | 82.1 | 26 |
| | | | | | | | | | | 97.7 | 94.3 | 91.1 | 88.1 | 85.3 | 27 |
| | | | | | | | | | | | 97.8 | 94.5 | 91.3 | 88.5 | 28 |
| | | | | | | | | | | | | 97.9 | 94.7 | 91.6 | 29 |
| | | | | | | | | | | | | | 97.9 | 94.8 | 30 |
| | | | | | | | | | | | | | | 98.0 | 31 |

**References:**


(1) Statistical Tables for Biological Agricultural and Medical Research, by Fisher and Yates, Hafner Pub. Co., '63, Table XX, 94-95.
(2) Tables of Normal Probability Functions, U.S. Government Printing Office, '53, Table I, 2-338.
(3) Pearson, E. and Hartley, H., Biometrika Tables for Statisticians Volume I, Cambridge University Press, '54 Table 28, 175, Table I, 104-110.

| Ordinal No. | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | Ordinal No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.92 | 1.88 | 1.83 | 1.74 | 1.70 | 1.66 | 1.62 | 1.58 | 1.54 | 1.50 | 1.46 | 1.43 | 1.39 | 1.36 | 1.32 | 1.32 | 1.29 | 1.25 | 1.22 | 1 |
| 2 | 4.9 | 4.8 | 4.6 | 4.6 | 4.5 | 4.3 | 4.2 | 4.1 | 4.0 | 3.9 | 3.8 | 3.7 | 3.6 | 3.5 | 3.4 | 3.4 | 3.3 | 3.2 | 3.2 | 2 |
| 3 | 8.1 | 7.8 | 7.6 | 7.4 | 7.2 | 6.9 | 6.8 | 6.7 | 6.4 | 6.3 | 6.2 | 6.1 | 5.8 | 5.7 | 5.6 | 5.5 | 5.4 | 5.3 | 5.2 | 3 |
| 4 | 11.1 | 10.9 | 10.6 | 10.2 | 10.0 | 9.7 | 9.4 | 9.2 | 9.0 | 8.7 | 8.5 | 8.4 | 8.1 | 7.9 | 7.8 | 7.6 | 7.5 | 7.4 | 7.2 | 4 |
| 5 | 14.2 | 13.8 | 13.3 | 13.1 | 12.7 | 12.3 | 12.1 | 11.7 | 11.5 | 11.1 | 10.9 | 10.6 | 10.4 | 10.2 | 10.0 | 9.7 | 9.5 | 9.3 | 9.2 | 5 |
| 6 | 17.4 | 16.9 | 16.4 | 15.9 | 15.4 | 15.2 | 14.7 | 14.2 | 14.0 | 13.6 | 13.3 | 12.9 | 12.7 | 12.3 | 12.1 | 11.9 | 11.7 | 11.3 | 11.1 | 6 |
| 7 | 20.6 | 19.8 | 19.2 | 18.7 | 18.1 | 17.9 | 17.4 | 16.9 | 16.4 | 16.1 | 15.6 | 15.4 | 14.9 | 14.7 | 14.2 | 14.0 | 13.8 | 13.3 | 13.1 | 7 |
| 8 | 23.6 | 23.0 | 22.4 | 21.5 | 20.9 | 20.3 | 19.8 | 19.5 | 18.9 | 18.4 | 18.1 | 17.6 | 17.1 | 16.9 | 16.4 | 16.1 | 15.9 | 15.4 | 15.2 | 8 |
| 9 | 26.8 | 25.8 | 25.1 | 24.5 | 23.6 | 23.3 | 22.7 | 22.1 | 21.5 | 20.9 | 20.3 | 20.0 | 19.5 | 18.9 | 18.7 | 18.1 | 17.9 | 17.4 | 17.1 | 9 |
| 10 | 29.8 | 28.8 | 28.1 | 27.4 | 26.4 | 25.8 | 25.1 | 24.5 | 23.9 | 23.3 | 22.7 | 22.4 | 21.8 | 21.2 | 20.9 | 20.3 | 20.0 | 19.5 | 19.2 | 10 |
| 11 | 33.0 | 31.9 | 30.9 | 30.2 | 29.5 | 28.4 | 27.8 | 27.1 | 26.4 | 25.8 | 25.1 | 24.5 | 23.9 | 23.6 | 23.0 | 22.4 | 22.1 | 21.5 | 21.2 | 11 |
| 12 | 35.9 | 34.8 | 34.1 | 33.0 | 31.9 | 31.2 | 30.5 | 29.5 | 28.8 | 28.1 | 27.4 | 26.8 | 26.1 | 25.8 | 25.1 | 24.5 | 24.2 | 23.6 | 23.0 | 12 |
| 13 | 39.0 | 37.8 | 36.7 | 35.9 | 34.8 | 33.7 | 33.0 | 32.3 | 31.2 | 30.5 | 29.8 | 29.1 | 28.4 | 27.8 | 27.4 | 26.7 | 26.1 | 25.5 | 25.1 | 13 |
| 14 | 42.1 | 40.9 | 39.7 | 38.6 | 37.4 | 36.7 | 35.6 | 34.8 | 33.7 | 33.0 | 32.3 | 31.6 | 30.9 | 30.2 | 29.5 | 28.8 | 28.1 | 27.8 | 27.1 | 14 |
| 15 | 45.2 | 44.0 | 42.9 | 41.3 | 40.5 | 39.4 | 38.2 | 37.1 | 36.3 | 35.6 | 34.5 | 33.7 | 33.0 | 32.3 | 31.6 | 30.9 | 30.2 | 29.8 | 29.1 | 15 |
| 16 | 48.4 | 46.8 | 45.6 | 44.4 | 43.3 | 42.1 | 40.9 | 39.7 | 39.0 | 37.8 | 37.1 | 35.9 | 35.2 | 34.5 | 33.7 | 33.0 | 32.3 | 31.6 | 31.2 | 16 |
| 17 | 51.6 | 50.0 | 48.4 | 47.2 | 46.0 | 44.4 | 43.6 | 42.5 | 41.3 | 40.1 | 39.4 | 38.6 | 37.4 | 36.7 | 35.9 | 35.2 | 34.5 | 33.7 | 33.0 | 17 |
| 18 | 54.8 | 53.2 | 51.6 | 50.0 | 48.8 | 47.2 | 46.0 | 44.8 | 43.6 | 42.9 | 41.7 | 40.9 | 39.7 | 39.0 | 38.2 | 37.4 | 36.7 | 35.9 | 35.2 | 18 |
| 19 | 57.9 | 56.0 | 54.4 | 52.8 | 51.2 | 50.0 | 48.8 | 47.6 | 46.4 | 45.2 | 44.0 | 43.3 | 42.1 | 41.3 | 40.1 | 39.4 | 38.6 | 37.8 | 37.1 | 19 |
| 20 | 61.0 | 59.1 | 57.1 | 55.6 | 54.0 | 52.8 | 51.2 | 50.0 | 48.8 | 47.6 | 46.4 | 45.2 | 44.4 | 43.3 | 42.5 | 41.7 | 40.5 | 39.7 | 39.0 | 20 |
| 21 | 64.1 | 62.2 | 60.3 | 58.7 | 56.7 | 55.6 | 54.0 | 52.4 | 51.2 | 50.0 | 48.8 | 47.6 | 46.4 | 45.6 | 44.4 | 43.6 | 42.9 | 41.7 | 40.9 | 21 |
| 22 | 67.0 | 65.2 | 63.3 | 61.4 | 59.5 | 57.9 | 56.4 | 55.2 | 53.6 | 52.4 | 51.2 | 50.0 | 48.8 | 47.6 | 46.8 | 45.6 | 44.8 | 44.0 | 42.9 | 22 |
| 23 | 70.2 | 68.1 | 65.9 | 64.1 | 62.6 | 60.6 | 59.1 | 57.5 | 56.4 | 54.8 | 53.6 | 52.4 | 51.2 | 50.0 | 48.8 | 48.0 | 46.8 | 46.0 | 44.8 | 23 |
| 24 | 73.2 | 71.2 | 69.1 | 67.0 | 65.2 | 63.3 | 61.8 | 60.3 | 58.7 | 57.1 | 56.0 | 54.8 | 53.6 | 52.4 | 51.2 | 50.0 | 48.8 | 48.0 | 46.8 | 24 |
| 25 | 76.4 | 74.2 | 71.9 | 69.8 | 68.1 | 66.3 | 64.4 | 62.9 | 61.0 | 59.9 | 58.3 | 56.7 | 55.6 | 54.4 | 53.2 | 52.0 | 51.2 | 50.0 | 48.8 | 25 |
| 26 | 79.4 | 77.0 | 74.9 | 72.6 | 70.5 | 68.8 | 67.0 | 65.2 | 63.7 | 62.2 | 60.6 | 59.1 | 57.9 | 56.7 | 55.6 | 54.4 | 53.2 | 52.0 | 51.2 | 26 |
| 27 | 82.6 | 80.2 | 77.6 | 75.5 | 73.6 | 71.6 | 69.5 | 67.7 | 66.3 | 64.4 | 62.9 | 61.4 | 60.3 | 58.7 | 57.5 | 56.4 | 55.2 | 54.0 | 53.2 | 27 |
| 28 | 85.8 | 83.1 | 80.8 | 78.5 | 76.4 | 74.2 | 72.2 | 70.5 | 68.8 | 67.0 | 65.5 | 64.1 | 62.6 | 61.0 | 59.9 | 58.3 | 57.1 | 56.0 | 55.2 | 28 |
| 29 | 88.9 | 86.2 | 83.6 | 81.3 | 79.1 | 76.7 | 74.9 | 72.9 | 71.2 | 69.5 | 67.7 | 66.3 | 64.8 | 63.3 | 61.8 | 60.6 | 59.5 | 58.3 | 57.1 | 29 |
| 30 | 91.9 | 89.1 | 86.7 | 84.1 | 81.9 | 79.7 | 77.3 | 75.5 | 73.6 | 71.9 | 70.2 | 68.4 | 67.0 | 65.5 | 64.1 | 62.6 | 61.4 | 60.3 | 59.1 | 30 |
| 31 | 95.1 | 92.2 | 89.4 | 86.9 | 84.6 | 82.1 | 80.2 | 77.9 | 76.1 | 74.2 | 72.6 | 70.9 | 69.1 | 67.7 | 66.3 | 64.8 | 63.3 | 62.2 | 61.0 | 31 |
| 32 | 98.08 | 95.2 | 92.4 | 89.8 | 87.3 | 84.8 | 82.6 | 80.5 | 78.5 | 76.7 | 74.9 | 73.2 | 71.6 | 69.8 | 68.4 | 67.0 | 65.5 | 64.1 | 62.9 | 32 |
| 33 | | 98.12 | 95.4 | 92.6 | 90.0 | 87.7 | 85.3 | 83.1 | 81.1 | 79.1 | 77.3 | 75.5 | 73.9 | 72.2 | 70.5 | 69.1 | 67.7 | 66.3 | 64.8 | 33 |
| 34 | | | 98.17 | 95.4 | 92.8 | 90.3 | 87.9 | 85.8 | 83.6 | 81.6 | 79.7 | 77.6 | 76.1 | 74.2 | 72.6 | 71.2 | 69.8 | 68.4 | 67.0 | 34 |
| 35 | | | | 98.26 | 95.5 | 93.1 | 90.6 | 88.3 | 86.0 | 83.9 | 81.9 | 80.0 | 78.2 | 76.4 | 74.9 | 73.2 | 71.9 | 70.2 | 68.8 | 35 |
| 36 | | | | | 98.30 | 95.7 | 93.2 | 90.8 | 88.5 | 86.4 | 84.4 | 82.4 | 80.5 | 78.8 | 77.0 | 75.5 | 73.9 | 72.2 | 70.9 | 36 |
| 37 | | | | | | 98.34 | 95.8 | 93.3 | 91.0 | 88.9 | 86.7 | 84.6 | 82.9 | 81.1 | 79.1 | 77.6 | 75.8 | 74.5 | 72.9 | 37 |
| 38 | | | | | | | 98.38 | 95.9 | 93.6 | 91.3 | 89.1 | 87.1 | 85.1 | 83.1 | 81.3 | 79.7 | 77.9 | 76.4 | 74.9 | 38 |
| 39 | | | | | | | | 98.42 | 96.0 | 93.7 | 91.5 | 89.4 | 87.3 | 85.3 | 83.6 | 81.9 | 80.0 | 78.5 | 77.0 | 39 |
| 40 | | | | | | | | | 98.46 | 96.1 | 93.8 | 91.6 | 89.6 | 87.7 | 85.8 | 83.9 | 82.1 | 80.5 | 78.8 | 40 |
| 41 | | | | | | | | | | 98.50 | 96.2 | 93.9 | 91.9 | 89.8 | 87.9 | 86.0 | 84.1 | 82.6 | 80.8 | 41 |
| 42 | | | | | | | | | | | 98.54 | 96.3 | 94.2 | 92.1 | 90.0 | 88.1 | 86.2 | 84.6 | 82.9 | 42 |
| 43 | | | | | | | | | | | | 98.57 | 96.4 | 94.3 | 92.2 | 90.3 | 88.3 | 86.7 | 84.8 | 43 |
| 44 | | | | | | | | | | | | | 98.61 | 96.5 | 94.4 | 92.4 | 90.5 | 88.7 | 86.9 | 44 |
| 45 | | | | | | | | | | | | | | 98.64 | 96.6 | 94.5 | 92.5 | 90.7 | 88.9 | 45 |
| 46 | | | | | | | | | | | | | | | 98.68 | 96.6 | 94.6 | 92.6 | 90.8 | 46 |
| 47 | | | | | | | | | | | | | | | | 98.68 | 96.7 | 94.7 | 92.8 | 47 |
| 48 | | | | | | | | | | | | | | | | | 98.71 | 96.8 | 94.8 | 48 |
| 49 | | | | | | | | | | | | | | | | | | 98.75 | 96.8 | 49 |
| 50 | | | | | | | | | | | | | | | | | | | 98.78 | 50 |

For sample sizes larger than 50 plotting position is estimated as:

$$\frac{100\ (\text{ordinal number}-0.5)}{\text{sample size}}$$

EXAMPLE:

Sample Size 51 — Ordinal number

$$0.98 = \frac{100(1-0.5)}{51} \quad 1$$

$$2.94 = \frac{100(2-0.5)}{51} \quad 2$$

$$99.02 = \frac{100(51-0.5)}{51} \quad 51$$

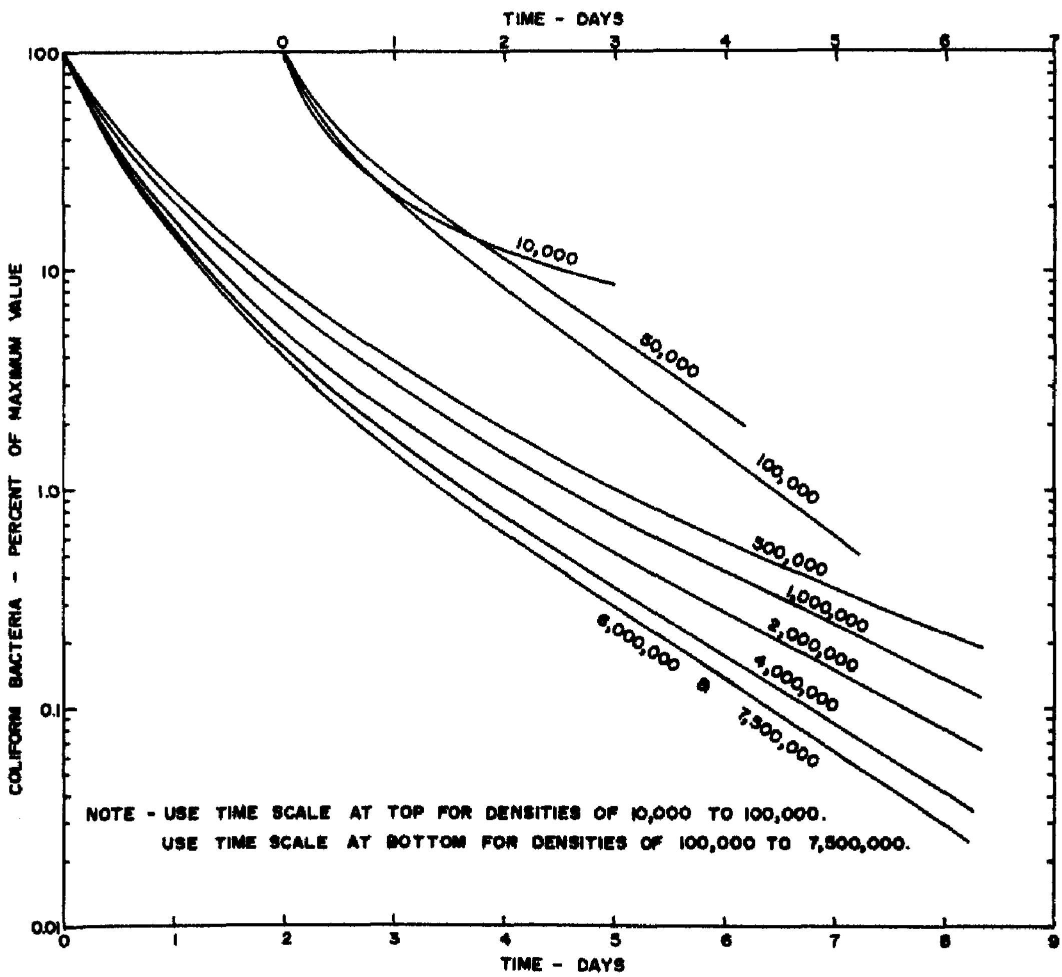


FIG. 8 EFFECT OF INITIAL DENSITIES OF COLIFORM BACTERIA ON SUMMER RATES OF DECREASE.

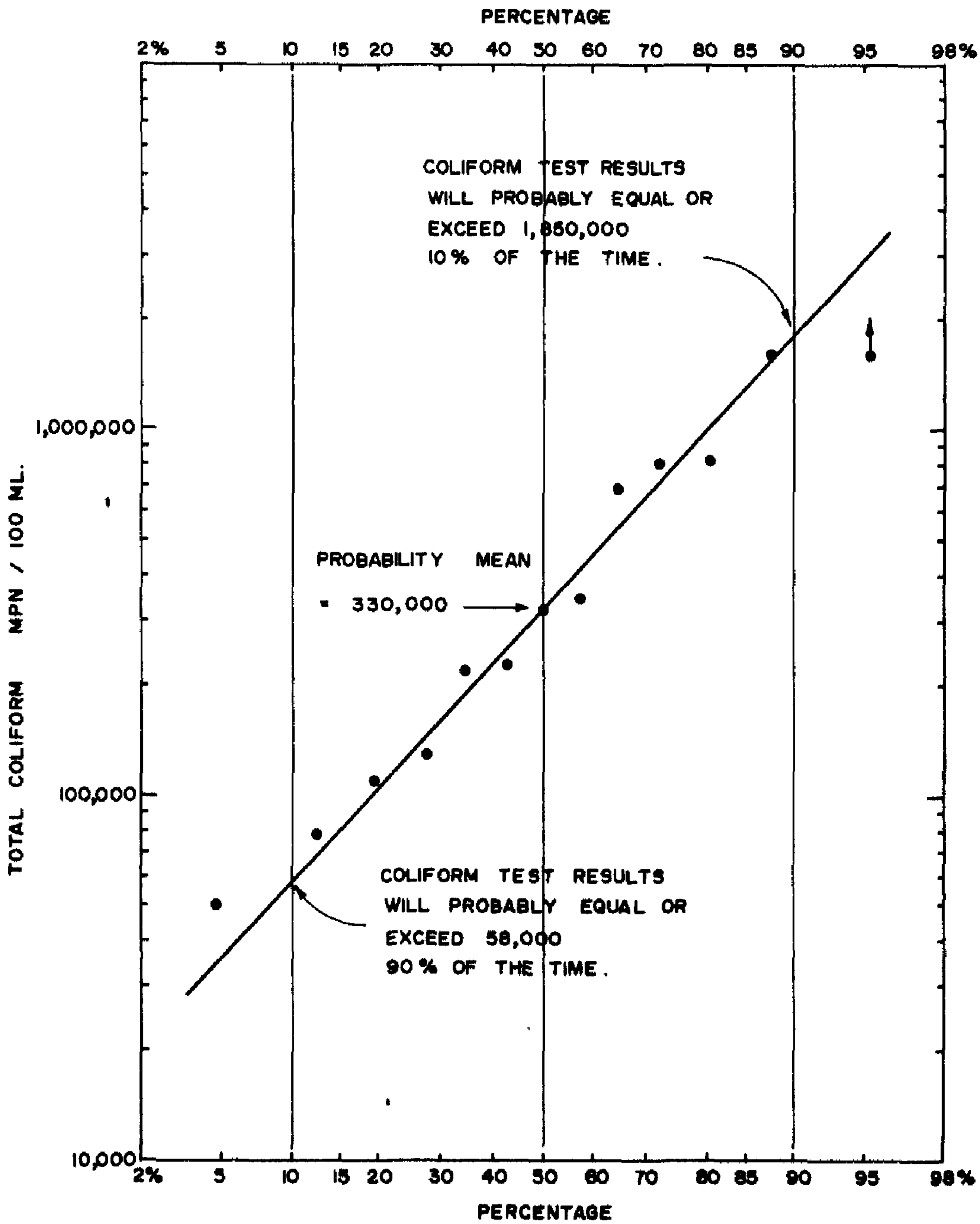


FIG. 9 COLIFORM PROBABILITY PLOT EXAMPLE (ACTUAL CASE).

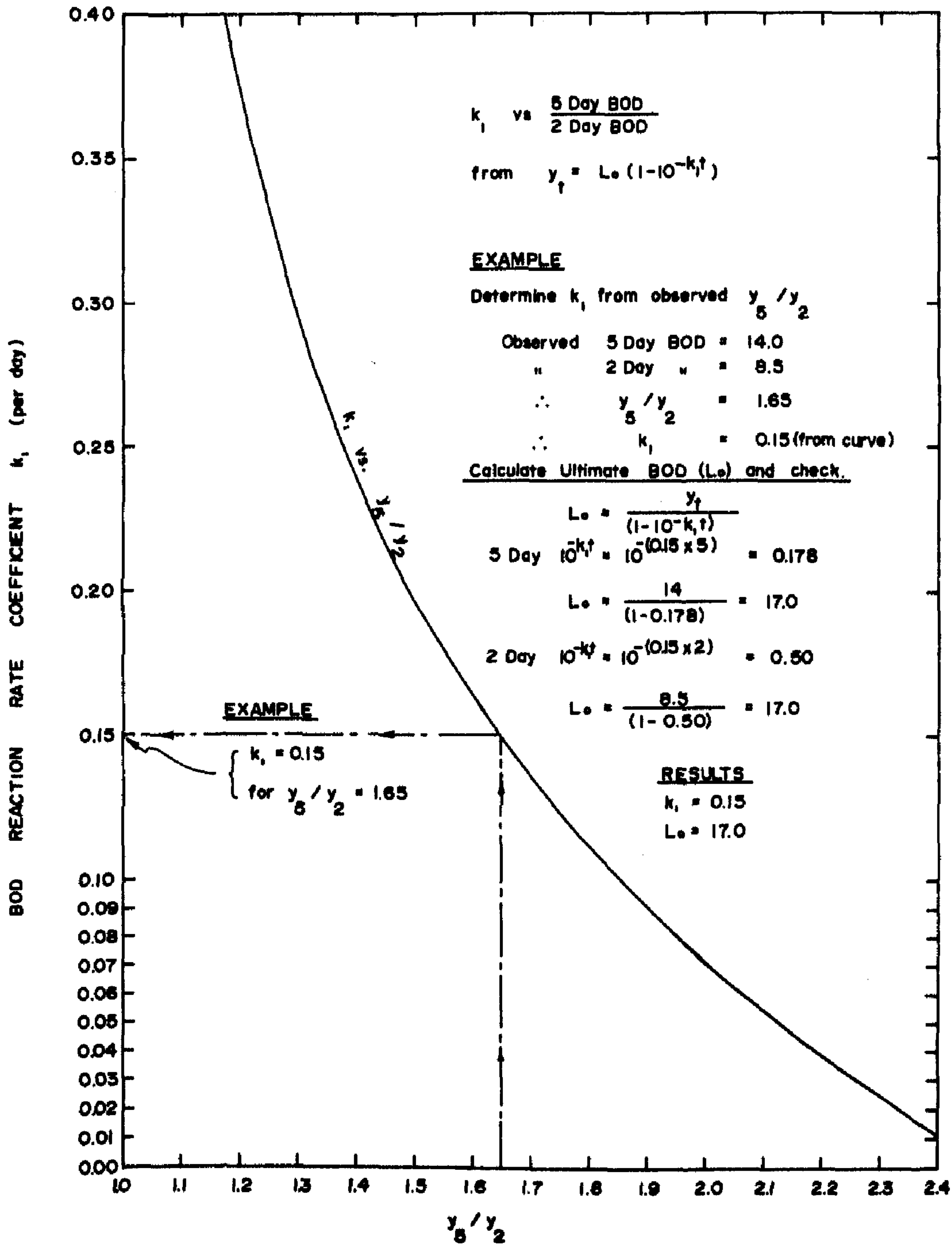


FIG. 10 BOD REACTION RATE AND "PHANTOM" ULTIMATE FROM 2 & 5 DAY BOD.



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