4

PROBLEM SOLVING

SOLVING a field water quality problem involves the following principal points:

A. Objectives

B. Investigation

1. Study Planning
2. Data Collection
3. Sample and Data Analyses

C. Reporting

1. Data Organization and Display
2. Interpretation
3. Report Writing
   a. Introduction
   b. Summary
   c. Conclusions
   d. Recommendations
   e. Predictions
   f. Area Description
   g. Water Uses
   h. Waste Sources
   i. Effects on Water Quality
   j. Appendix

D. Demonstrations

Objectives

Careful thought should be given to the development of study objectives. These should encompass clear, concise, positive definitions of the investi-

gation's purpose, its scope, and its boundary limitations. Study objectives should be realistically oriented to the numbers. competencies and disciplines of investigative personnel involved, to budgetary limitations for the study, and to the length of time allocated to the study, including final report preparation. Ultimately as the study progresses and it concluded, its success and accomplishments will be judged on the satisfaction, or degree of satisfaction, of the objectives stated at the instigation of the project. Study objectives become extremely important tools to guide and control subsequent investigation, to delineate avenues of approach towards problem solving, and eventually to judge success.

Planning

A field investigation encompasses three equally important areas of activity: study planning, data collection, and sample and data analyses. Study planning involves a myriad of details.

First, maps of the waterway in question must be secured and points of access noted. Tentative sampling stations should be selected from the maps based on points of access, and stream-mile designations developed for major landmarks on the waterway and the tentatively selected sam-

Figure 10. Mobile chemical and microbiological laboratories receiving samples near river bank.

pling stations. Development of stream mileages necessitates that the maps be accurate and of suitable scale.

Following a "desk top" analyses of available background data and other information related to the problem in question, a reconnaissance survey is indicated of the reach of waterway to be studied, as well as principal contributing pollution sources. During the reconnaissance survey a judgment is reached on the potential effects on water quality of individual waste sources, the reach or reaches of waterway that are of potentially greatest concern in the particular investigation, and possible sampling sites and actual points of access. A judgment should be reached on the advantages and disadvantages of sampling the entire waterway by boat as opposed to a cartop or trailered boat that is lowered into the water from several points of access along the waterway. Perhaps answers to the problem can be satisfactorily obtained by sampling the stream while wading and, should this be the case, much time, effort, and expence could be saved in so doing. Observations should be made at various points of access on stream width, depth if ascertainable, nature and type of stream bed, relative flow, as well as any other morphometric features that would seem to contribute towards a better organized sampling procedure when samples are collected. It is extremely important to know where boats and other equipment may be lowered into the waterway and possible difficulties that may be encountered when this is done. It is equally important to ascertain that proportion of the samples that may be collected by wading or by some means other than by boat. Observations should be made that may later relate to the use of such gear as conventional biological sampling dredges, square foot stream samplers, and various types of fish nets or seines. During the reconnaissance survey contacts can be made with local officials or local investigators who may be encouraged to participate in some manner with the investigation. Arrangements should be made with land owners to cross private lands at times when samples are to be collected from the waterway, should this be necessary.

Water samples for chemical analyses should be collected from access points along the waterway during the reconnaissance survey to ascertain the relative magnitude of pollution at various points, and to aid in the judgment of selecting sampling stations. Concurrently the aquatic organisms that can be observed qualitatively on rocks and other submerged objects should be noted and recorded for similar use.

Following the completion of a reconnaissance survey, and subject to modification or change during the course of the field sampling, decisions can be made on the following:

1. Types of samples necessary to point to a solution to the problem (i.e. plankton, periphyton, benthos, vascular plants or fish)
2. Sampling points for each of the selected types of samples

3. Periodicity of sampling and approximate collection time for a specific sample type and
4. Approximate number of samples necessary to complete the study.

A field investigation of a problem that demands the services of a biologist or the collection of biological samples should be investigated also by the chemist, the microbiologist, the sanitary engineer, and perhaps a representative of another pertinent discipline. It goes without saying that particular points in the development of solutions to specific problems are not confined specifically to the biological discipline, but instead must be a consideration of any discipline's representative engaged in the study. Thus, the points that are discussed herein are related specifically to the biologist but can be used with appropriate modifications for associated disciplines. Indeed, biological data will serve to complement chemical, physical, and other data in the process of formulating a solution to a specific problem.

The next aspect of study planning involves, logically, the carrying out of details that are necessary to initiate the process of data collection. Decisions must be made on methods of sample handling, sample preservation, and transportation of samples to a base laboratory. In the conduct of biological investigations these decisions are often not complex. Samples are placed in appropraite sample containers, usually preserved with a solution of formaldehyde and transported to a base laboratory either at the completion of the field study or at intervals by commercial transportation. The number of samples expected to be collected during an investigation will determine the relative number of sample collection containers that must be made ready for the study. Sampling equipment, data cards, notebooks and all of the necessary paraphernalia associated with the collection, retention, and shipment of biological samples must be organized and arrangements made to transport same to the study site either at the study instigation or by commercial means in time to ensure its being on hand when the investigators arrive.

A part of the study planning involves the making of travel arrangements, room accommodations, transportation of samples and equipment both to and from the sampling area, and arragements for such items as outboard motor gasoline, cartons for shipping collected samples, and ice for sample preservative, if this is a necessary consideration.

Adequate survey planning can save so much time and expense during the field study that it is worthwhile to make a list of judgments that are necessary during this planning stage, as well as a list of items that are necessary to ensure a succesful survey. By checking this list one can reduce the possibility of oversight that otherwise would be a cause of frustration at a later time.

In addition, a preliminary survey of pertinent literature is of extreme importance. Data that are already available may serve as guides to addi-

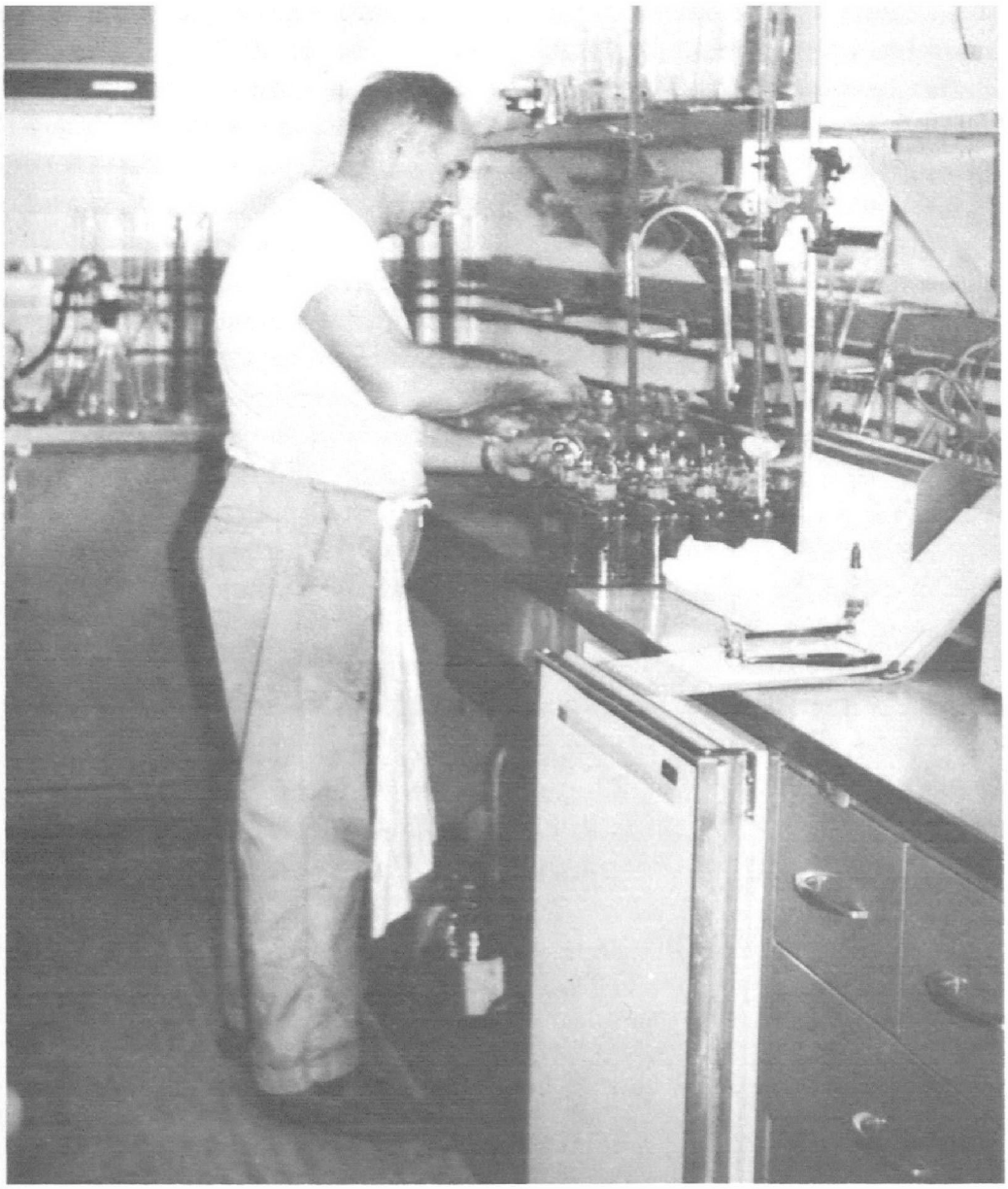

Figure 11. Laboratory analyses being conducted inside mobile laboratory.

tional investigation. A thorough study of the most complete maps of the study area will facilitate both organizational planning and initial field investigation.

Station Selection

Preliminary to the collection of a sample, the investigator must firmly establish the location of sampling stations. Station selection varies with the physical features of the waterway and this discussion will relate to streams, lakes, reservoirs, and estuaries.

Biological sampling stations for the stream environment should be routinely located close to or at those sampling stations selected for chemical

and microbiological analyses to enhance interpretation through the use of interrelated data. Sampling stations should be located upstream and downstream from suspected pollution sources, and from major tributary streams, and at appropriate intervals throughout the stream reach under investigation. The upstream stations should depict conditions unaffected by a pollution source or tributary. The nearest downstream station to the pollution source or tributary should be so located that it leaves no doubt that conditions depicted by the sample can be related to the cause of any environmental change. The minimum number of downstream stations from this point should be located in the most severe area of the zone of active decomposition, downstream in an area depicting less severe conditions within this zone, near the upstream reach of the zone of recovery, near the downstream reach of the recovery zone, and in the downstream reach that first shows no effect from the suspected pollution source. Precise station location will depend on the flow, the strength, volume and type of pollution entering at the source, and the entrance of additional sources of pollution to complicate the stream recovery picture. When water in tributary streams is found to be polluted or to influence water quality in the primary stream, these streams should be similarly investigated.

A stream usually is composed of riffles and pools. These areas will vary in depth, velocity of flow, and types of substrate that form the stream bed. Because the biologist seeks to determine changes that occur in water quality as depicted by aquatic organisms and to relate these changes to particular sources, he must compare observations at a particular station with observations and findings from an upstream station, as well as a station within the stream reach that is unaffected by a suspected source. To accomplish this an effort should be made to collect samples from habitat types that are morphometrically similar. Riffle samples should be compared with riffle samples and pool samples compared with pool samples. Both should be studied where feasible. To determine the extent of each major environmental change produced by pollution, the biological investigator may need to choose a number of stations in addition to those selected for routine chemical or bacteriological sampling.

Plankton samples are collected usually at one point within the study station, most commonly at midstream 1 to 2 feet below the surface. Samples for bottom associated organisms should be collected at a number of points on a transsection line between the stream banks. Optimally, these samples should be collected at a minimum of (5) points across the stream (mid and two quarter points and at near zero water level with banks); more than one sample may, at times, be collected from each point and retained separately. Realistically the objectives of a particular survey and the number of stations at which bottom fauna are collected may dictate the number of samples from a particular station. Attached growths are sampled wherever they occur.

The receiving waters from a lake or reservoir should be studied in the same manner as influent streams. The effluent of a natural lake will usually give a better than average composite of the epilimnionic waters of the lake. The discharge from a reservoir penstock located below the thermocline, however, will not give a representative sample of the productive zone of the reservoir but shows water quality in a portion of the hypolimnion instead. A study would be indicated to show the effect of the low-level discharge on the receiving waters.

Within the lake or reservoir, a number of sampling sites may be chosen depending on the problem under investigation and the conditions to be studied. An investigation of the kinds and relative abundance of aquatic vegetation would naturally be limited to the littoral area. A mapping of aquatic plants often proves useful for future comparisons. Fish sampling

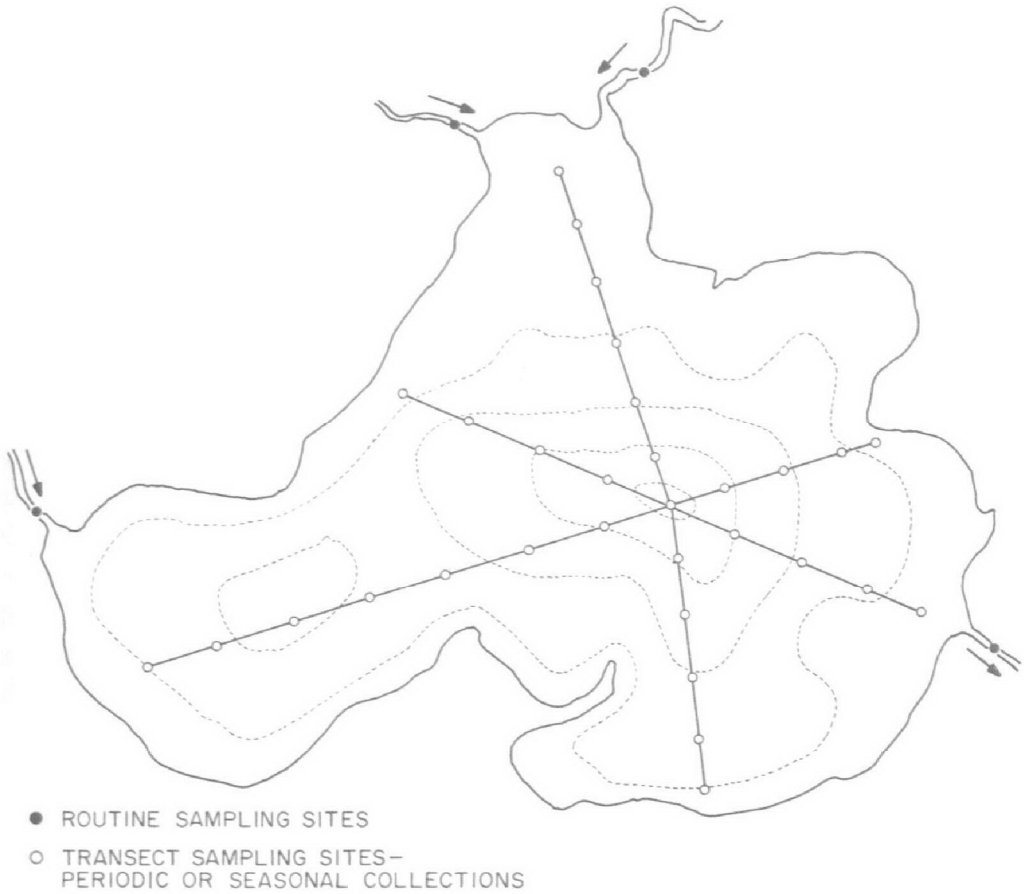

Figure 12. Diagram of a natural lake basin showing suggested sampling sites. Samples taken from points on transaction lines on a periodic or seasonal basis are valuable to determine vertical water characteristics and the benthic standing crop.

also is often more profitable in shallow water areas, although gill nets set in the region of the thermocline and below may sample a fish population not usually observed in shallow water.

The use of transections in sampling a lake bottom is of particular value because there are changes in depth and because benthos concentration zones usually occur. Unless sampling is done systematically and at relatively close intervals along transections, especially those that extend across the zone between the weed beds and the upper extent of the hypolimnion, concentration zones may be missed entirely or inadequately represented. Maximum benthic productivity may occur in the profundal region. Because depth is an important factor in the distribution of bottom organisms, productivity is often compared on the basis of samples collected from similar depth zones. Collections from a transection will sample all depth zones, and a sufficient number of samples must be taken to make the data meaningful.

A circular lake basin should be sampled from several transections extending from shore to the deepest point of the basin. A long narrow basin is suitable for regularly spaced parallel transects that cross the basin perpendicular to the shore, beginning near the inlet and ending near the outlet. A large bay should be bisected by a transection originating near shore and extending to the lake proper.

There are definite advantages in sampling the benthic population in winter beneath the ice cover in lakes. Samples can be collected at definite, spaced intervals on a transection, and the exact location of sampling points can be determined. Also, collections are at a time of peak benthic population when emerging insects do not alter the benthic population.

Transactions also aid in sampling the palnkton population. Because of the number of analyses necessary to appraise the plankton population, however, more strategic points are usually sampled, such as water intakes, a site near the dam in the forebay area or discharge, constrictions within the water body, and major bays that may influence the main basin. Because of significant population variation, plankton samples must be taken vertically at periodic depths, and at different times over the 24-hour day.

Reservoirs are usually long and narrow water bodies with the widest portions occuring downstream. They are particularly suitable for the placement of imaginary transection lines that extend perpendicularly from one shore to the opposite shore. Sampling stations can be conveniently located on these transections. In addition water use return waters or areas designated for water use removals should be sampled.

The selection of sampling stations in estuaries combines the aspects of stream sampling with those of the more static lake environment. Water within the estuary is controlled by tides and the force of water discharged by the river and, because of this, particular constituents of water quality

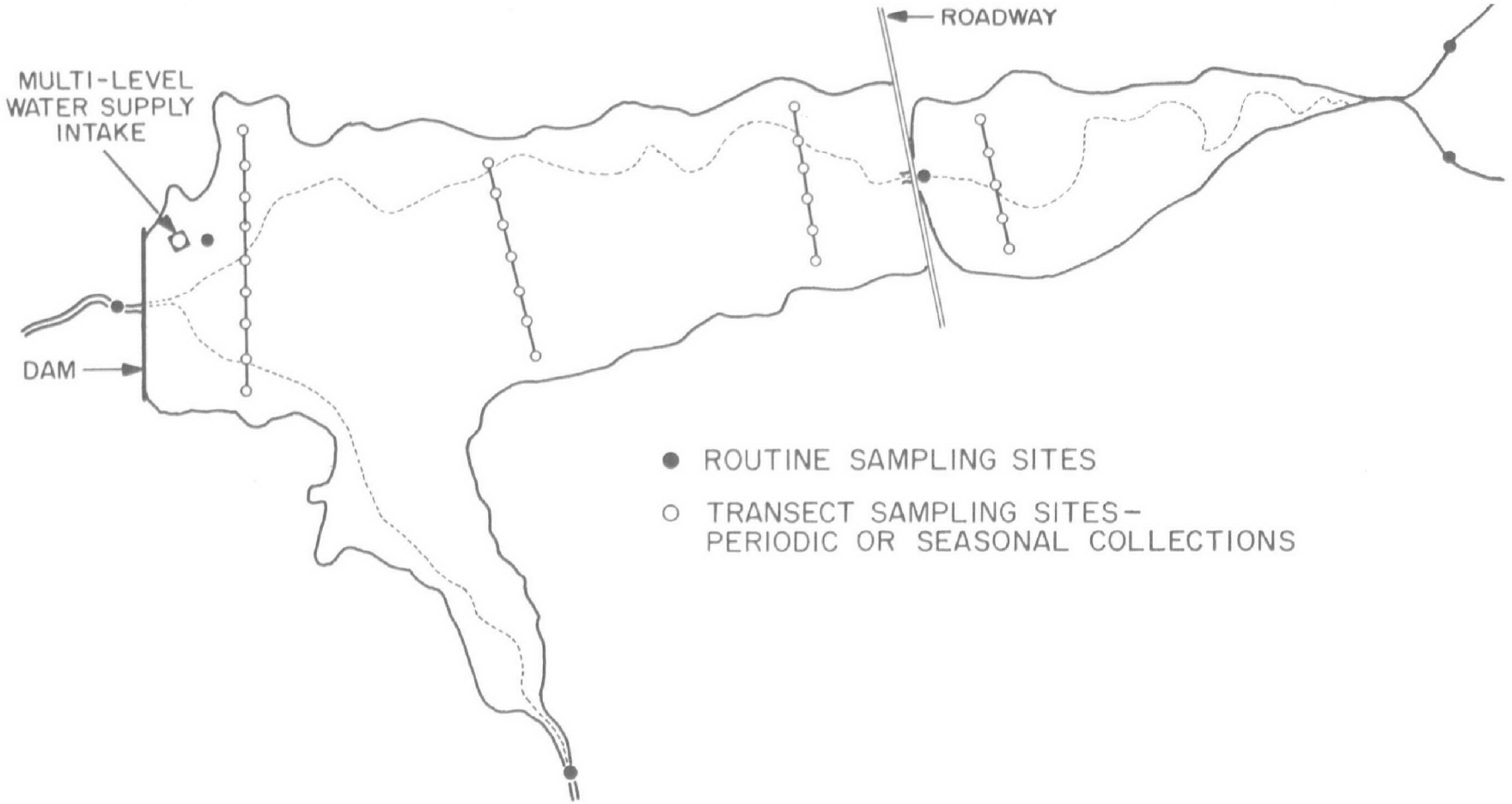

Figure 13. Diagram of a long, narrow reservoir showing suggested sampling stations.

may remain localized in a given area for a considerable period of time before they are dispersed or carried out to sea. Thus, the flow characteristics of the water mass are extremely important in order to define water quality and prognosticate effects of waste discharges on it. The flowing water portion of an estuarine study should be attacked in a manner similar to that described for the stream environment. Sampling stations within the true estuary can be profitably developed along transection lines that either cross the estuary, more or less perpendicularly from one shore to another, or that extend out of the estuary in two or more directions from a suspected point source of pollution. Whenever possible, samples should be collected from areas that represent the estuarine habitat unaffected by pollution, as well as areas that depict environmental changes produced by it.

Sampling Periodicity

Weekly collections, as a minimum, are desirable throughout the season of active biological growth to measure planktonic populations and chemical constituents that may change rapidly. In special studies, samples are often collected daily or even periodically during a 24-hour day to assess these changes. During the non-growing season, monthly samples of these constituents should be adequate except where otherwise indicated by the objecives of the study. A reconnaissance and mapping of the aquatic vegetation should be done during maximum vegetation growth, usually in midsummer.

Insect representatives of the bottom organism community emerge from the water as adults periodically throughout the warm weather period; time of emergence depends on the species involved. Life histories of these organisms tend to overlap so that at no time is there a dearth of these organisms within the bottom associated community. Bottom fauna should be sampled during the annual seasons; the standing crop will be highest, however, during the fall and winter periods when insect emergence is minimal, and one of the sampling dates should reflect this period.

Because of the report deadline or limited personnel available, the theory and practice of station location and sampling periodicity may not be the same. The objectives of a study may be met by investigating only bottom fauna and attached organisms in a stream, and these on only one occasion. Much can be learned from this minimal effort. The investigator should keep in mind that water quality effects from organic wastes will likely be at their worst during the warm weather low-flow period. When streams become covered with ice in northern climes during winter, another period with severe conditions of existence for bottom fauna occurs in late winter. The zone of active decomposition resulting from an organic waste source will be transferred a considerable distance downstream under ice cover.

Little knowledge may be gained from only one series of plankton samples from a stream. Because these organisms are carried by the currents, a given sample is representative of water quality at some point upstream rather than at the place of sampling.

Data and Sample Collection

The collection of data and samples from a particular station involves making a number of scientific observations. Flow measurements on streams, inlets and outlets to standing bodies of water such as lakes and reservoirs, suspected municipal and industrial waste sources, and water use drawoff and return points, which can be correlated with sampling dates, are of utmost importance. Such data permit a calculation of the amounts of particular water quality constituents passing a point at a given time, and estimates can be made from these data on daily, monthly, or annual contributions. Rainfall may be a contributing factor to investigations concerning major aquatic plant nutrients and should be sampled to determine annual contributing amounts of nitrogen and phosphorus. A house-to-house survey of the area draining to a watercourse may be indicated to determine types of waste treatment and to project potential impact of wastes that are discharged to or reach the watercourse. The types and amounts of fertilizers applied to lands within the drainage basin, as well as the period of the year when fertilizers are applied, may be of importance to the study. Groundwater may be a factor and should be sampled from appropriate adjacent wells for those constituents of importance.

On approaching a stream station a number of observations must be made that will later be considered in interpreting the biological findings.

Observations are made on water depth; presence of riffles and pools; stream width; flow characteristics; bank cover; presence of slime growths, attached algae, scum algae, and other aquatic plants, as well as red sludgeworm masses; and unusual physical characteristics such as silt deposits, organic sludge deposits, iron precipitates, or various waste materials from manufacturing processes.

Organisms associated with the stream bed are studied most often in the biological evaluation of water quality. These organisms are valuable to relate water quality because they are not equipped to move great distances through their own efforts and, thus, remain at fixed points to indicate water quality. Because the life history of many of these organisms extends through 1 year or longer, their presence or absence is indicative of water quality within the past, as well as the present. Bottom associated organisms are relatively easy to capture with conventional sampling equipment and the amount of time and effort devoted to their capture and interpretation is not as great as that required for other segments of the aquatic community.

The investigator should ask himself three basic questions: Based on a knowledge of preferred organism habitats, what bottom fauna should I

expect to find at this station? Specifically, where would I expect to find these creatures? What is the appropriate gear with which to capture them? A close search of the respective areas should be made noting and collecting qualitatively the various types of organisms. A commercial 30-mesh sieve is a handy exploratory tool.

The qualitative search for benthos should involve the collection of organisms from rocks, plants, submerged twigs or debris, or leaves of overhanging trees that become submerged and waterlogged. It is often convenient to scrape and wash organisms from these materials into a bucket or tub partially filled with water and then to pass this water through the sieve to concentrate and retain the organisms. The collected sample may be preserved for organism sorting and identification later. The investigator should search until he is certain that he has collected the majority of species that can tolerate the particular environment. In some environments it

FIELD COLLECTION CARD

Date _____ Hour _____ Collector _____

Field Designation _____

Station Location _____

Sample No. _____ Stream Miles _____

Weather _____

Bottom: _____ Rock: _____ C. Gravel F. _____: C. Sand F. _____

% : _____ Sandy Loam: _____ Silt Loam: _____ Silt:

: _____ C. Clay F. _____ : _____ Organic Sludge:

Sample Location _____ Sample Depth _____

River: Width _____ Depth _____ Current _____

: Temp _____ DO _____ pH _____

: Phth Alk _____ Tot Alk _____ Cond _____

Sampler :	Ek :	Pet :	Sq Ft :	Qual :	:
No. of Samples:	:	:	:	:	:
Fish: Gear :	Shocker :	Dip Net :	Seine :	:	
Sample Time :	:	:	:	:	
Sample Area :	:	:	:	:	

Remarks:

Figure 14. Field Collection Card for Benthic Samples.

Desired items for a field biological collection card may be arranged on a 5" × 8" unlined card for convenience. Cards can be carried in a field notebook; they may be filed after field and laboratory use. The backside of the card may be ruled to itemize the organisms observed in the laboratory examination of the collected sample.

is possible only to collect qualitative samples because the physical nature of the waterway may be such that quantitative sampling is not feasible.

Qualitative sampling determines the variety of species occupying a reach of a waterway. Samples may be taken by any method that will capture representatives of the species present. Collections from such samplings indicate changes in the environment, but they generally do not accurately reflect the degree of change. Mayflies, for example, may be reduced in the stream because of adverse conditions from 100 to 1 per square foot, whereas sludgeworms may increase from 1 to 14,000 per square foot. Qualitative data would indicate the presence of both species, but might not necessarily delineate the change in predominance from mayflies to sludgeworms.

The basic principal in qualitative sampling is to collect as many different kinds of animals as practical. Obviously, because of the rarity of some forms, the probability of collecting a specimen of every kind is remote and a limit must be imposed on the collector's efforts. Two convenient limiting methods are:

(1) Presetting a time limit on the collector's effort at each sampling point. A minimum of 30 minutes and a maximum of an hour is a convenient range in which to establish this limit.

(2) Sampling in an area until new forms are encountered so infrequently that "the law of diminishing returns" dictates abandoning the sampling point. This method requires professional judgment —but if after 10 minutes only a single species or organism is found, the sampler can move to the next sampling site where he might continue to find new forms after searching more than an hour.

A number of tools readily obtained in any community are valuable in this type of sampling:

a. Pocket-knives are excellent tools to remove animals from crevices in rocks, to peel bark from decaying logs thus exposing animals, and to slip under animals to lift and transfer them to sample containers.
b. Mason jars in ½ to 1 pint sizes serve as the most economical sample containers and provide visibility of the preserved specimens.
c. Common garden rakes are valuable to retrieve rocks, brush, logs and aquatic vegetation for inspection.
d. Fine-meshed dip-nets are good devices for sweeping animals from vegetation or out from under over-hanging rock ledges.
e. Buckets are handy to quickly receive rocks and debris, thus preventing escape of the swift running animals.
f. Sheet polyethyelene, 6 x 6 feet, can be spread on the stream bank and substrate materials placed upon it. As the materials begin to dry the animals will abandon their hiding places and can be seen readily as they migrate across the sheet seeking water.

g. U.S. Standard Series No. 30 soil sieves can be used to scoop up fine sediments and sieve out its inhabitants. The entire qualitative sample can also be screened to standardize the organism sizes taken at various sampling sites.
h. Any other tools, such as forceps, scalpels, shovels, and forks are legitimate devices and can prove their merit in individual situations.

Following these general observations, the investigator collects appropriate quantitative samples of the various kinds of organisms present in the aquatic area. He makes certain that: (1) The sampling area selected is representative of stream conditions, and (2) the sample is representative of and contains those forms predominant in the area and encountered during the qualitative search.

Bottom samples in lakes usually may be collected with an Ekman dredge, although the physical composition of the bottom determines to a great extent the type of samples that must be used to collect an adequate sample. The Ekman dredge (Ekman, 1911) consists of a square box of sheet brass 6 x 6 inches in cross section.* The lower opening of this box is closed by a pair of strong jaws so made and installed that they oppose each other. When open, the jaws are pulled apart so that the whole bottom of the box is open; the jaws are held open by chains attached to trip pins. To close the dredge, the trip pins are released by a brass messenger sent down the attachment rope and the jaws snap shut by two strong external springs. The hinged top of the box may be equipped with a permanent 30-mesh screen to prevent loss of organisms if the samples sinks into mud deeper than its own height. The sampler is especially adapted for use in soft, finely divided mud and muck; it does not function properly on sand bottoms or hard substrates. The Ekman can also be mounted on a pipe for shallow stream sampling and tripped by a thrust-through rod.

The Petersen dredge (Petersen, 1911) is a most versatile stream bed sampler to collect bottom life. It is widely used to sample hard bottoms such as sand, gravel, marl, clay, and similar materials. It is an iron, clam-type dredge, samples an area of 0.6 to 0.8 square foot, and weighs between 35 and 70 pounds depending on the rare use of additional weights that may be bolted to its sides. By means of a rope, the dredge is slowly lowered to the bottom to avoid disturbing and flushing away significant lighter materials. As tension is eased on the rope, the mechanism holding the jaws apart is released. As the rope is again made taut, a sample is secured. The operator controls the dredge by maintaining tension on the rope until the dredge is placed. This is helpful in sampling gravel or rubble, as the operator can determine through sound and touch the type of bottom and by carefully manipulating the dredge, can secure a better sample than would otherwise be possible. In streams with gravel and rub-

* Ekmans are made also in 9" x 9" and 12" x 12" sizes, but because of size of grabs, these are almost impossible to operate effectively on many occasions. Through long experience the author recommends only the 6" x 6" size.

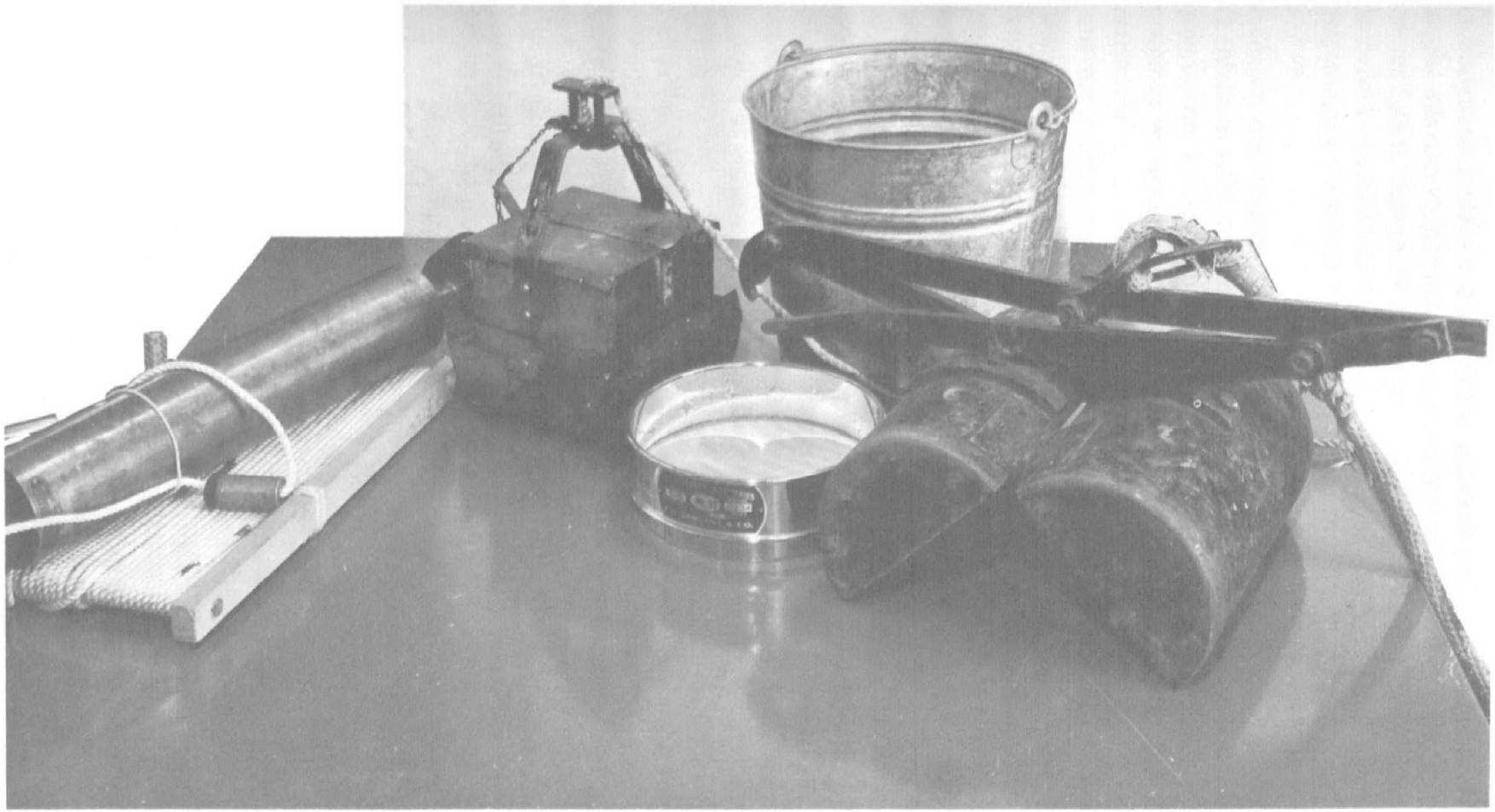

Figure 15. Biological collecting equipment. From left, Kemmerer sampler, Ekman dredge, U.S. Standard No. 30 sieve, washing bucket, and Petersen dredge.

ble beds that permit wading, another technique is for the investigator to place the dredge and then stand on the jaws working them into the stream bed with his weight, thus gradually closing them. When the dredge is surfaced, careful and rapid placement and subsequent discharge, endwise, of the dredge into a bucket whose lip is placed at the water's surface prevents loss of material.

The orange-peel dredge, is a multijawed, round dredge with a canvas closure serving as a portion of the sample compartment. It is available in a variety of sizes. Its sampling area is a function of depth of penetration and this area must be calibrated, usually with the volume of sediment contents. It has received wide use in marine waters and in the Great Lakes, where it has advantages over other tools for sampling sandy substrates.

The ponar dredge is receiving increased use in deep lakes. In comparative studies it is more efficient than the Petersen dredge when samples are secured from deep (>100 feet) waters. In appearance it is similar to a Petersen dredge but it has side-plates and a screen on the top of the sample compartment.

The Smith-McIntyre dredge has the heavy steel construction of the Petersen, but its jaws are closed by strong coil springs. Its principal advantage is its stability or operator control in rough waters. Its bulk and heavy weight requires operation from large boats equipped with a powered winch.

Core samplers have been used to sample sediments in depth and collect small areas (2–4 sq. inches) of the mud-water interface. Their efficient use requires dense animal populations. Corer design varies from hand-pushed tubes to explosive driven and automatic surfacing models. The Phleger type is the most widely used corer in water quality studies. It is a gravity corer, relying on its weight (near 100 lbs.) to drive its sample tube into the substrate. The length of core retained will vary with substrate texture; 30 inches is near the maximum length. A core of this length is adequate for most physical, chemical or fossil examination to delineate recent environmental changes.

The Wilding, or stove-pipe, sampler is the only sampler that will quantitatively sample the fauna inhabiting the bottom and/or the vegetation in areas with dense aquatic weed growths. Its operation may be restricted to the vegetation, or mud-water interface sediment may be included.

Drift nets may be suspended in flowing waters to capture invertebrates that have migrated into the water mass from the bottom substrates and are temporarily being transported by currents. Their principal uses have been to study migratory movements and to evaluate sublethal toxicants, especially insecticides, on the fauna. Before toxicants become lethal the animals are weakened and cannot maintain their benthic position and thus are swept away by the currents and carried into the nets.

These nets must be standardized in an individual study. As of now no single style of net has been standardized among investigators. It is recommended that these nets be designed with a 1 x 1 foot upstream opening, with U.S. Standard Series No. 30 netting (or finer, with subsequent screening for uniform organism size), and with a net-bag length of 36 inches.

After suspension in the water, these nets require constant tending. Within a fraction of an hour the nets efficiency is reduced through clogging of the net by drifting animals and detritus that soon results in significant volumes of water and organisms being diverted around the mouth of the net.

Other sampling gear, and their uses, will be described in the 13th Edition of Standard Methods for the Examination of Water and Wastewater.

After the bottom sample is collected by one of the deepwater sampling devices, it is brought to the surface and placed in a large pail or tub. Water for sample dilution is added to the pail, and the sample is mixed into a slurry with the slurry finally being passed through a U.S. Standard No. 30 mesh sieve while the sieve is being rotated in the water. The washing operation is repeated until all fine material has passed through the sieve, and all organisms are retained in the sieve. The organisms and coarser debris are then removed form the sieve and are preserved. It is often easier to sort the organisms from the debris when the organisms are alive. Time schedules and extensive field operations, however, often dictate that sample collection and examination take place at different times during the year. Wide-mouthed, tapered pint freeze jars, obtainable from most grocery stores, have proven to be excellent bottom organism sample containers. When these jars are filled half full with 10-percent formalin before the days activities of sample collection, it is a time-saving process to transfer the concentrated sample from the side of the sieve to the jar of preservative by lightly hitting the sieve against the top of the jar. The investigator is assured always of a minimum of 5-percent formalin in the sample container, a sufficient strength to preserve the collected organisms. After the samples are preserved in the field they are returned to the laboratory where the organisms are separated from the debris, placed in respective groups, identified, and enumerated.

To sample riffle areas in streams, a square-foot bottom sampler, originally described by Surber (1936), is widely used. It consists of two 1-foot-square brass frames hinged together at right angles; one frame supports the net which is held extended downstream by current velocities, the other encloses the sampling area. In field operation, the sampler is so placed that organisms dislodged by hand from the substratum within the sampling frame will be carried into the net by the current. In stagnant or in slowly moving water, it often is not practical to employ this square-foot sampler.

In practice, it may be found convenient to remove the larger rocks from inside the sampling frame, placing them in a bucket or tub partially filled with water. Here, the organisms can be washed or scraped from the rocks, and concentrated by a sieve as described earlier, before being combined with those from the Surber sampler in a sample jar with preservative.

Artificial substrates have been successfully employed in studying bottom fauna in flowing streams. One multiple-plate sampler constructed of tempered hardboard (Hester and Dendy, 1962) has been especially suitable for studying stream inhabitants in those streams that do not possess a natural substrate suitable for the attachment of benthic forms. A sampler constructed of eight 3-inch squares, separated by seven 1-inch squares, and held in place by a bolt or threaded rod exposes slightly more than 1 square foot of surface to which organisms can attach.

Artificial substrates are placed in the water for 3- to 6-weeks and then carefully removed to prevent losing the organisms that have made them a temporary home. As nearly as possible the substrates should be placed at similar depths and in similar physical relationship to the stream at all stations. Usually they are placed about 1-foot beneath the surface or 1-foot off the stream bed. The multiple-plate sampler can be reduced in size to three plates only and placed vertically near the surface, at mid-depth, and near the bottom at a particular station. Loss of some substrates because of vandalism or flooding should be anticipated.

Periphyton include that assemblage of organisms that grow on free surfaces of submerged objects in water and cover them with a slimy coat. Cooke (1956) comprehensively reviews the literature on the subject. Periphyton play an important role in flowing waters because these organisms are the major primary producers in that environment. Thus, they are an important part of a lake or reservoir study of both the influent and receiving streams. A number of substrates have been proposed with which to study attached organisms including glass slides, cement blocks, wooden shingles, and plexiglass plates (Grzenda and Brehmer, 1960). Growths on such substrates may be analyzed qualitatively or quantitatively.

The type of artificial substrate employed to collect organisms is not terribly important as long as the same type is used at all such sampling stations in a particular investigation. Any type will be somewhat selective in those organisms that are attracted to it. They do tend to favor drift organisms or those that become detached from their dwelling areas and float downstream with the current. When the same type of sampler is used at each station, data collected among the stations should be comparable.

Patrick et al. (1954) developed a slide-carrying device, termed the Catherwood Diatometer, to sample the diatom populations of streams. It consists of a plastic base mounted on a lead bar shaped like a boat. On the plastic base are mounted two floats designed so that the depth to which the diatometer is sunk can be varied. Between the floats, behind a

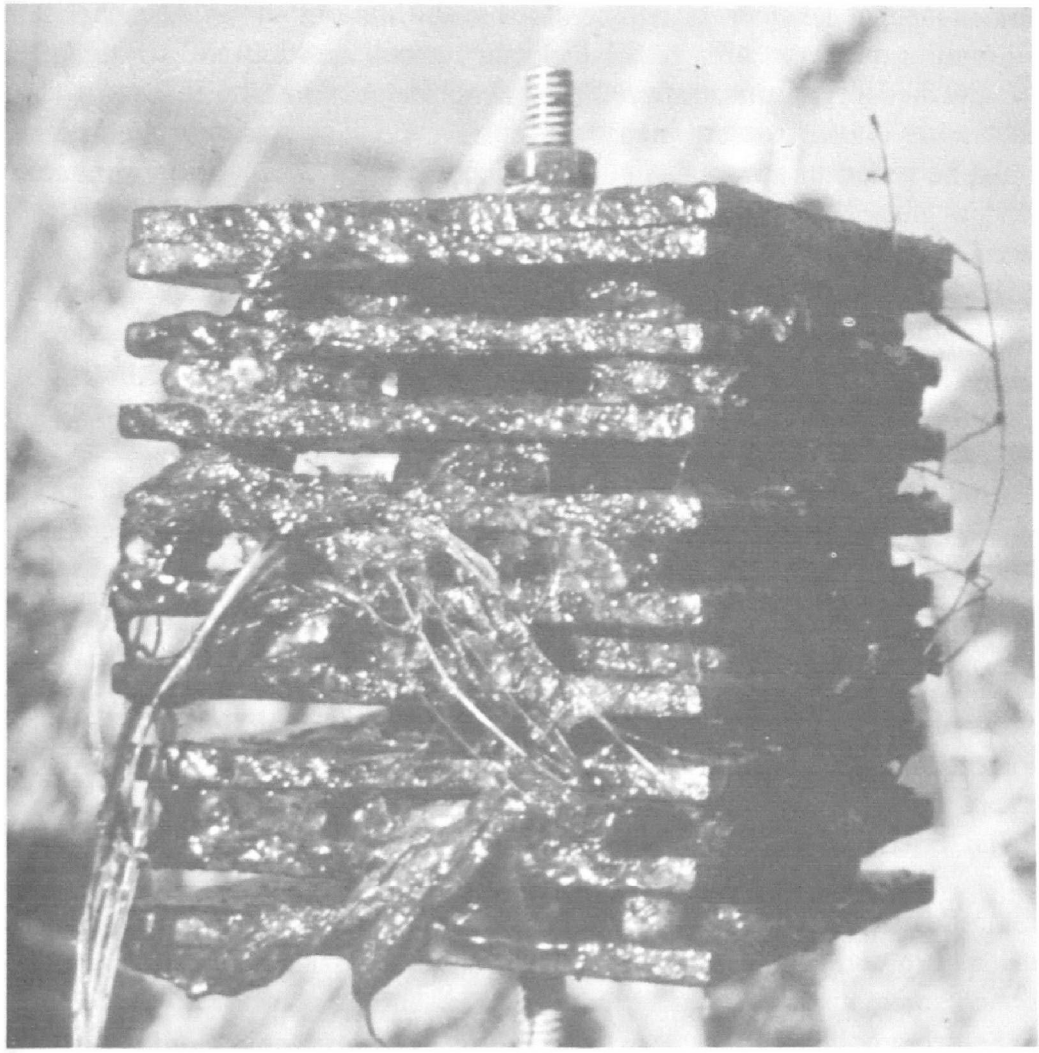

Figure 16. A multiple-plate artificial substrate colonized by aquatic organisms (Hester-Dendy type).

plastic V-shaped vane, the plastic slide holder slotted to hold six slides vertically is mounted edgewise to the current. The vane prevents excess washing of the slides. It was stated that 1 week was sufficient to expose the slides and that the population of an unpolluted stream could be estimated as adequately with this method as with the usual methods of collecting diatoms. Calculations upon which these estimates are based must be corrected when dealing with polluted streams.

A comprehensive review on limnological methods to investigate periphytic communities has been prepared by Sladeckova (1962). She lists 448 references as a bibliography and portrays a large number of devices on which attached organisms can grow and be sampled. In a summary she states that there is no single, universal method for the quantitative evaluation of periphyton for every purpose. An analysis of ecological factors influencing the periphytic community may make methods for the evaluation of this community on natural substrata preferable. On the contrary, the

use of artificial substrata is essential for the determination of periphyton formation on a unit area or for the study of colonization and stratification of attached organisms, especially in deep water. The choice of exposure technique is often determined by circumstance. The duration of exposure must be tested in advance. Lund and Talling (1957) completed an earlier review with 777 references; they also discussed methods with special reference to algae, both planktonic and attached. Sladecek and Sladeckova (1964) discussed the glass slide method for the determination of periphytic production in particular. Methods were cited for the calculation of production rates.

In the study of attached organisms in waters receiving acid mine drainage, it was found that extreme corrosion of the slide holding device contributed to a substantial loss of samplers during the study period. A type of putty (Plasti-tak*) has been found to be extremely useful to secure microscope slides to clay bricks or to the upper fiber board plate of a multiplate sampler (Thomas, 1968). Advantages to this procedure include good holding power, noncorrosive aspects in acid or salt water, ease of artificial substrate placement, low cost, and removal of single slides without disturbing adjacent ones. The surface to which the adhesive is applied must be dry and clean and the adhesive will release in fast water after about 3 weeks.

To obtain a history of sediment deposition or to permit selection of strata within the sediments, sampling of these by a commercial core sampling device is expedient. Much information can be obtained of a historical nature and can be related to the problem under investigation through the chemical and biological examination of sediment cores.

Samples collected for plankton analysis are most often similar to those collected for the analyses of chemical water quality. They may be collected with the aid of a Kemmerer sampler or similar device that permits capture of a sample from a particular water strata.

Fish samples may be collected by nets, seines, poisons, and electrofishing. Electrofishing is conducted by means of an alternating or direct electrical current applied to water that has a resistance different from the fish. This difference in resistance to pulsating direct current stimulates the swimming muscles for short periods of time, causing the fish to orient and be attracted to the positive electrode. An electrical field of sufficient potential to demobilize the fish is present near the positive electrode, but decreases in intensity with distance. After the fish are identified, weighed, and measured, they commonly can be returned to the water uninjured.

The electrofishing unit may consist of a 110-volt, 60-cycle, heavy duty generator, an electrical control section, which is a modified commercially sold variable voltage pulsator, and electrodes. The electrical control section provides selection of voltages from 50 to 700 volts a.c. and 25 to

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350 volts d.c. The a.c. current acts as a standby for the d.c. current and is used in cases of extremely low water resistance. The variable voltage allows control of field size in various types of water.

Meaningful samples of littoral vegetation may be difficult to secure. Sampling, per se, is often not necessary. It is usually sufficient to map, identify, and estimate abundance of the principal components of the aquatic vegetation population.

Comprehensive investigation of particular field problems may necessitate special investigative tools that can be developed through modification of existing tools. The development and use of these devices depends in large measure on the ingenuity and imagination of the investigator. Special studies that may be performed in conjuction with a field investigation would include the conduct of bioassays to test organisms in particular effluents or other substances where toxicity to aquatic life may be suspected. The procedure to conduct bioassays is well described in Standard Methods for the Examination of Water and Wastewater (Anon., 1965).

Sample Analyses

For a detailed discussion of the laboratory examination of biological samples, Standard Methods for the Examination of Water and Wastewater should be examined.

When samples are collected of animals associated with the lake or stream bed the organisms and debris are usually preserved with 10 percent formalin. The formalized sample is washed in the laboratory to remove the strong formalin solution. From this point it is necessary to remove and segregate the animals on which an interpretation will be made from the debris within the sample jar. A number of flotation methods have been proposed by various authors to reduce the time expended in this operation. When an investigation includes stream reaches that are heavily polluted with organic sludges or that produce prolific growths of slimes and other attached organisms, flotation methods do not work well. Thus, as a routine measure the somewhat laborious effort of separating organisms from debris through hand sorting must be employed.

A white enamel pan with a depth of approximately 1½″ is often used in the hand picking operation. It is convenient to half fill the pan with water and then place 2 or 3 tablespoons of material from the sample jar in the center of the pan. By teasing the sample to all sides with the aid of forceps, small animals can be removed without difficulty. It is helpful for later indentification to keep the removed organisms separated into the taxonomic groups that are discernible with the unaided eye. When it is noted that organisms within the collected sample are limited to a few (2 to 4) kinds and are extremely abundant as they often are when sludgeworms reproduce in great numbers in organic sludge, samples may be split to reduce time and labor in removing organisms. This is accomplished by placing the sample in the white pan without water, leveling the sample

surface, and randomly selecting ½, ¼, 1/16, or 1/32, of the sample for organism removal. When this is done, the entire sample should be examined for those larger organisms that may not be numerous. In reports written principally for those outside of the biological discipline, bottom faunal abundance is expressed usually as the number of a particular kind of organism per square foot. Organisms from a 6″ x 6″ Ekman dredge sample, for example, would be multipled by 4 to arrive at the number per square foot. When the sample is split and only an aliquot examined, the appropriate conversion multiplication must also be used. Further identification through the use of a stereoscopic microscope and counts to ascertain numbers within a particular group are made to facilitate interpretation of water quality.

Slimes and other attached growths are identified and estimates made of relative abundance. Quantitative methods are often employed. Chlorophyll determinations may be used as an indicator of those plants that possess this material and the determination is often helpful to separate attached algal quantities from slimes.

Chlorophyll, an enzyme present in green plants, in the presence of light converts carbon dioxide and water to basic sugar, a process that is termed photosynthesis. Chlorophyll increases in lakes as the lakes become more eutrophic; thus chlorophyll measurements provide comparative data on

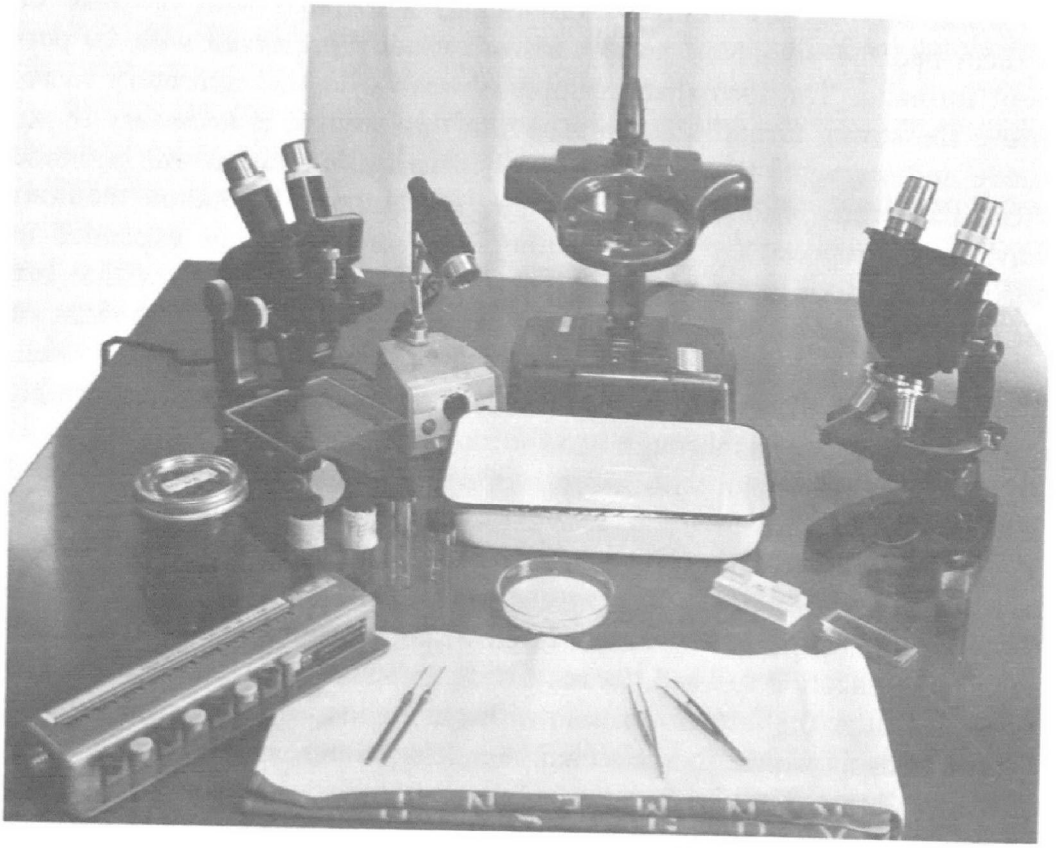

Figure 17. Sorting, enumeration, and identification equipment used in analyzing benthic samples.

eutrophication (Deevey and Bishop, 1942; Kozminski, 1938; Manning and Juday, 1941; Anderson, 1961).

The quantity of chlorophyll has also been used as a general index of the quantity of algae present (Harvey, 1934; Riley et al., 1949; Tucker, 1949). Chlorophyll is related closely to primary production or the conversion of organic materials to living plant tissue (Manning and Juday, 1941; Ryther and Yentsch, 1957; Odum et al., 1958). Because a large quantity of algae may be present, but not growing, and conversely a small population of algae may exhibit a substantial growth rate, the quantity of algae may not be related directly to primary production. Factors such as light intensity, nutrient availability, temperature, age or viability of algal cells, and size of the cells influence the quantity of chlorophyll per unit of algae present (Odum et al., 1958).

Chlorophyll-bearing cells may be filtered from the water with membrane filters (0.45 micron pore). Filters and cells are placed in vials of acetone for extraction of the pigments and for solution of the filters (Creitz and Richards, 1955). Samples are then centrifuged to remove particulate suspended materials. The clear supernatant pigment-bearing acetone is examined on a recording spectrophotometer. Spectrums are evaluated and the quantity of chlorophyll determined as outlined by Richards with Thompson (1952).

Some waters contain sufficient plankton (phyto- and/or zooplankton) so that samples must be diluted to obtain adequate numerical information; however, with a sparse plankton sample, concentration should be used. The phytoplankton in samples from most natural waters require neither dilution nor concentration and should be enumerated directly. Correspondingly, zooplankton often are not sufficiently abundant to be counted without concentration. Selection of methods and materials used in plankton enumeration depends on objectives of the study, density of plankters in the waters being investigated, equipment available, and experience of the investigator.

The Sedgwick-Rafter cell has been and continues to be the most commonly employed device for plankton enumeration because it is easily manipulated and provides reasonably reproducible information when used with a calibrated microscope equipped with an eyepiece measuring device, usually a Whipple ocular micrometer. It can be used to enumerate undiluted, concentrated, or diluted plankton samples. The biggest disadvantage associated with the cell is magnification. The cell cannot be used for enumerating very small plankton unless the microscope is equipped with special lenses that provide sufficient magnification (400X or greater) and clearance between objective lenses and the cell.

The Sedgwick-Rafter cell is 50-mm. long by 20-mm. wide by 1-mm. deep. Since the total area is 1,000 $mm.^2$, the total volume is 1×10^{12} cubic μ, 1,000 $mm.^3$, or 1 ml. A "strip" the length of the cell thus constitutes a volume 50-mm. long, 1-mm. deep, and the width of the Whipple field.

Two or four strips usually are counted, depending on the density of plankters. Counting more than four strips is not expedient when there are many samples to be enumerated; concentrating procedures then should be employed, and counts made of plankters in the concentrate.

$$\text{No. per ml.} = \text{Actual Count} \times \frac{1{,}000}{\text{Volume of "strip" } (\text{mm.}^3)}$$

If the sample has been concentrated, the concentration factor is divided into the actual count to derive the number of organisms per ml. For separate field counts (usually 10 or more fields):

$$\text{No. per ml.} = \text{avg. count per field} \times \frac{1{,}000}{\text{Volume of field} \times \text{No. of fields}}$$

When special lenses are not used and there is a need to enumerate small plankton, unusually abundant, other procedures may be employed in conjunction with and related to counts obtained from the Sedgwick-Rafter cell.

Lackey (1938) used a drop counting method in his examination of Scioto River, Ohio, phytoplankton. In this method, the sample is first centrifuged and ". . . after thorough agitation by alternately sucking it in and spurting it out of the pipette. the exact number of drops was counted and a sufficient number of drops of the decanted portion was added, so that one drop of catch bore a definite relationship to the amount centrifuged." One drop of sample is put on a glass slide and a cover glass added; 5 low-power fields and 10 high-power fields are examined, and number of each species is recorded at the magnifications used. Enumeration is repeated on 3 such mounts for a total of 15 lowpower fields and 30 high-power fields.

No per ml = avg. no. per field × no. of fields per drop or per cover slip × no. of drops per ml ÷ the concentration factor.

The concentration factor = ml of original sample ÷ ml of concentrate × (100 − percent of preservative in sample).

Lackey's method has the advantages of including all organisms in the catch, simplicity and ease of manipulation, and instant use of the high power magnification where identification with the low power is questionable. Certain disadvantages are inherent in the method: (1) because water normally is used as a mounting medium enumeration must be accomplished relatively rapidly to prevent dessication and subsequnt distortion of organisms; (2) results are not sufficiently accurate when only one slide-mount is examined, thus necessitating preparation and enumeration of at least three or more slide-mounts; and (3) the investigator should be sufficiently familiar with plankton to rapidly identify and count the specimens encountered.

Application of the membrane filter method of plankton counting requires a vacuum pump, special filtering papers, and experience in deter-

mining the proper amount of sample to be filtered. Plankton in samples from waters containing substantial quantities of suspended matter such as silt may be difficult to enumerate by this method since, in the process of filtering, the suspended matter tends to crush the plankton or otherwise obscure them from view. However, the method has certain features that make it particularly adaptable for use on waters with a low phytoplankton and silt contents. Primary among these features, the method permits the use of conventional microscope lenses to achieve high magnification for enumeration of small plankton (the membrane filter retains very small organisms), provides relatively rapid processing of samples if the investigator is familiar with the procedure and the plankton, does not require counting of individual plankters to derive enumeration data, and increases the probability of observing the less abundant forms (McNabb, 1960).

The sample is filtered through a 1-inch membrane filter. The wet filter is removed and placed on top of 2 drops of immersion oil on a microscopic slide, and 2 drops of immersion oil are placed on top of the filter. The filter is air-dried at room temperature until clear (approximately 48 hours). A cover slip is added prior to examination.

When examined, the magnification and sampling field or quadrat must be of such size that the most abundant species will appear in at least 70 but not more than 90 percent of the microscopic quadrats examined (80 percent is optimum). Otherwise the field size or the amount of sample concentrated must be altered. The occurrence of each species in 30 random microscopic fields is recorded.

> Number of organisms per milliliter = density (d) from table 4 × number of quadrats or fields on membrane filter ÷ number of milliliters filtered × formalin dilution factor [0.96 for 4 percent formalin].

Plankton samples form the Madison, Wis., sewage treatment plant effluent diversion study (Mackenthun et al., 1960) were concentrated by settling with a liquid detergent and were counted by the drop technique. To concentrate the phytoplankton, 500 ml. of stream water were placed in l-liter glass settling cylinders to which were added 20 ml. of commercial formalin to preserve the sample, and 10 ml. of a detergent to settle the sample. Sedimentation of the plankton was complete in 24 hours, after which the supernatant was carefully siphoned from the cylinder, and the concentrate was washed into 100 ml. centrifuge tubes. These were spun at 2,000 r.p.m. for 6 minutes. The supernatant in the tube was decanted and the concentrate was washed into screw-capped storage vials and brought to the nearest 5 ml. by the addition of 4% formalin and the use of a volume standard. In making the drop count, 5 low-power fields and 10 high-power fields were observed on this slide, and the magnification as well as number of each species of organisms was recorded. This procedure was repeated on 3 such mounts so that totals of 15 low-power fields

Table 4. Conversion Table for Membrane Filter Technique (Based on 30 Scored Fields)

Total occurrence	F%	d
1	3.3	0.03
2	6.7	0.07
3	10.0	0.10
4	13.3	0.14
5	16.7	0.18
6	20.0	0.22
7	23.3	0.26
8	26.7	0.31
9	30.0	0.35
10	33.3	0.40
11	36.7	0.45
12	40.0	0.51
13	43.3	0.57
14	46.7	0.63
15	50.0	0.69
16	53.3	0.76
17	56.7	0.83
18	60.0	0.91
19	63.3	1.00
20	66.7	1.10
21	70.0	1.20
22	73.3	1.32
23	76.7	1.47
24	80.0	1.61
25	83.3	1.79
26	86.7	2.02
27	90.0	2.30
28	93.3	2.71
29	96.7	3.42
30	100.0	?

$$\text{Where } F = \frac{\text{total number of species occurrences} \times 100}{\text{total number of quadrats examined}}$$

and 30 high-power fields were observed. The number of a particular type of organism in 1 liter of water was determined by the following formula:

$$\text{No./l} = \frac{\text{(Avg No./field) (No. fields/coverslip) (No. drops/ml)} \times 1{,}000}{\text{Concentration factor}}$$

$$\text{The concentration factor} = \frac{\text{ml. of original sample}}{\text{(ml. of concentrate) (0.94)}}$$

where 0.94 accounts for the dilution of the sample by the addition of formalin and the detergent.

The average volume in cubic microns of each species was obtained by measuring 20 individuals. The volume contributed by each species was expressed in parts per million by use of the following formula:

$$\text{Volume (ppm)} = \text{(No. org/l) (avg species vol in } \mu^3) \times 10^{-9}.$$

Palmer (Palmer and Maloney, 1954), developed a new counting slide for nannoplankton.

Mackenthun employed constable tubes to determine cell volume in a 1956 Wisconsin study. Concentrated algal samples were obtained on July 25, 1956, and again on August 8, 1956, from Station 1 in the Menasha Channel, Fox River, at mileage designation 38.5, at Station 2 from the Rapide Croche Dam at mileage designation 19.5, and Station 3 upstream from De Pere Dam at mileage designation 7.0. The concentrated algal samples were obtained by centrifuging 50 gallons of river water at 12,000 r.p.m. and suspending the residue in 1 gallon of algal-free water. A blender was employed in resuspending the algae. An aloquot sample of this 50 to 1 concentration was used for biological analyses.

Ten ml. of the concentrated samples, equivalent to 500 ml. of raw water, were centrifuged at an approximate speed of 2,000 r.p.m. in a constable tube. The addition of a small amount of detergent to the constable tube will facilitate the packing of small blue-green algae. On August 8, 50 liters of river water were strained through a fine plankton net at the 3 stations for comparative purposes. The cell pack or cell volume as calculated on a raw-water basis was as follows:

Cell pack (ml./1.)

		August 8	
Station	July 25	Centrifuged	Net plankton
1	0.068	0.086	0.071
2	.058	.066	.038
3	.036	.045	.031

Both the centrifuged and net plankton samples taken on August 8 displayed color stratification in the constable tube. The upper white layer was composed principally of single blue-green algal cells and small fragments of blue-green algal colonies. The middle light green layer was principally blue-green colonies and many celled filaments or larger fragments of these filaments of *Aphanizomenon, Anabaena,* and *Gloeotrichia.* In addition, there were numerous single blue-green cells and some colonial greens with a few diatoms. The lower dark layer was predominately blue-green algae, because of their abundance in the sample, but diatoms were heavily concentrated. The large-celled *Lyngbya birgei* was most concentrated in this layer, as was the dinoflagellate, *Ceratium.*

The packed cells, or residue, from the constable tubes were washed in distilled water and were dried and ignited in a platinum dish. The following results were obtained:

	Mg. dry Wgt./L			Mg. Ash/L			Mg. Vol. Sol./L		
Sta.	7-25C	8-8C	8-8N	7-25C	8-8C	8-8N	7-25C	8-8C	8-8N
1	9.8	14.6	11.8	4.4	6.8	3.0	5.4	7.8	8.8
2	10.6	14.4	8.6	5.4	4.6	2.0	5.2	9.8	6.6
3	4.8	6.4	7.2	2.0	2.8	1.2	2.8	3.6	6.0

C—Centrifuged sample N—Net plankton Vol. Sol.—volatile solids

Segments of lake bottom core samples may be analyzed microscopically to determine the diatom composition of the layered segments. To examine diatomaceous sediments in lake bed core sediments, an aliquot solids sample based on a packed volume of a selected core segment is oven-dried, suspended in equal parts of water and concentrated nitric acid, gently boiled for 45 minutes, and allowed to cool. Potassium dichromate crystals (0.1 gram) are added, the mixture cooled, washed into a centrifuge tube, and water added. The sample is washed 3 times by alternately centrifuging, decanting, and adding water. The inorganic residue is then diluted to a specific volume of water (200 ml. per gram of original sample), then 2 drops of liquid household detergent are added, the sample is stirred, and 2 drops of sample are withdrawn by a large bore pipette and placed on a cover slip. The sample on the cover slip is evaporated to dryness on a hot plate. Following drying the hot plate temperature is increased to 350° F, a clean microscopic slide is placed thereon, and a large drop of suitable microscopic mounting media such as Harleco* or Styrax* is placed on the slide. After 10 minutes, with slight cooling, the cover slip with the dried sample is inverted onto the mounting medium drop and pressed firmly into place. The slide is then examined for diatom skeletons.

Reporting

Reporting of the findings is equally as important as any other aspect of problem solving. A report represents the end product of the investigation. It is often the only link between the field investigation, which may take considerable time, money, and effort, and the public or particular report recipient. A report often recommends corrective actions to abate a problem, and these abatement efforts are necessary for the advancement of society. Thus, the report may be the most important part of a particular investigation, particularly because of the effect that it can have on broad political changes that may be focused on a problem area.

A report has certain basic yet essential features. The first of these is the title page, or cover, listing the author(s) and the responsible agency or where the report may be obtained. The title should not be too long but it should identify precisely the report contents. The second feature involves the summary, conclusions, recommendations and predictions, which are usually placed near the front of the report for ease in finding and value in display. The third basic component involves the report narrative, which includes the display of data, such as charts and figures and the discussion. The last is the report appendix.

The report *introduction* should describe briefly the problem and its location, the study objectives, the inclusive dates of the investigation, the authority for the study, and by whom the study was performed. It may re-

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late briefly the methods used to conduct the study, but generally such descriptions should be placed in the appendix, particularly when they are lengthy and include nonstandard ones. The introduction is often placed near the front of the report, and is followed by the summary.

The summary, conclusions, recommendations, and predictions may be the only parts of the report that are read by many of the report audience. These sections represent a condensation of the entire study; they should be drafted with great care.

When not preceded by the introduction, the first paragraph within the *summary* should introduce the study and should identify what was studied, where the study took place, who made the study and when, and what the study objectives were. The summary should briefly and concisely relate how the study was accomplished and what was found in the investigation. The entire summary should be as brief as possible and yet contain these essential facts. Stringent review and editing should always be employed. The summary should contain those particular facts that will be used to formulate conclusions. The language of the summary should be specific, and numerical data to substantiate or explain particular statements should be given where appropriate.

The *conclusions* should be concise, positive, lucid statements that relate what may be concluded from the summarized data and other observations. There is often a difference of opinion among report writers regarding the numbering of thoughts or paragraphs within the conclusions. From the standpoint of conciseness and adherence to a particular thought, it is helpful to number conclusions in consecutive order, at least initially. After these have been edited and re-edited the numbers may be removed without harm to the text material. Many writers prefer to retain the numbers. The report narrative and the data it contains must support the conclusions. The conclusions in turn must support the recommendations, and each recommendation should have a supporting conclusion.

Recommendations should be preferably numbered in consecutive order and developed with great care and sound logic. Recommendations represent the groundwork towards abatement or problem correction.

Predictions may or may not be within the investigation's objectives. They are of great value to the report's reading audience, however, to ascertain that water quality which is expected to be attained when all recommendations are met, when 50 percent or 30 percent of the recommendations are completed, or if no action is taken as a result of the investigation. Such predictions might well follow that section of the report devoted to recommendations.

The narrative within the report body supports the summary, conclusions, and recommendations. Its structure can be enhanced, and omissions avoided, by a carefully prepared outline listing all necessary items in logical continuity.

The *area description* section should include a general area location map, as well as a specific map of the study reach showing stations sampled, principal population centers and principal waste sources. Background information on municipal and industrial development and land use is helpful here.

The *water uses* section describes in informative detail those uses associated with:

(a) Municipalities,
(b) Fish propagation and production,
(c) Recreation,
(d) Industrial water supply,
(e) Navigation,
(f) Irrigation, and
(g) Hydropower.

Monetary damages resulting from existing or predicted water quality associated with these uses, and benefits from recommendations made should be noted where possible.

The *waste sources* section discusses wastes entering the waterway including:

(a) Municipal,
(b) Industrial, and
(c) Agricultural.

Measured or computed waste loads to specific stream reaches, with itemized particular wastewater constituents where possible, should be ascribed to each major waste source described specifically and separately.

The *effects of pollution on water quality and uses* include the findings of fact and their discussion, analyses and interpretation. This is the report section that bears the major burden of support for the conclusions and recommendations. Its principal discussions center around various water quality standards and specifically bacterial pollution, aquatic life in all its many facets, and aesthetic considerations. Featured within this section are data display and data interpretation.

Organizing the data entails graphs, photographs, and tables. Here a spark of ingenuity and imagination will reap great rewards. Often a report is "sold" by the manner in which data are organized and presented. Data first are arranged in tables. Lengthy, detailed tables should be placed in the report appendix—if placed in the narrative, they detract from reading coherency. Easy-to-follow summary tables, prepared as a digest of the tabulated data in the appendix, are helpful in the narrative to explain and substantiate discussion and conclusions.

Relationships among particular components within the data or trends among stream reaches of particular water quality components may be

shown as graphs. Graphs should be uncluttered, pertinent, and easy to follow. Broad lines to illustrate trends are preferred. Should the reader wish to verify a particular value at a given point, he will consult the detailed tables. Graphs should "picture" important information and be used sparingly only to underscore principal points.

In developing a report, do not say that certain information may be found in Table X or Figure Y, because this type of statement does not give the reader any vital information. Rather, make a positive factual statement using pertinent data within the sentence to substantiate the statement, and refer to the appropriate table or figure parenthetically as a source to substantiate the data used and to gain additional information. Interpret for the reader. Do not expect the reader to interpret tabular data or figures without help from the report narrative. It is always the readers prerogative to agree or disagree with the writer's interpretations.

Data interpretation gives meaning and vitality to the report. Interpretation is a clear statement of what is meant by what was found.

What is the problem?

Why is it a problem?

What is the cause?

What are the effects?

What corrections can be instituted?

Where should these be made?

When should corrections be initiated, and completed?

Data interpretation includes an evaluation of visible observations, of factors such as the physical drift of organisms into the sampling station from a tributary or an area unaffected by pollution, and of organism population trends throughout the study reach. Other studies often are cited to substantiate the writer's findings or to show that other investigators have found similar, or different, phenomena under comparable circumstances. Citations from other works should be adequately and correctly referenced. Unless the report is a literature search, literature citations should be reserved for important points that can be made more positive or more clear with additional clarification or substantiation from an outside source.

The report *appendix* is the proper recipient of long or complex tables, charts or tables listing scientific names, discussions of methods or procedures, descriptions of special studies performed to ascertain particular facts described in report narrative, and elaborate calculations. These materials should not detract from the reading of the report narrative by being placed within it.

An appropriate report cover should be designed that will wrap the package suitably to present to the reader.

The writer should read aloud his report to ascertain illogical approaches and flaws in rhythm. This procedure may be the greatest aid to

self-editing. Good technical writing is clear and concise and omits needless words. The specific word should be chosen instead of the general, the definite word instead of the vague, the concrete word instead of the abstract. Qualifying words should be avoided! Rarely is there more than one proper word to express a particular idea. A discriminate writer will search for that word, and when it is found he will profit thereby.

Finally the report should be submitted to an associate whose judgment is respected for review (Mackenthun, 1969). When a report is submitted to a reviewer, both writer and reviewer assume certain specific obligations. The writer should submit his report for review only after completing his own revision as discussed.

The writer has an obligation to inform the reviewer of the report's purpose and its expected audience. Is the purpose of the report to inform generally? To establish a specific fact in the literature? To establish policy? To interpret data? To serve as a basis for conference or litigation in resolving a particular problem? Will the audience be the general lay public, people technically trained in the report's subject, or will it represent a mixture of several technical skills and varied interests?

The writer is obligated to:

(a) Strive for the best in manuscript preparation, placing it in final form as talents permit;

(b) Be meticulous about data accuracy, grammar, punctuation, and spelling;

(c) Develop the report for the reading level of the report's audience;

(d) Forward a minimum of two manuscript copies to each reviewer —it may be desirable for the reviewer to retain one and return one with comments in the report margin to the writer; and

(e) Avoid writing down everything that has been done with the expectation that their viewer will cut, organize, and reconstruct the manuscript.

The writer should prepare himself mentally for critical review comments. Remember, the reviewer usually attempts at all times to be helpful and constructive. A "no comment" reviewer most likely has not fulfilled his obligation and is of no help to the writer.

A proper review entails consideration of the technical message, as well as the manner in which the message is presented. A review can be editorial only, but rarely can a technical review disregard the editorial aspects. Good grammer and technical competence usually are inseparable. A technical reviewer reads a document for clarity, technical accuracy, and to determine whether a dual meaning is present in the written word:

The reviewer is obligated to:

(a) Consider the purpose the report is designed to fulfill;

(b) Be constructive, thorough, and helpful with comments;

(c) Be certain of his own accuracy in suggesting changes;

(d) Base comments on the technical level and interests of report audience;

(e) Avoid sarcasm, argument, or destruction of the writer's style for the sake of expression in the reviewer's words; and

(f) Appreciate that the purpose of the review is to help the writer produce a better report.

Demonstrations

Following a field study with its report including conclusions, recommendations, and predictions, there is urgent need to ascertain the correctness and value of those recommendations and predictions. Assuming that the proffered recommendations are feasible technically and monetarily, their value should be demonstrated through appropriate action. Far too many studies are terminated with a report. Technical advancement can best be made by effecting sound and logical demonstrations to determine the correctness of particular recommendations and predictions. Through time, and using the investigative report and implemented demonstrations as a basis of fact, future investigators can adapt and modify their recommendations and predictions to answer future problems in an improved manner.