# Water Quality and the City Ecosystem

*ELVIS J. HOLT*

Environmental biology is an exciting subject to teach, for it crosses many disciplines and has broad implications. In one form or another the subject has become an "in thing" in many schools. However, the significant point is that it offers the possibility of challenging students to integrate a variety of information into a unifying experience with man as the central figure.

An unusual and highly successful sequence of experiences on water quality has been developed at Purdue University. Ecologic principles are presented in a problem-solving manner. The setting encompasses a city ecosystem, its water supply, its sewage-treatment facilities, and a river ecosystem. The response of our sophomore and junior biology and wildlife majors and a group of high school biology teachers has been gratifying.

An outline of the goals and selected objectives is appended. Note especially the variety of objectives and how they evolve in complexity and yet form a continuum around the central theme.

## *Why Study the Water Supply?*

Courses in environmental biology that appeal to students from several disciplines have added to the usual heterogeneity of the classroom. Knowing where to begin is therefore a significant criterion for success. This unit on one aspect of aquatic biology is introduced by means of an audiotutorial presentation. Students are supplied with behavioral objectives, a taped lesson, and an outline of coverage. By these means each student understands what is expected. This method provides a way to circumvent some of the inequalities existing among students, resulting from different backgrounds, by allowing each student to determine the rate of his own progress in achieving the objectives. This is not to suggest that desired results cannot be achieved by other methods of presentation; rather, it is meant to indicate that in this situation an audiotutorial approach has advantages. The facilities available to students for this presentation are shown in fig. 1.

The introduction is a broad survey of aquatic environments. A main thread through the survey is a comparison of the physical–chemical stability within aquatic environments. The presentation begins with the chemical properties that are common to all aquatic environments. It continues with examples of adaptations that enable organisms to withstand the stresses encountered; for example, osmoregulation and rheotaxis. The presentation concludes with an introduction to the central theme of the unit: an overview of water-quality parameters and how they can be used to show the effects of a city on its water resources.


**Fig. 1. Students working in study booths. Facilities are supervised and available anytime during the week while school is in session. This presentation takes the place of a regular laboratory period.**

To most of us in this country, water is merely a familiar resource, supplied by the city at the turning of a faucet. The source and the ultimate destination of this resource are often of little concern as long as the water is esthetically pleasing as it comes from the faucet and as long as a bond issue for the long-overdue or overburdened treatment plant doesn't arise. A common feeling of the populace is that the city ecosystem presents too many other challenges to necessitate being concerned over the cheapest commodity (in quantity) that enters the home. But let the water supply have the slightest odor, color, or taste or the sewer back up into the basement during a storm, and we are immediately aroused. Accusations begin to fly. At such times the city fathers and engineers wish people were better informed or properly informed about water and sewage—about the

The author is assistant professor of biology, Purdue University, Lafayette, Ind. 47907. He obtained his B.S. (1961) and M.S. (1964) in zoology from Brigham Young University and his Ph.D. (1969) in environmental physiology from Purdue. He has taught general zoology, human anatomy and physiology, and environmental biology since he joined the Purdue faculty, in 1964.

processes of getting the water to us and of getting rid of it when it becomes so "corrupted" that we don't want it anymore.

Water in a city exhibits a characteristic of water in any ecosystem; that is, it has a cycle—if not within a city, then in many cases between cities. The cycle through the city begins with groundwater and surface water as potential sources. How do they differ? The differences dictate the treatment necessary prior to distribution. Groundwater may be nearly free of harmful bacterial contamination compared with surface water—but unfortunate ecologic and economic consequences result when the people of the ecosystem decide they just don't like water so hard that it rattles in a can!

About two thirds of the water leaving the distribution center is returned (to the city) in the form of sewage. At least two changes should occur before this water can be safely returned to the natural cycle from which it was temporarily removed: the organic materials should be removed and the harmful bacteria should be eliminated. In our course the basic methods of treating sewage are presented in the classroom, to acquaint students with the actual operations they will see on their field trip.

Sewage-treatment plants (STPs) are places few students would visit on their own. Yet most look back on the experience as being informative and worthwhile—if the teacher is familiar with the plant or has arranged for a knowledgeable person to guide the tour. The STP is an excellent example of an ecosystem. Furthermore, students should understand that tax dollars build and operate STPs and that everyone should be familiar with what he's paying for; that is, the opportunity to educate the public should not be overlooked.

Interest in the function of the STP can be generated by discussing such things as reuse of water, volume of sewage, problems presented by combined sanitary and storm sewers (found in most cities), the amount of each tax dollar required to operate the plant, and the effect of a growing population on the quality of the effluent when the plant has a fixed efficiency (fig. 2).

**Fig. 2. Before the tour of the STP two students compare samples of influent and primary- and secondary-treatment effluents. The Wabash River is about 250 m beyond the secondary-treatment facilities, which are on the rise in the background.**

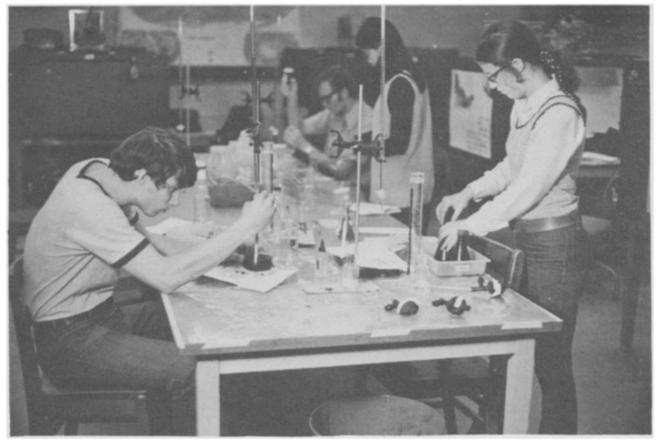

**Fig. 3. Students familiarize themselves with the Winkler Method for determining dissolved oxygen. The student on the right is preparing to analyze for oxygen in dark bottles for B.O.D. data.**

As the principles of operation are viewed and discussed, they are shown to be analogous to those of any ecosystem. A delicate balance must be maintained between the components of the system and the environment if the functional integrity of the system is to be maintained. Usually, there are examples of recycling of products to be discussed: activated-sludge systems, use of methane to heat anaerobic digesters, or the manufacturing of products. Energy-conversion and feedback models are also evident. (A suggested brief reference is the U.S. Department of Interior's *A Primer on Waste Water Treatment*.)

After seeing the influent and the treatment processes in operation, everyone eagerly awaits seeing what actually goes into the river. Some view the water with a sigh of relief: the system really works! Others are preoccupied with thoughts about people living downstream who might otherwise encounter untreated water.

Standing in a position where students can see both the sewage-plant effluent and the river, the instructor has a stage for discussion about water pollution, STP efficiency, tertiary or advanced types of treatment, self-cleaning capacities of the river, water-cycling, and the like.

If the receiving stream is a typical midwestern one like the Wabash River, some students will immediately label it polluted because of its silty, turbid appearance. But appearance alone is a poor criterion as to the quality of water or whether the river is suitable for its intended function. The necessity of using more scientific criteria in making judgments is emphasized.

At the termination of the field trip each student is asked to formulate, in writing, an hypothesis about the effects of the STP effluent on the river ecosystem. Through this experience the student begins to organize the relevant ecologic principles.

*Collecting Data for Statistical Analysis*

In subsequent classes students become acquainted with laboratory methods used to gather water-quality data. Experience has shown that a preliminary experience is essential before students use the techniques in actual experimental situations. This prior acquaintance results in students' obtaining experimental data that are sufficiently accurate to permit statistical analysis (fig. 3). The theory supporting each method, the operation of the instruments and equipment, and the various endpoints are emphasized. Table 1 summarizes the water-quality parameters investigated, the method of determination, and the expression of results. The methods used are those outlined in the American Public Health Association's *Standard Methods for the Examination of Water and Wastewater,* 12th ed., 1965.

When time and facilities permit, it is beneficial for students to alter the water sample and again determine values for the various parameters. For example, the addition of salt or heat has an effect on conductivity, and drinking water differs from deionized water in hardness. Dissolved $O_2$ in water can be reduced by heating or vacuum. The aeration effects of a stream can be simulated by pouring the water, low in $O_2$, from one container to another. This serves to emphasize the relationship of dissolved gases to temperature and, also, the contribution of turbulence to the aeration of streams.

If students prepared just to collect and accumulate data the experience would have limited value. The opportunity to expand this kind of experience through data analysis, drawing inferences, and making predictions is, however, too often delayed until graduate school or beyond. The intention of this exercise is to acquaint students with basic statistical procedures. The exposure, though brief and devoid of theoretic aspects, gives the student an entirely new perspective on, and enthusiasm for, collecting data.

An objective is to prepare students to make tests for differences between two sets of data. They are informed of the central-limit theorem, standard deviation, variance, degrees of freedom, the t test or some comparable method, and the appropriate table to determine whether the calculated value differs significantly from the expected value. Students are provided with definitions and sample problems to increase their confidence in working with these methods.

Equipped with the necessary methods, students are prepared to go about their work—like all respectable scientists—of collecting, analyzing, and reporting data. This experience in experimentation is a team effort: four or five students comprise each group. A group leader is designated; he makes individual assignments and is responsible for the group's compilation of data. Group participation is the preferred way because of the exchange of data and the communication that takes place.

Water samples are provided from four stations along the river: above the city, close to the sewage-plant outflow, and five and eight miles below the outflow. Each group determines the values for water-quality parameters (see table) as well as the biologic oxygen demand (B.O.D.) for two or more of the four samples. The number of replicate determinations for each sampling station is based on the number of samples one chooses to have for analysis. Data from all lab sections are pooled and compiled according to the water-quality parameters for each of the four sampling locations. Each student receives a copy of the pooled data, which he will analyze.

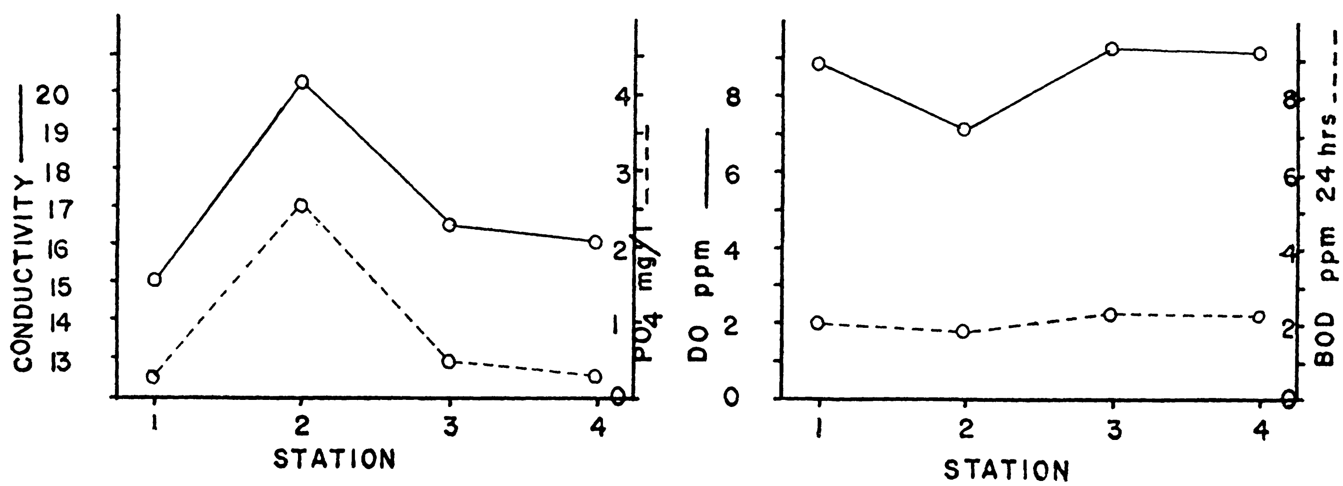


**Fig. 4.** Typical mean value data plots for conductivity, $PO_4$, D.O., and B.O.D. $N = 12$ for each mean. Total distance between stations 1 and 4 is nine miles. Station 2 samples were purposely collected close to the STP outflow.

It is important that the method and locations for collecting samples from the river be the same for all who participate. One set of samples is purposely collected close to the STP outflow, station 2, to provide data on the quality of water entering. These samples must come from precisely the same location, for a short-distance variation makes a great deal of difference in how much dilution has occurred. These samples provide an estimate of the efficiency of the

## Sequence of experiences on water quality at Purdue: topics, goals, and selected objectives.

WATER AND AQUATIC ENVIRONMENTS

*Goals:* For the student to attain understanding of the—
- Basic physical and chemical properties of water.
- Distinguishing characteristics of aquatic environments.
- Stresses encountered in various types of aquatic environments.
- Influence of man on water quality.

*Objectives:*
- Define the basic physical and chemical properties of water; for example, dipole molecule, surface tension, specific heat, and density.
- Cite an example of the significance of each water property.
- Identify distinguishing characteristics of marine, estuarian, and freshwater environments.
- Compare the general characteristics of lotic and lentic environments.
- Compare the stresses present in the five kinds of aquatic environments listed.
- Define water pollution and identify seven water-quality parameters.
- Describe how man's activities can alter water quality.

WATER IN THE CITY ECOSYSTEM

*Goals:* For the student to become aware of the—
- Quality of water recommended for human consumption.
- Alternate methods for processing water before and after its use in a typical city.

*Objectives:*
- Identify standards for seven water-quality parameters.
- Compare the qualities of surfacewater and groundwater.
- Describe a method for softening water.
- Define sewage, primary treatment, and secondary treatment.
- Recognize the effect of an expanding population on the "essentially fixed" sewage-treatment technology of the past 60 years.

SEWAGE TREATMENT AND THE RIVER ECOSYSTEM

*Goals:* For the student to gain an understanding of and appreciation for the—
- Sewage-treatment processes and the major operational problems encountered.
- Homeostatic balance that is essential among all facets of the sewage-treatment process.
- Analogous relationships between a sewage-treatment plant and any other ecosystem.
- General characteristics of the Wabash River ecosystem.

*Objectives:*
- Observe and identify the function and efficiency of primary and secondary sewage-treatment processes, anaerobic digesters, and chlorination.
- Discuss how the various sewage-treatment processes are dependent on each other.
- Compare the influent, effluent, and river water in regard to content, color, and odor.
- Identify and discuss the following characteristics of the river ecosystem: overall purpose, source, volume, flow rate, location, and kinds of entering effluents.
- Contruct an hypothesis, primarily from subjective reasoning, as to the effect of sewage effluents on the quality of river water.

WATER QUALITY METHODS

*Goal:* For the student to become familiar with and use modern methods of assaying water quality.

*Objectives:*
- Demonstrate proficiency in the operation of instruments and equipment.
- Determine values for $PO_4$, pH, hardness, turbidity, conductivity, D.O., and total and coliform bacteria from the water sample provided.
- Fabricate variations in the quality of the water sample to provide additional experience in these methods.
- Complete a data and summary form describing the water sample.

BASIC STATISTICAL METHODS

*Goals:* For the student to—
- Understand the use of statistical tests in the analysis of data.
- Develop an appreciation of the benefits that can be derived through statistical examination of data.

*Objectives:*
- Describe the central limit theorem and the appropriate sampling procedures.
- Calculate mean, standard deviation, variance, and t value.
- Complete a sample problem set involving the t test for significant difference between two mean values.

DATA-COLLECTING, ANALYSIS, AND REPORTING

*Goal:* For the student to understand the basic relationships of water quality to the total ecology of aquatic ecosystems.

*Objectives:*
- Collect water samples from four predetermined stations along the river: near the sewage plant effluent, one mile above the effluent, and five and eight miles below the effluent.
- Determine values for $PO_4$, pH, hardness, turbidity, conductivity, D.O., B.O.D., and total and coliform bacteria.
- Construct data plots of mean values for each parameter in regard to the four sampling stations.
- Analyze data by means of the statistical methods previously acquired.
- Synthesize and write a discussion and conclusions based on the data.
- Present and defend one conclusion in a small-group discussion.

STP. A comparison of these data with those from samples taken farther downstream makes it possible to show how the river usually recovers from the insult to it, by dilution or by natural cleaning mechanisms.

Thus far students have been primarily involved in completing rather straightforward objectives: listing, defining, describing, classifying, and comparing. When the student applies statistical methods to the data he begins to undertake more complex objectives: plotting, computing, analyzing, interpreting, organizing, synthesizing, and predicting. Here the student has a much greater latitude of involvement. Consequently, the kind and the degree of performance are varied; they depend on what the student chooses to do and how he does it. For the better students the exercise is essentially open-ended. We believe that by letting the students respond to a series of simple-to-complex behavioral objectives they will be better able to achieve the established goals, which require some insight into the ecosystem concept and attitudinal changes.

In this kind of experience the student becomes a part of the real world, wherein he collects data from a dynamic system. The results obtained are beyond the control of the instructor. That is to say, this is not a "canned" experiment. Students really become excited about the experiment, because it is theirs and they are going to draw some conclusions based on their data. Some students go beyond what is expected of them: they wish to analyze the data the way a researcher would. It would be too much to expect each student to do t tests for all possible combinations of stations; therefore each student selects those parameters that have the most meaning and that will enable him to derive the best possible conclusions about the hypothesis originally posed.

## *Discussions for Interpretation*

Developing a discussion, finding inferences, making predictions, and drawing conclusions is undoubtedly the best synthesizing experience in this unit. This experience forces students and teacher to think and reason about the complexity of ecologic problems and to reflect on the need for data from several fields of science. Having gone through the process of acquiring information, collecting and analyzing data, and formulating some conclusions, the students are now eager to put the capstone on their efforts: they want to share their findings, and the reasons for their findings, with others.

This opportunity is provided in small-group (10–12) discussion sessions. Each student is expected to present and support one of his conclusions by using his data and analyses. Fig. 4 is a sample of data collected and prepared for presentation. These data illustrate some general trends. Mean values for stations 1 and 4 do not normally differ at the 0.05 level of significance, whereas data from station 2 usually do. These values are more representative of the quality of the effluent than of the river water. Such results are excellent to illustrate the quality of sewage treatment, the role of dilution, and the capabilities of the river for self-repair. The high conductivity and the $PO_4$ values for station 2 are not a reflection of inefficient sewage treatment or management; rather, they bear out the fact that secondary treatment does not remove salts or phosphates. By comparing the conductivity of tap water with these data from the STP effluent it can be shown that the latter is about twice the former. This illustrates another effect of the city on the quality of its water resource. To remove the salts and phosphates the plant must be expanded to include advanced treatment processes. The taxpayer can have whatever quality of water he is willing to pay for.

Discussion sessions at which each student presents and supports one of his conclusions must be carefully planned and appropriately supervised to be successful. The person directing the discussion must allow the students to do the talking and, when necessary, interject questions that will caution students against making statements that are not supported by data.

**Summary of water-quality parameters investigated, the methods of analysis, and the units used to express results.**

| *Parameter* | *Method of analysis* | *Results expressed as* |
|---|---|---|
| $PO_4$ | Spectrophotometer | mg/liter orthophosphate |
| pH | pH meter | pH |
| Hardness | EDTA titration | mg/liter $CaCO_3$ |
| Conductivity | Solu bridge | equivalent to $x$ grains NaCl/gal HOH |
| D.O. | unmodified Winkler | ppm $O_2$ |
| Turbidity | turbidimeter | A.P.H.A. turbidity units (ppm $SiO_2$) |
| Total bacteria | Millipore BHI broth | bacteria/100-ml sample |
| Total coliform bacteria | Millipore Mf-Endo broth | bacteria/100-ml sample |

During the discussion the points listed below should be considered. Some have a direct relationship to the data; others are inferences that can be made as a result of completing the unit objectives.

1. Which t test would have been most appropriate to test the hypothesis posed?
2. Sources of error: how valid are the data?
3. Is the river unpolluted if no difference exists between stations 1 and 4?
4. Do data coincide with the known efficiencies of the STP?
5. Important variables: flow rate, season, water source, etc.
6. Discuss the roles of STP personnel and the taxpayer as to the treatment sewage receives before it enters the receiving system.
7. How important is a good technician where endpoints are based on color change?
8. Formulate a generalization from the data.

## *Conclusions*

The success of these experiences is largely attributed to the following:

1. The experiments represent the real, dynamic world.

2. The experiences deal with contemporary ecologic situations.

3. These experiences form a continuum. They evolve from straightforward descriptive information to the more complex analyzing, synthesizing, and writing experiences.

4. Students often express the idea that for the first time they can see the interrelationships between academic subjects that previously seemed isolated.

5. The resulting "total" ecologic picture is developed multimedially; that is, in lectures, an audio-tutorial session, laboratories, a field trip, and small-group discussions.