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ENVIRONMENTAL QUALITY CONTROL AND THE THERMAL POLLUTION PROBLEM

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In accordance with the invitation to this conference, I will begin with a pair of carefully selected, well-documented case histories of river surveys carried out by the Limnology Department of the Academy of Natural Sciences of Philadelphia related to a particular environmental problem. Each shows the way in which ecological considerations were successfully built into the developmental and operational process of an industrial plant. Following these I wish to develop the broader consideration of environmental stress and to explore alternative means of coping with this general problem and finally to consider how the approach used in each of the case histories might be expanded to include entire ecosystems.

The first program was designed to determine whether the heated waste water of the Savannah River Plant of the AEC operated by E. I. duPont de Nemours and Company had any effect upon the aquatic organisms living in the Savannah River in the vicinity of the plant. Limnological studies began at four sites on the river a year <u>before</u> plant construction was complete. The first survey was carried out in the summer of 1951 and data is still being gathered. By selecting a control area or station well above any possible effects of plant operation and three stations below the waste water discharge (Fig. 1) any adverse effects due to plant operation could be detected. Details of this study have been published by Patrick, Cairns, and Roback (1967) and will be only briefly summarized here. In choosing stations for comparative studies it is important that they have comparable habitats. Since these studies were designed to detect gross reduction in species diversity (i.e. number of species) which is a usual consequence of environmental stress

(Patrick, 1949 and Cairns, 1966) the quality of the environment or types of habitats present are more important than the dimensions of the area. These surveys were carried out by field teams of specialists including an algologist, a protozoologist, a lower invertebrate zoologist, an entomologist, an ichthyologist, a chemist-bacteriologist, and several field assistants. Usually, this team spent several weeks in the field on each survey. Upon returning to Academy laboratories, several weeks to several months was needed for identifying specimens depending on the group collected (e.g. fish might take less time than insects). Additional specialists were usually consulted during this period. We constantly endeavoured to keep our efforts comparable both between stations and surveys. Specimens of all species collected, except the fragile protozoans, were placed in the Academy collections.

In addition to the major surveys just described, cursory surveys were carried out periodically by two limnologists. Continuous biological monitoring was accomplished by placing Catherwood Diatometers (Patrick, Hohn, and Wallace, 1954) at each station. These devices, which suspended microscope slides in the photosynthetic zone, provided data on the structure of the diatom community at regular intervals (Fig. 2 and 3). Although the species comprising the diatom "community" change frequently, the number of species (Table 1) and the structure of the curve remain very similar as long as unusual stress (or pollution) does not develop. Good correlations have been found between changes in the structure of the diatom community and the entire community of aquatic organisms. Literature searches and some laboratory bioassays on the effects of heated water discharge were also included in the program. The extensive environmental monitoring program run by the Savannah River Plant was also an important consideration, but since I was not involved, it will not be discussed here.

A summary of the biological results for the major surveys is given in Table 2; and for the chemical analyses and temperature data in Table 3. No gross differences were noted between the control station and the other stations and all stations remained in the "healthy" range from 1951 to 1960 (the period covered in this paper) according to the system proposed by Patrick (1949). (Histograms illustrating the nature of the biological changes which would have been caused by pollution are given in Fig. 4). Some operational details are classified and therefore thermal loading rates cannot be given. However, the temperature ranges in Table 3 indicate the effect of plant operation on the thermal regime of the river was not great. Two points are important (1) frequent biological assessments were made before and after plant operation began to determine its effect upon the aquatic environment and (2) estimating a biologically acceptable thermal loading level from laboratory bioassays and a search of the literature and then checking frequently in the receiving stream to verify that no degradation was occurring has enabled the plant to use the river without interfering with other beneficial uses including fishing.

Some environmental changes have occurred which presumably affect all stations in the survey more or less equally. The installation of Clark Hill Dam many miles above the survey area between May 1952 and August 1954 seems to have created more stability in the water level of the river and increased its productivity. The latter appears to be the result of reduced turbidity at certain seasons consequently enlarging the photosynthetic zone and the production of algae. In addition the river banks have become more stable with a resulting increase in the stability of certain habitats. The river was dredged and straightened before the 1960 survey (station 5 had to be relocated because a newly dredged main channel bypassed it), but with the exception noted this also affected all stations including the control. During the period covered by the Patrick, Cairns, Roback (1967) paper, the upstream city of Augusta, Georgia increased markedly in population, and its associated industrial complex also expanded and diversified as well. Control station 1 is closest to this urban-industrial complex and would be expected to be affected most. It is interesting to note that although station 1 remains in the healthy category, its species diversity relative to the other stations has declined occasionally. This could be either random variation or the aggregate effects of the pollutional load added to the river in the Augusta and other upstream areas. If pollutional load is the causative factor, presumably the stream is able to "rejuvenate" or cleanse itself because the downstream stations have a higher number of species at these times than does station 1.

The second example of use without abuse of an aquatic environment is that of the Dickerson Plant of the Potomac Electric Power Company on the Potomac River. Although the approach and methodology for this study were essentially similar to those used on the Savannah River, only the protozoan data (Cairns, 1966) has been published and some of the chemical-physical data and backup protozoan data associated with this paper has been filed with the Library of Congress.* The limnological studies on the Potomac River were carried out in

*Document 8902, AIDAux. Publ. Proj., Photodupl. Serv., Libr. of Congress. Microfilm copy - $2.50 Photoprint copy - $6.25

the area from Point of Rocks to Whites Ferry which are in the vicinity of Frederick, Maryland (Fig. 5). Since the volume of water in the river varies seasonally, surveys were made during both high and low flow conditions. The first pair of surveys (i.e. high and low water) was carried out before plant operations began. The first power unit of the PEPCO plant at Dickerson went into operation in the spring of 1959 and the second unit in the spring of 1960. A second pair of surveys was carried out in 1960 and a third pair in 1961 to evaluate the effects of these two units. A third power unit was in operation in 1962 and a fourth pair of surveys was carried out that year to evaluate the effects of this unit. In 1963 and 1965 a single survey was made during the period of low flow and warm water conditions to further evaluate the effects of this additional unit. Catherwood diatometers were also installed at each station to provide continual biological monitoring of river conditions between surveys. These studies are continuing although I no longer participate in them. The Potomac River stations remained in the "healthy" category according to the diversity assessment methods of Patrick (1949) and Patrick et al (1954) throughout the time I participated in these surveys. A summary of the biological data is given in Table 4 and chemical-physical data in Table 5. Patrick (personal communication) has informed me that more recent evidence indicates that all stations on both the Savannah and Potomac Rivers remain in the healthy category.

A cluster analysis of these Potomac River Survey stations based on protozoan presence-absence data has recently been prepared by Cairns and Kaesler (in manuscript) using various combinations of Jaccard coefficients relating 46 aggregations (or "communities") containing a total of 647 species. An example of a dendrogram prepared from this data is given in Fig. 6. Similarities of aggregations of species within a survey were nearly always greater than similarities among aggregations from different surveys, indicating linear or along-stream environmental influence. Within-survey similarities for the early and late surveys were usually higher than similarities within middle year surveys, a possible indication of environmental change at all stations including the control - and subsequent biotic adjustment. This clustering analysis revealed no changes in the aquatic biota that could be attributed to thermal pollution as a direct result of the operation of the electric power generating station.

These studies were carried out with the cooperation of appropriate state agencies in Georgia and South Carolina for the Savannah River, and the State of Maryland for the Potomac River. These agencies were always informed and consulted well in advance of each survey and invited to send representatives - which was done when pressures of other work permitted. Representatives, at all levels, in these agencies were most cooperative.

These situations are not dramatic - no rivers were grossly damaged with accompanying fish kills; there were no spectacular confrontations between the various groups involved; and although the communities of aquatic organisms changed, the successional pattern appeared to be similar for the areas studied in each of the rivers (of course, there were considerable differences between these two rivers). The two factors that are of interest are (1) a truly multi-disciplinary group consisting of administrators, plant waste disposal engineers, and ecologists from state regulatory agencies and a research organization worked successfully toward a common goal - preserving the river; and (2) extensive use of river water was made over a number of years without interfering with other beneficial uses or degrading the aquatic community inhabiting the receiving waters.

These are examples of what might be done more generally with techniques that have been available for years. Although I have been asked to discuss heated water discharges, my assignment also includes a discussion of the larger problem of managing the environment so that the total impact of all environmental stress will not cause a general collapse of the ecosystem upon which our survival depends. In order to successfully reach a harmonious relationship with our environment, we must begin with a holistic approach - a view of the environment as a system. Dealing rigidly with ecological problems a fragment at a time will not produce results that will fulfill our needs and expectations. Starting with a very simple example of this, the temperature increase in coolant water may be quite similar in several power plants but the impact of the discharged heated waters upon the receiving waters, as measured by the temperature increase over the ambient temperature, may be quite different. An example of this distinction has been provided by Squire (1967). The data obtained by Squire (Table 6) indicates that a cooling water temperature increase of about 20°F is typical for plants in his study area. This uniformity is probably a result of the requirements of the plant. However, the temperature increase above ambient (Table 7) in the outfall areas ranges from 4°F - 20°F. From the evidence in the Squire (1967) paper, one would assume that the operational prerequisites of these power plants were determined more by "in plant" effects than environmental effects.

Another example of the danger of using a fragmented approach to ecological problems is the summation of several environmental stresses. The stream flowing through a recently sprayed forest and receiving quantities of insecticides will have a biota less resistant to other forms of stress than an entirely uncontaminated stream. Therefore our standards and laws must in some way evaluate the total effect of all the stresses under the control of man. We must have environmental quality control techniques functionally similar to those successfully used in industry for producing a product. Although the assessment of environmental quality is considerably more complex than the assessment of the various components of an industrial process, the same principle applies. That is - adequate assessment, feedback of information, and a quick response procedure. The rationale and framework for this approach has already been given (Cairns, 1967).

The related and complementary problems of increased energy production and population growth are forcing us to make a choice between a complex "quality" environment and a simplified "quantity" environment. A good example of a quality environment is a complex forest consisting of a great variety of plants and animals which will persist year in and year out with no interference from man. This ecosystem is a complex mixture of biological, chemical and physical interactions, many of which cancel each other out. For example, if there are several predators regulating the population of rodents and one disappears, the effect is often reduced by a population expansion of other predators also feeding upon the rodents. Therefore, the system is one of dynamic equilibrium, with the system itself being stable but with many of its components undergoing change. A simple system such as a corn field produces a quantity of material immediately useful to man, but is notoriously unstable. Without constant care and attention it would cease to be useful and would disappear. So the history of civilization has been one of widespread simplification of the environment with consequent increased management requirements.

When man simplifies an ecosystem, he creates numerous ecological problems. When a complex natural area is cleared and planted with corn, it requires protection against insect pests. To reduce the number of these pests, insecticides are applied and the diversity of life in the soil and in the field is further reduced. Because certain of the pests may become resistant to the insecticides after repeated application, there is a gradual escalation of concentrations of these, which may further simplify the ecosystem. At the same time, other organisms including man are beginning to have substantial amounts of these insecticides incorporated into their own tissues. For example, concentrations of DDT in the fat deposits of human tissues in the United States average eleven parts per million and Israelis have been found to have as much as 19.2 parts per million (Erlich, 1968). So the overall question is whether we will be able to control not only thermal pollution but all the other problems producing the environmental crisis. To come up with a workable method for a single form of stress without considering the others will only cause a slight delay in the inevitable catastrophe. Only with total environmental planning, including population control, will we be able to have a meaningful program to insure a harmonious relationship with the environment.

The problems caused by the discharge of heated water from steam-electric power plants and other sources is only a portion of the total problem. However, it is by no means so insignificant that we can afford to ignore it. The following are a few comments on the background of the problem.

The warming of our surface waters is not restricted to the present. As Wurtz (in press) points out, the early settlers destroyed the vegetational canopy which probably resulted in warming runoff waters. Very likely, these environmental alterations affected the biota inhabiting the surface waters. One can only estimate the extent of these changes because the extensive data required to establish gradual changes in an ecosystem do not exist for most of our surface waters today - years ago it was even rarer. One of the major problems of environmental planning is that most of the changes (excluding fish kills and the like) are so slow that even a trained ecologist may not know they are occurring unless appropriate data is being gathered. In this respect, ecology is no different from politics, economics, or industrial marketing.

Predictions of industrial use of coolant water suggest that some basic policy decisions of social importance should be made now! Though many industries use water to carry off heat generated by various processes and agricultural and domestic use warms it, the greatest source of thermal loading is the steam-electric industry. Thermo-electric (as opposed to hydro-electric) power production in the United States is expected to amount to 2,000 billion kw per hour by 1980 (Stroud and Douglas, 1968). Using present production methods, this will require approximately 200 billion gallons of water per day out of an estimated total supply of 1,200 billion gallons per day for the entire continental United States. Singer (1968) estimates that one quarter of all surface waters will be used for cooling in 1985. Both fossil and nuclear fueled plants use water as a coolant because of its high specific heat - air will not function nearly as well. Recent trends indicate that demand for electric power will double every six to ten years. Single existing power plants may now require up to one-half million gallons of water each minute for cooling purposes and economic considerations apparently favor the construction of even larger plants. Unfortunately, the distribution of water is geographically uneven and usually varies seasonally as well. In certain watersheds the entire volume may be required by the local power plant during low flow conditions. An additional drawback is that this period of maximum use may coincide with the warmest period of the year when surface waters are already at or near maximum annual temperatures and the organisms inhabiting them closest to their upper temperature tolerance limit. One possible solution to the thermal loading problem is the fast-breeder reactor as a power source - these are supposed to obtain 75% efficiency as compared with 2-3% in the reactors now in use. Until these become a reality one must at least consider what the consequences of further expansion using present methods will be.

The literature is replete with data on the effects of temperature changes in the aquatic environment. Kennedy and Mihursky (1967) have prepared a bibliography of 1220 key references on this subject and earlier Raney and Menzel (1966) produced a 34 page bibliography primarily devoted to the effects of heated discharges on fish. A general discussion of various problems associated with temperature changes together with a selected bibliography are included in "Temperature and Aquatic Life", Holdaway *et al* (1967). The physiology of temperature adaptation has been covered by Prosser (1967). Recently a two part (biology and engineering) National Symposium on Thermal Pollution was held under the joint auspices of the Federal Water Pollution Control Administration and Vanderbilt University. I have recently prepared a summation of the problem for Scientist and Citizen (Cairns, in press c). Clearly It would be most useful to attempt to interpret the significance of these publications as they relate to the management of our surface waters. Heated waste waters may affect aquatic organisms in the following ways:

(1) killing them (a) directly (b) indirectly (reduced oxygen, food, decreased resistance)

(2) causing internal functional aberations (changes in respiration, growth, life history, etc.)

(3) competitive exclusion by more tolerant species

(4) interference with spawning or other critical activities

As any "tropical" fish fancier knows, each fish has environmental requirements that differ from those of other species. Though ranges may overlap for many species there is something unique about the requirements of each one. The same generalization applies to aquatic species other than fish. Thus each ecosystem and drainage basin is inhabited by the mixture of species particularly suited to that environment. The ecosystem may share characteristics in common with other ecosystems but each is also significantly different from the others. All this would seem obvious to the point of triviality if laws designed to protect ecosystems were not general laws based on "average conditions" which rarely consider specific regional systems as functional units with interdependant, interacting parts. It would be ruinous if farmers ignored the unique characteristics of a region. The techniques for regional management are available (Watt, 1966)-

it is our behavioral patterns and attitudes that need to be changed!

Electric power companies and all others using the environment (including each individual since we all add to the total load) for waste disposal have two alternatives: (1) continue to increase stress on the environment and regard the resulting damage as a necessary price for our standard of living, or (2) manage the environment so that it serves the greatest number of beneficial uses. The dangers of choosing the first alternative should be abundantly clear! If not, there will soon be more "environmental backlashes" to provide the necessary evidence. The second should appeal to nearly everyone - at least initially! If we agree to manage the environment to suit the greatest number of beneficial uses, we must first define these, and establish goals eliminating or restricting any uses that clearly imperil our reaching them. This would require a number of regional organizations coordinated and supervised by a national organization. Obviously nothing of this sort now exists although Ehrlich (1968) proposes a national organization which he calls "The Department of Population and Environment".

Assuming that an organizational framework for environmental management has been developed there would be two not necessarily mutually exclusive alternatives (1) adjust our society to fit the environment as it now exists so that no further deterioration ensues, or (2) deliberately modify the environment to function well under a set of conditions that we create. I have for many years advocated the first choice (Cairns 1965, 66, 67, in press a) but am beginning to favor the second alternative in certain circumstances. Before discussing this, however, let us examine the consequences of choosing the first alternative. One would have to set biological, chemical, and physical quality control standards for each ecosystem. Once these social decisions have been made, a continually operating ecological surveillance system would be established at critical points in each ecosystem. This would provide continual feedback of ecological information which would be the basis for immediate action should environmental quality fall below established standards in any part of the ecosystem. Techniques for this have been available for years (Cairns 1965, 1967) although the time required for biological information is many orders of magnitude greater than for chemical and physical data. New techniques are needed to reduce this lag period and producing them is well within the capabilities of ecologists once the need has been established.

Our civilization has been founded on the concept of shaping the environment to fit our needs so the second alternative should have much appeal. "Unused" land or water seems to inspire all sorts of people and organizations to make it "useful". Against these powerful, well financed forces, are a small but vocal group of conservationists who want primeval wilderness - this group usually loses! Most of us would probably like some of each - that is some areas deliberately modified to suit certain of our needs and others essentially undisturbed to satisfy our other needs. What I am proposing is when we feel it necessary to destroy an existing ecosystem that it be replaced, not by chance, but by an ecosystem containing new organisms suited to the altered environment. Thermal loadings provide an excellent opportunity to examine the pros and cons of this approach. Naylor (1965) summarizes some of the literature reporting on warm water immigrants (some from fairly distant areas) which have become established in British and other European waters receiving heated effluents. Naylor makes the point that if substitution is desirable, heat-tolerant species should be deliberately introduced since natural distribution methods are too dependant on chance. A deliberate attempt to establish certain plants in a heated water discharge area in California has been reported by North (in press). Why not stock warm water fish and invertebrates below heated discharges into cold water streams to enable the power plant to make fuller use of the stream and provide fishing as well? For streams which already have warm waters, one might breed selected strains of heat tolerant aquatic organisms. There are several important disadvantages to this approach (Cairns, in press b). First, establishing a functioning balanced aquatic community with many complex interactions requires more than throwing a few appropriate species together. Usually there is a lag period which may be five years or more before a state of dynamic equilibrium is reached. Failures are also quite likely. In areas of rapid industrial growth, new unexpected demands for environmental modification might prevent the system from ever stabilizing. An unstable system is not likely to fill as many needs as a stable one, nor is its functioning likely to be as predictable. The second disadvantage is that once the new aquatic community has become established, it will be dependant upon existing conditions - in this example, higher than normal temperatures. Should the power plant shut down in mid-winter due to a strike or to replace broken or worn out equipment, it is quite likely that some or all of the heat tolerant and heat <u>dependant</u> species will die. Any "tropical" fish fancier who has had a heater failure on a cold night knows this. If aquatic environments are deliberately altered by wastes and species cultured to fit the new conditions, then our antipollution laws must be extended to include the failure to <u>maintain</u> the new conditions. For power plants this would mean <u>continual</u> discharge of heated water which has obvious disadvantages - particularly when the plant becomes obsolete. The payment for transforming the aquatic environment would also have to be settled. There is much to be said for reaching a harmonious relationship with the present environment.

However, how does one reach a harmonious relationship with an environment that is constantly changing? Habitats and their inhabitants have changed irreversibly long before the advent of man. Of course man has modified the environment rapidly and strikingly in many areas - in most areas of the world he is a determinant, and in many areas the major determinant of the nature and extent of these changes. Of course man cannot exist apart from the environment and must use parts of it. In doing so he contributes to the changes that occur. Unfortunately only the most selfish and superficial consideration of the consequences of these changes has characterized most uses made of the environment. For example, strip mining is a "cheap" source of fuel if one considers only the cost of removing coal from the ground. Disruption of both terrestrial and aquatic ecological systems is enormous and no one can assess the total cost but it will probably make strip mining very expensive indeed.

We have the capacity to analyze ecological systems*, to determine cause and effect relationships, to measure the roles of the various major components, and to estimate the consequences of various courses of action. Computor programs for systems analysis (i.e. the holistic approach for the analysis of complex problems) are already well established in most universities, airline operations, etc. With increasing stress upon the environment and evidences of environmental degradation

*Watt (1968) has proposed an excellent operational definition of a system as "An interlocking complex of processes characterized by many reciprocal cause-effect pathways".

all around us, we can no longer afford to tackle the problem a fragment at a time!

The most drastic changes needed to implement these recommendations are social - essentially changes in attitudes and behavior (Tinbergen, 1968). However, there is one area in which research is badly needed - that is in the development of rapid biological information or data gathering systems with lag times approaching those for chemical-physical data. At the present time biological data gathering to determine the effects of heated water or other waste discharge may require days, weeks, or months instead of seconds, minutes, or hours. Simple, economical, rapid assessment techniques are essential to a large scale systems optimization approach.

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Construction of Histograms

In order to make a graphic representation of conditions in each station, histograms (Fig. 4) were constructed according to a system devised in the Conestoga Basin studies (see footnote 1), with the various organisms grouped as follows:

Column I[2]	Column I contains species of diatoms, blue-treen algae, and green algae which, according to Liebmann[3], Kolkwitz[4], Fjerdingstad[5], and our own findings, are known to be tolerant of pollution.
Column II	Oligochaetes, leeches, and pulmonate snails.
Column III	Protozoa.
Column IV	Diatoms, red algae, green algae other than those included in Column I.
Column V	Prosobranch snails, triclad worms, and a few smaller groups.
Column VI	Crustaceans and insects.
Column VII	Fish.

The number of species represented in each column determines the height of the column. So that the heights of the columns in a histogram might be comparable, they are expressed on a percentage basis. The bases used for comparison in this survey are the numbers of species for each of these columns averaged from findings in a number of similar regions of Middle Atlantic.

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1. Patrick, Ruth 1949 - see literature cited.
2. In this report Column I has been revised because it was found that not all species of blue-green algae encountered were characteristic of pollution. This is also true of the genus Spirogyra. At present the problem of classifying algae as to their tolerance to a wide range of environmental conditions is under study.
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Coastal Plain rivers which are known to be free of pollution. The following numbers of species are taken to represent 100 percent:

Column I	4
Column II	6
Column III	41
Column IV	81
Column V	11
Column VI	47
Column VII	15

Determination of River "Health"

A "healthy" river is one which has a balance of organisms, i.e., one in which the biodynamic cycle is such that conditions are maintained which are capable of supporting a great variety of life forms. The algae are mostly diatoms and green algae, and the invertebrates and fish are represented by a great variety of species.

Columns I and II have been found to vary widely, depending on the ecological conditions and degree of enrichment of a station. A "healthy" station has been found to be one in which at least three of Columns IV, V, VI, and VII are 50 percent or over.

"Semi-healthy" is the condition in which the balance of life as described for a "healthy" station has been somewhat disrupted, but not destroyed. Often a given species will be represented by a large number of individuals. This condition is noted in the histograms by a double-width column and indicates that something has happened that has destroyed the check on this species. Under other circumstances, conditions have altered so that a certain group will have a great many more species present than usually occur, while other groups will be greatly depressed. Thus the pattern is an irregular one. It may be defined as follows:

1. One or more columns double-width; two of Columns IV, V, VI, and VII under 50 percent, or

2. At least one of Columns I and II over 100 percent or less than 25 percent; at least two of Columns IV, V, VI, and VII under 50 percent or

3. At least two of Columns I, II, and III double-width or over 100 percent. Three of Columns IV, V, VI, and VII less than 75 percent, and at least one less than 50 percent.

"Polluted" is the condition in which the balance of life found in "healthy" stations is severely upset. However, conditions are favorable for some groups of organisms. Such a condition may be defined as follows:

1. Columns IV, V, VI, and VII under 50 percent; either or both Columns I and II over 100 percent or less than 25 percent, or

2. Columns IV, V, VI, and VII under 50 percent, Columns I or II double-width, or

3. Three of Columns IV, V, VI, and VII under 50 percent; Column I or II double-width and over 100 percent.

"Very polluted" is a condition which is definitely toxic to plant and animal life. Often many groups are absent. It may be defined as follows:

1. At least two of Columns V, VI, and VII absent; Column IV below 50 percent, or

2. Columns IV, V, VI, and VII present, but below 25 percent; Column I or II below 50 percent.

The histograms are used to represent graphically some of the evidence obtained during the course of the survey. It is important to note that the conclusions are not based on the histograms alone but rather on the overall biological, chemical, physical, and bacteriological results.

Figure Captions

Figure 1. Diagrammatic map of the Savannah River basin after Patrick, Cairns, and Roback (1967). Station 2 was not included in the 1967 paper or in this discussion because it was only a tributary of the Savannah and ecologically distinct from the other survey stations.

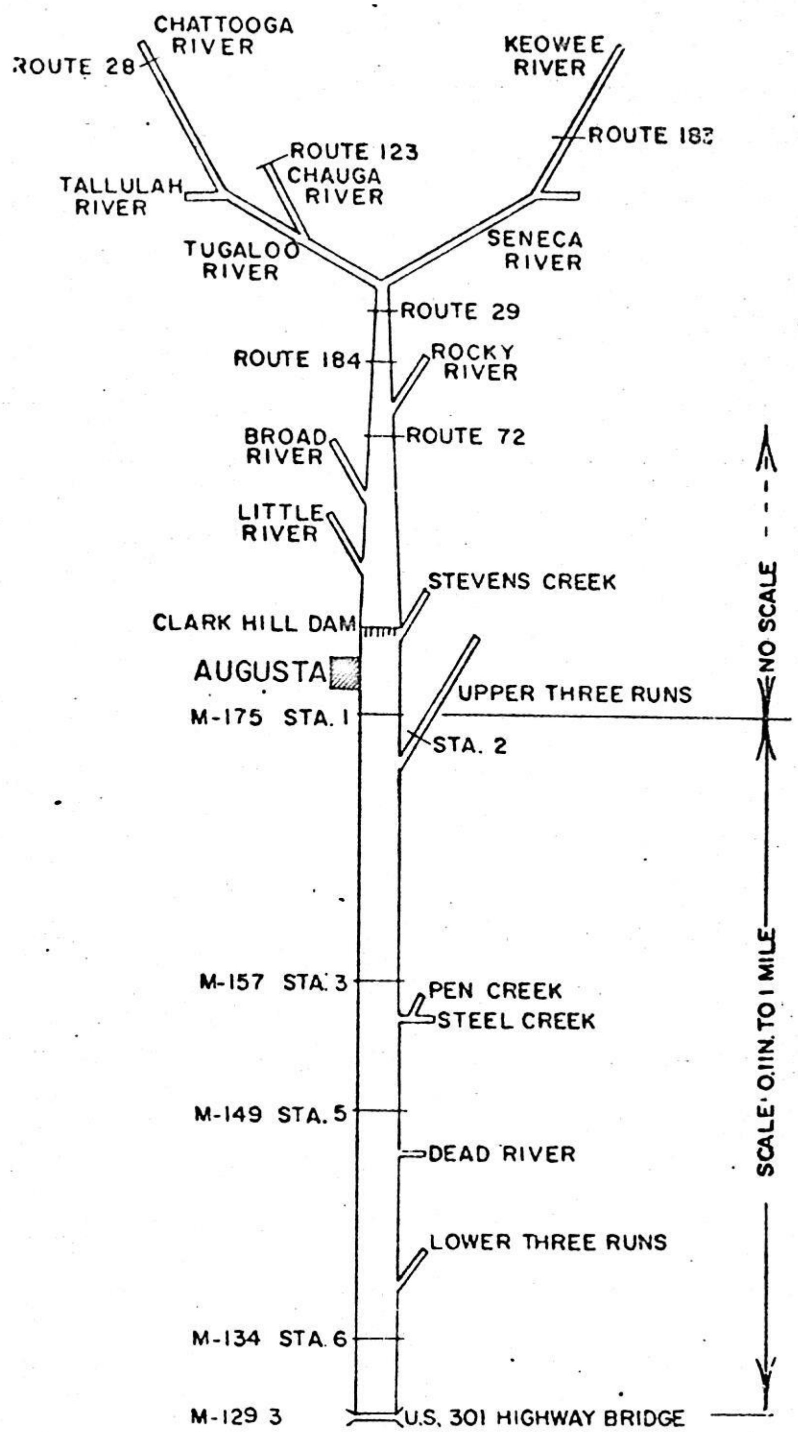
Figure 2. Graph of the diatom population from a stream not adversely affected by pollution (from Patrick et al, 1954).

Figure 3. Graph of the diatom population from a "polluted" stream (from Patrick et al, 1954)

Figure 4. "Idealized" histograms showing changes in the structure of the aquatic "communities" following various degrees of pollution following the system of Patrick (1949).

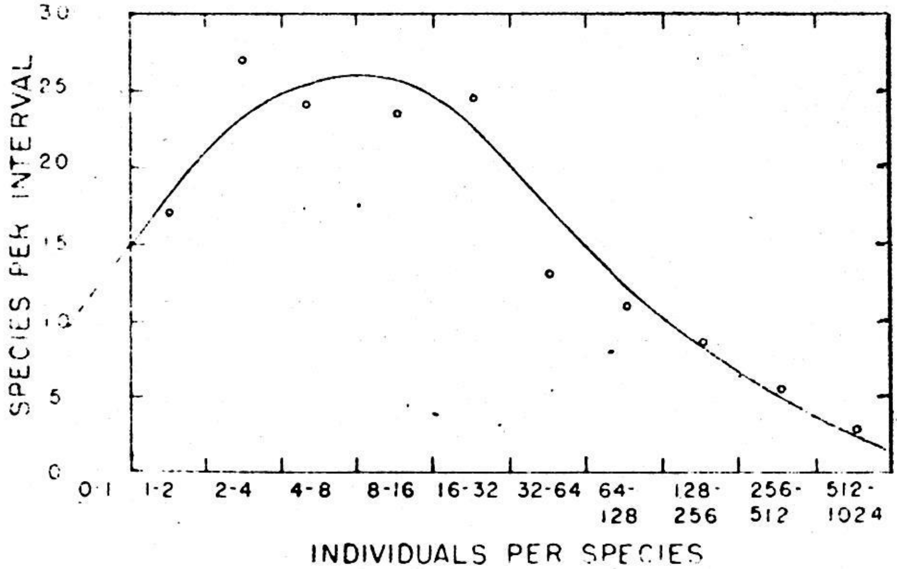
Figure 5. Diagrammatic map of the Potomac River study area (from Cairns, 1966) showing power plant site and three stations.

Figure 6. Dendrogram prepared by the unweighted pair-group method showing similarities among all low-water aggregations (from Cairns and Kaesler, in manuscript).



Diagrammatic map of Savannah River basin.

Figure 1



SPECIES PER INTERVAL
30
25
20
15
10
5
0
0-1
1-2
2-4
4-8
8-16
16-32
32-64
64-128
128-256
256-512
512-1024
INDIVIDUALS PER SPECIES

Figure 2

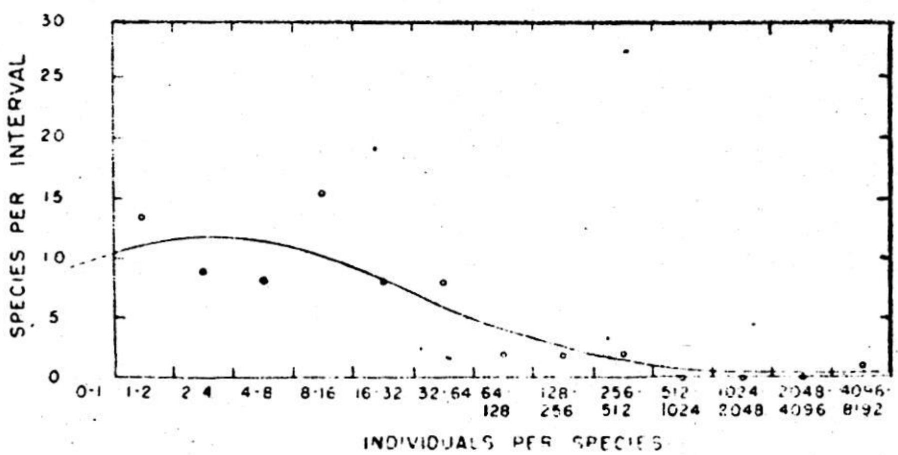
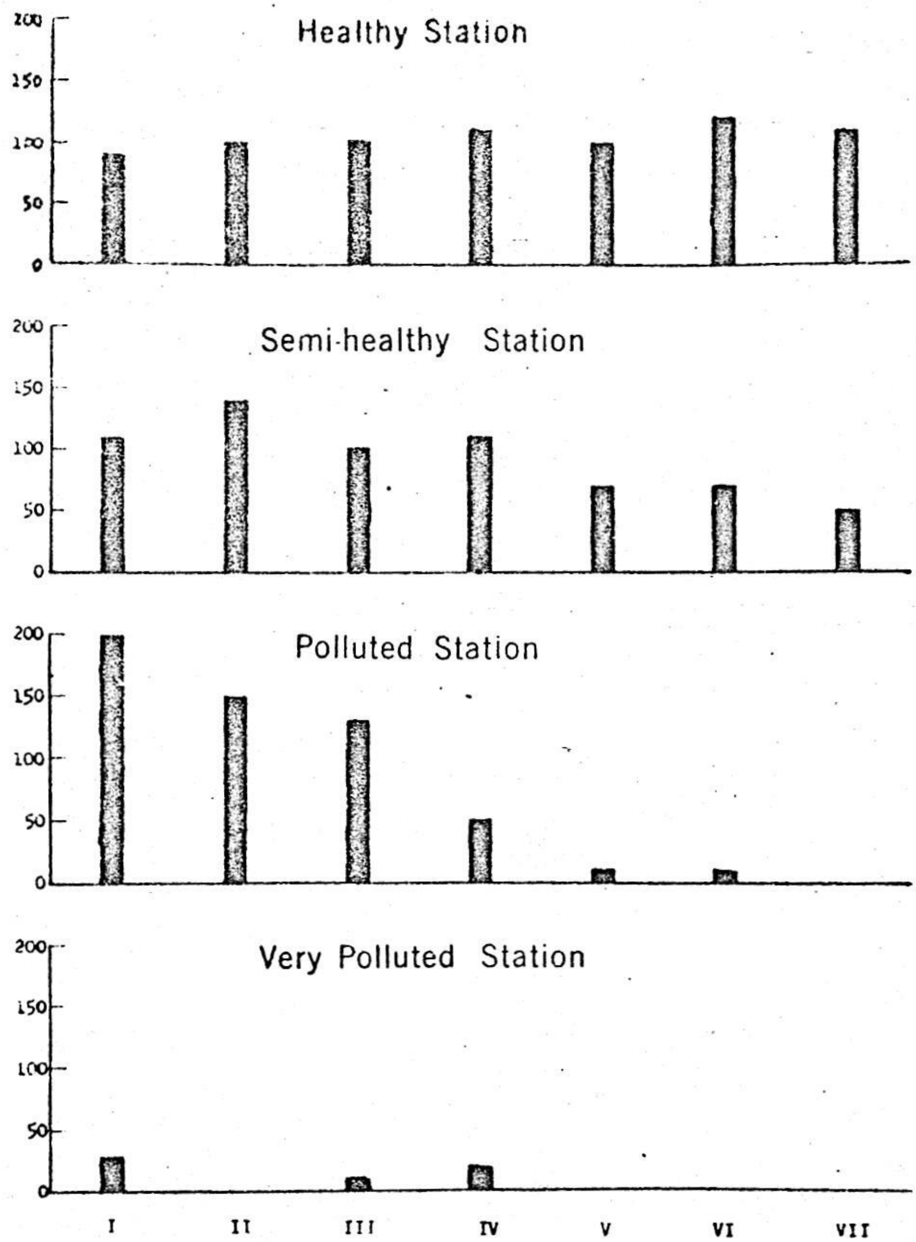
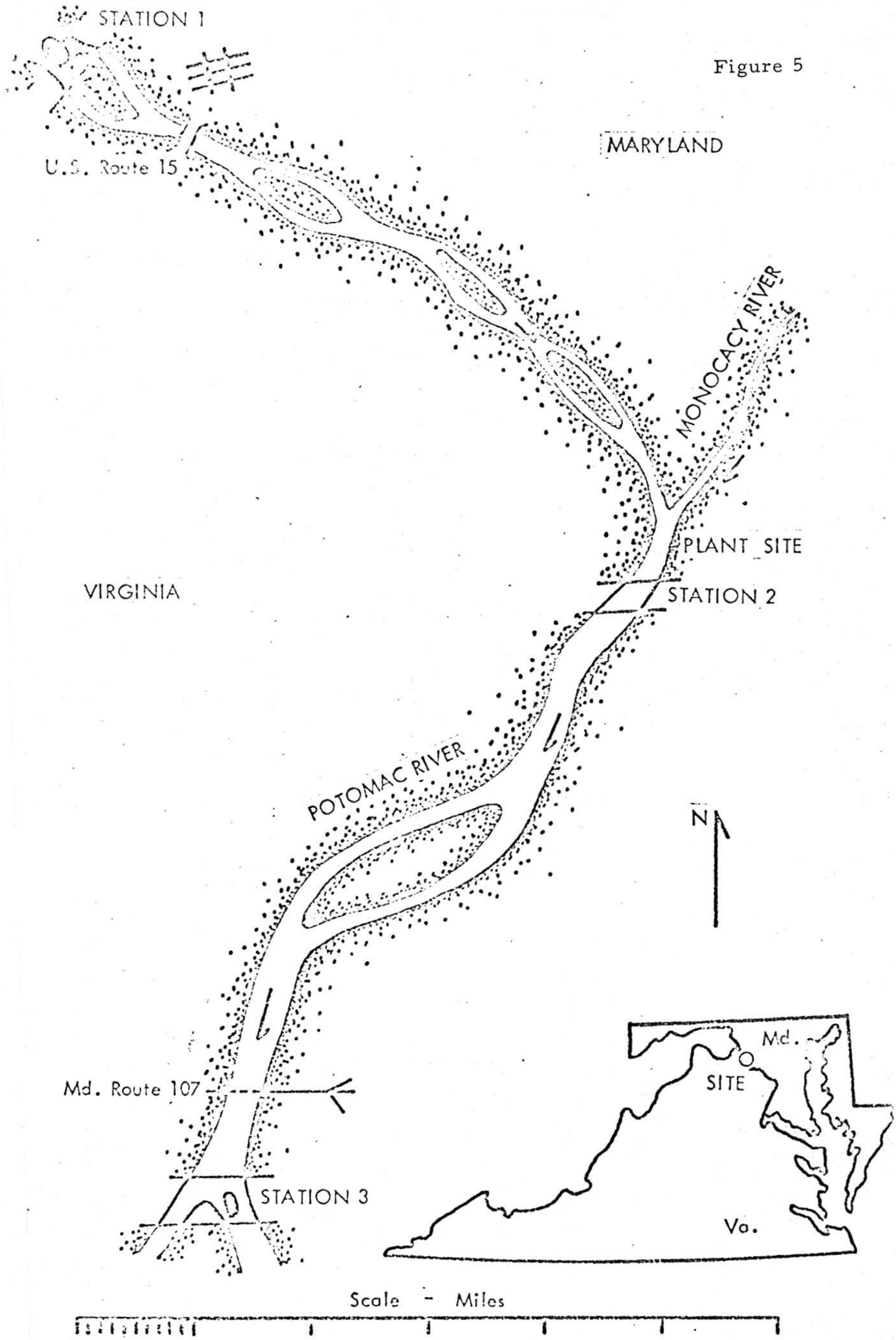

SPECIES PER INTERVAL
30
25
20
15
10
5
0
0-1
1-2
2-4
4-8
8-16
16-32
32-64
64-128
128-256
256-512
512-1024
1024-2048
2048-4096
4096-8192
INDIVIDUALS PER SPECIES

Figure 3



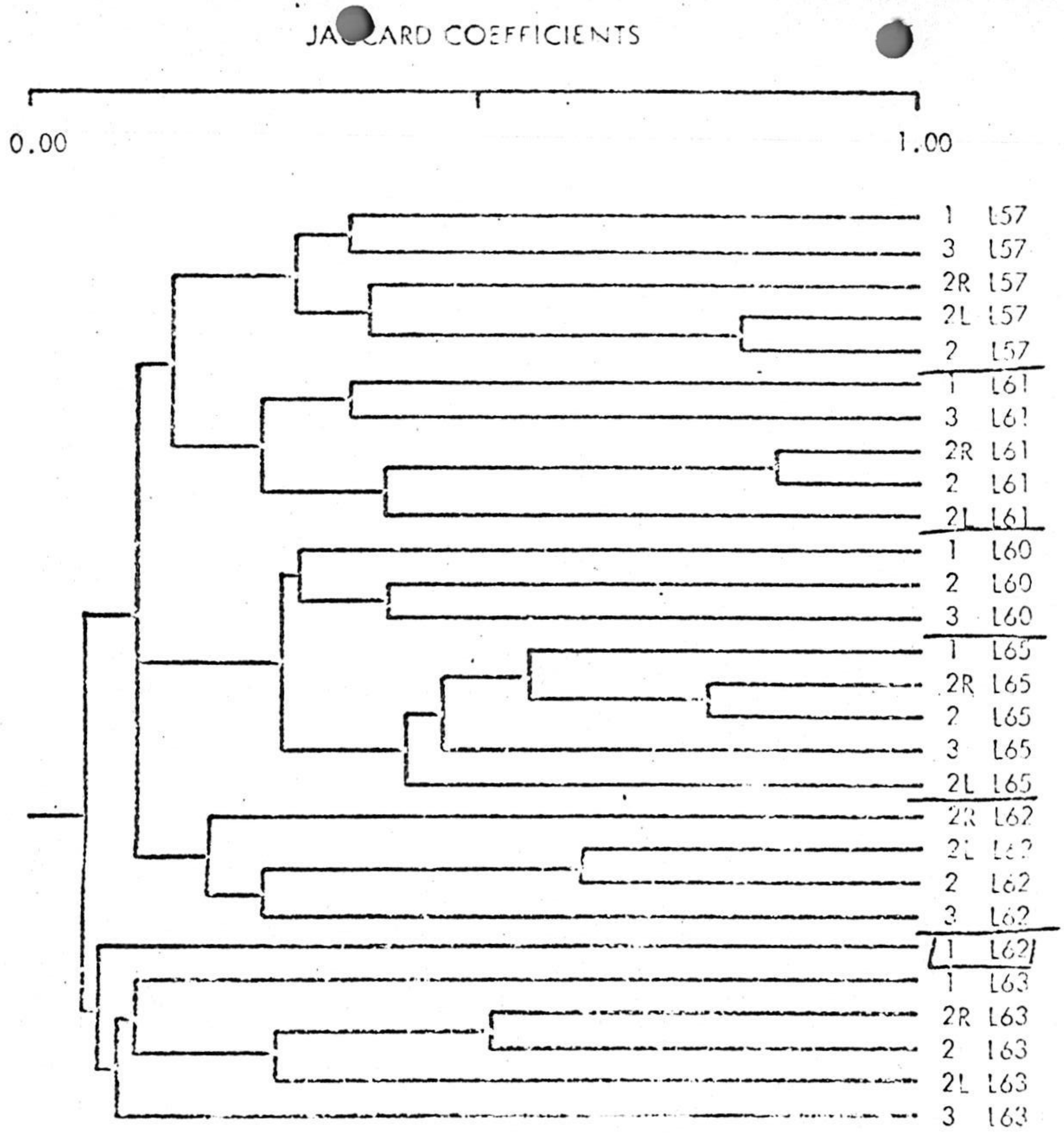
Healthy Station
Semi-healthy Station
Polluted Station
Very Polluted Station
200
150
100
50
0
I
II
III
IV
V
VI
VII

Figure 4



STATION 1
U.S. Route 15
MARYLAND
MONOCACY RIVER
PLANT SITE
STATION 2
VIRGINIA
POTOMAC RIVER
N
Md. Route 107
STATION 3
Md.
SITE
Va.
Scale - Miles
1
0
5

Figure 5



JACCARD COEFFICIENTS
0.00
1.00
1 L57
3 L57
2R L57
2L L57
2 L57
1 L61
3 L61
2R L61
2 L61
2L L61
1 L60
2 L60
3 L60
1 L65
2R L65
2 L65
3 L65
2L L65
2R L62
2L L62
2 L62
3 L62
1 L62
1 L63
2R L63
2 L63
2L L63
3 L63

Figure 6

Table Captions

Table 1. Comparison of readings from two diatometers located in the same area of the Savannah River. Note the remarkable consistance of results in different seasons and different years.

Table 2. Numbers of species found at the Savannah River survey stations from 1951 to 1960 (from Patrick, Cairns, and Roback, 1967).

Table 3. The ranges for all stations recorded for various environmental parameters on each of the Savannah River surveys from 1951 to 1960 (from Patrick, Cairns, and Roback, 1967). Note the rather compact temperature ranges for each survey indicating that the operation of the Savannah River Plant had comparatively minor effects upon the temperature regime of the river. Note the 1951 ranges, before plant operation began, is quite close to the ranges for other years.

Table 4. Number of species found at the Potomac River survey stations from 1956 to 1965.

Table 5a. Results, in ppm except where indicated, of chemical analyses from the August 1965 Potomac survey.

5b. Results, in °C, of temperature studies from the August 1965 Potomac survey.

Table 6. Flow and temperature change of cooling water at generating plants at time of surveys (from Squire, 1967).

Table 7. Increases over ambient temperatures on two surveys (from Squire, 1967).

Table 1

Diatometer	Date	a'	Specimen number in modal interval	Species in mode	Observed species	Species in theoretical universe
No. 2	Jan. 1954	.181	4-8	19	151	181
No. 2	Apr. 1954	.209	2-4	24	169	200
No. 2	Oct. 1954	.219	4-8	21	142	168
No. 2	Jan. 1955	.202	4-8	19	132	166
No. 1	Apr. 1955	.198	2-4	25	165	221
No. 2	July 1955	.197	2-4	20	132	180
No. 2	Oct. 1955	.188	2-4	27	171	253
No. 2	Jan. 1956	.229	2-4	30	185	229
No. 2	Apr. 1956	.245	4-8	35	215	252
No. 2	July 1956	.227	2-4	24	147	185
No. 2	Oct. 1956	.200	2-4	23	149	206
No. 2	Jan. 1957	.219	2-4	29	177	233
No. 2	Apr. 1957	.204	2-4	21	132	185
No. 2	July 1957	.253	4-8	29	181	203
No. 1	Oct. 1957	.188	2-4	25	157	232
No. 2	Jan. 1958	.229	2-4	27	152	212
(January 1954-1957 averages)			---	24	159	202

Table 2*

	Moderately High Flow Summer, 1951				Low Flow Fall, 1951				Winter, 1952				High Flow Spring, 1952			
	ALGAE															
Division	1	3	5	6	1	3	5	6	1	3	5	6	1	3	5	6
Cyanophyta	6	11	7	8	2	3	6	2	2	2	2	2	2	2	4	1
Chlorophyta	6	14	22	20	5	9	9	12	6	13	9	5	11	8	11	12
Rhodophyta	1	1	1	1	1	1	1	1	—	—	1	1	—	1	—	—
Bacillariophyta	93	88	60	117	89	87	103	74	77	44	58	75	50	55	39	48
Chrysophyta	1	—	—	—	—	—	—	—	1	1	1	1	1	1	—	1
TOTALS	107	114	90	146	97	100	119	89	86	60	71	84	64	67	54	62
	PROTOZOA															
Class																
Mastigophora	12	9	8	14	10	11	18	20	7	4	11	19	9	13	11	18
Sarcodina	2	—	—	3	4	6	5	10	2	1	4	5	1	5	5	6
Ciliata	5	9	8	5	8	13	10	9	17	13	13	31	13	11	8	19
Suctoria	—	—	—	—	—	1	1	1	—	—	—	—	—	—	—	—
TOTALS	19	18	16	22	22	31	34	40	26	18	28	55	23	29	24	43
	INVERTEBRATES															
Phylum																
Porifera	—	1	—	—	1	1	—	—	1	1	1	1	—	1	1	—
Platyhelminthes	—	1	1	—	1	1	—	—	—	1	1	—	—	1	1	—
Nemertea	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1
Nematoda	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Tardigrada	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Polyzoa	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Aschelminthes	7	9	4	5	5	6	7	5	11	7	17	6	5	6	3	4
Bryozoa	—	1	—	—	1	—	1	—	1	1	—	—	1	1	—	1
Annelida	2	5	2	3	5	3	3	1	4	4	6	1	2	4	6	5
Mollusca	2	10	5	7	7	11	5	5	4	2	1	4	4	4	7	6
Arthropoda	—	1	—	—	—	2	1	2	—	3	3	1	1	4	3	3
TOTALS	11	28	12	15	20	24	17	13	21	19	30	13	13	21	21	20

*From Patrick, Cairns, and Roback (1967)

Table 2 (cont.)

INSECTS

Order	Moderately High Flow Summer, 1951				Low Flow Fall, 1951				Winter, 1952				High Flow Spring, 1952			
	1	3	5	6	1	3	5	6	1	3	5	6	1	3	5	6
Odonata	6	6	3	6	2	6	5	4	2	6	11	4	6	5	5	4
Ephemeroptera	6	5	4	5	5	12	10	6	7	5	8	7	15	8	7	15
Plecoptera	1	1	3	4	2	3	4	5	5	12	9	9	3	4	4	4
Hemiptera	4	4	5	7	6	1	6	4	—	—	—	—	3	5	3	2
Megaloptera	—	1	1	2	1	1	1	2	—	1	1	—	1	—	1	—
Coleoptera	7	11	10	14	10	11	11	13	8	10	11	10	14	16	20	15
Trichoptera	6	8	1	7	1	3	2	1	3	2	11	6	6	2	4	3
Diptera	6	1	2	4	1	4	6	4	7	8	4	10	16	9	25	12
TOTALS	36	37	29	49	28	41	45	39	32	44	55	46	64	49	69	55

FISH

Order	1	3	5	6	1	3	5	6	1	3	5	6	1	3	5	6
Amiiformes	—	—	—	—	—	—	—	1	1	—	1	1	—	—	—	1
Lepisosteiformes	—	—	—	—	1	—	—	1	1	—	—	—	1	—	2	2
Clupeiformes	1	1	1	—	1	1	—	—	1	1	—	—	1	2	2	3
Cypriniformes	3	6	5	4	2	4	5	3	9	10	10	10	10	11	8	15
Anguilliformes	—	—	—	—	—	1	—	—	—	—	—	—	1	1	—	1
Cyprinodontiformes	—	—	—	1	—	1	—	—	1	1	—	—	1	1	1	1
Percopsiformes	—	—	—	—	—	—	—	—	1	—	—	—	1	1	1	1
Mugiliformes	—	—	—	—	1	—	—	—	1	1	—	1	1	1	—	1
Perciformes	5	8	4	7	6	4	5	5	5	6	5	7	9	6	6	7
Pleuronectiformes	—	1	1	1	—	1	1	—	1	—	1	—	—	—	1	1
Beloneiformes	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
TOTALS	9	16	11	13	11	12	11	10	21	19	17	19	25	23	21	33

Table 2 (cont.)

ALGAE

Division	Low Flow Summer, 1954		Low Flow Early Fall, 1955				High Flow Spring, 1956				High Flow Spring, 1960				Low Flow Early Fall, 1960			
	1	6	1	3	5	6	1	3	5	6	1	3	5	6	1	3	5	6
Cyanophyta	8	11	5	7	7	6	3	5	3	3	5	3	9	5	5	5	7	5
Chlorophyta	12	12	5	4	11	6	3	3	5	4	6	1	5	3	2	6	7	4
Rhodophyta	3	2	2	1	2	2	2	1	1	2	—	—	—	—	1	1	3	2
Bacillariophyta	79	68	85	76	82	105	89	88	87	74	84	73	76	64	66	77	85	87
Chrysophyta	1	1	1	1	1	1	1	—	1	1	1	—	—	—	1	1	1	1
TOTALS	103	94	98	89	103	120	98	97	97	84	96	77	90	72	75	90	103	99

PROTOZOA

Class	1	6	1	3	5	6	1	3	5	6	1	3	5	6	1	3	5	6
Mastigophora	25	22	25	26	25	27	20	18	19	23	24	24	33	22	23	26	25	25
Sarcodina	15	7	4	8	4	8	7	5	5	7	9	7	9	11	12	11	9	14
Ciliata	21	28	13	18	19	20	14	15	13	21	20	22	25	24	20	22	27	28
Suctoria	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—	1	1	—
TOTALS	61	57	42	52	48	55	41	38	37	51	53	54	67	58	55	60	62	67

INVERTEBRATES

Phylum	1	6	1	3	5	6	1	3	5	6	1	3	5	6	1	3	5	6
Porifera	1	—	1	1	1	—	2	1	1	1	1	—	—	—	1	2	2	—
Platyhelminthes	1	1	—	—	1	—	1	1	1	—	1	—	1	1	—	1	—	1
Nemertea	—	—	—	—	—	—	—	—	—	—	1	—	—	1	—	—	—	—
Nematoda	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1	—
Tardigrada	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
Polyzoa	—	—	—	—	—	—	—	—	—	—	1	—	1	1	1	1	2	1
Aschelminthes	2	—	2	3	2	2	1	—	—	—	—	—	—	—	—	—	—	—
Bryozoa	—	—	2	1	2	—	—	—	—	—	—	—	—	—	—	—	—	—
Annelida	2	2	2	3	4	7	2	3	2	2	3	4	4	—	3	3	4	1
Mollusca	6	3	7	5	7	7	6	4	4	5	9	11	11	10	8	11	9	11
Arthropoda	1	2	—	2	4	4	4	—	1	2	2	2	5	1	—	1	3	—
TOTALS	13	8	14	15	21	20	17	9	9	10	18	17	22	14	13	19	22	14

Table 2 (cont.)

INSECTS

Order	Low Flow Summer, 1954		Low Flow Early Fall, 1955				High Flow Spring, 1956				High Flow Spring, 1960				Low Flow Early Fall, 1960			
	1	6	1	3	5	6	1	3	5	6	1	3	5	6	1	3	5	6
Odonata	8	9	3	5	9	6	6	7	4	4	3	6	7	1	3	4	6	3
Ephemeroptera	9	7	9	7	10	9	8	7	10	9	2	2	4	8	5	4	2	4
Plecoptera	2	3	1	1	2	3	2	2	2	2	—	—	—	—	—	—	—	—
Hemiptera	2	1	2	2	1	4	4	5	4	4	5	1	2	—	1	2	2	—
Megaloptera	1	2	1	1	1	1	1	1	1	2	—	1	—	—	—	—	1	1
Coleoptera	11	20	7	8	8	11	7	7	13	11	9	13	7	5	7	8	5	6
Trichoptera	7	5	7	7	7	6	7	8	6	6	3	4	4	4	5	6	8	5
Diptera	17	19	14	10	16	18	11	10	14	8	11	8	13	7	5	10	11	9
TOTALS	57	66	44	41	54	58	46	47	54	46	33	35	37	26	26	34	35	28

FISH

Order	Low Flow Summer, 1954		Low Flow Early Fall, 1955				High Flow Spring, 1956				High Flow Spring, 1960				Low Flow Early Fall, 1960			
	1	6	1	3	5	6	1	3	5	6	1	3	5	6	1	3	5	6
Amiiformes	1	—	—	—	1	—	—	1	1	1	—	—	1	1	1	1	—	1
Lepisosteiformes	—	1	1	—	—	—	1	1	1	1	2	1	2	2	2	1	2	2
Clupeiformes	3	3	6	2	3	4	3	2	2	3	3	3	4	4	4	3	5	5
Cypriniformes	3	16	10	7	9	9	7	10	11	9	8	8	10	9	13	10	12	14
Anguilliformes	—	1	1	—	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Cyprinodontiformes	1	1	1	1	1	1	1	1	1	2	2	2	2	1	2	2	1	2
Percopsiformes	—	1	1	—	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Mugiliformes	—	1	1	1	1	—	1	—	1	1	1	1	1	1	1	1	1	1
Perciformes	8	11	13	11	12	8	8	12	11	10	13	12	13	11	14	12	13	12
Pleuronectiformes	1	1	1	1	1	1	1	1	1	—	1	1	1	1	1	1	1	1
Beloneiformes	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—
TOTALS	17	36	35	23	30	25	24	30	31	29	32	30	36	33	40	33	37	40

Table 3*

Chemicals	June, 1951	October, 1951	January, 1952	May, 1952
	Variation on a Survey			
Alkalinity (m.o.)	21.00 - 33.60	19.10 - 21.80	18.00 - 20.00	20.00 - 21.60
Chloride	0.60 - 2.40	1.00 - 2.30	2.00 - 3.20	1.80 - 2.40
Carbon Dioxide	4.3 - 6.8	3.9 - 6.8	4.9 - 7.2	5.2 - 6.6
Dissolved Oxygen	6.74 - 6.90	7.87 - 8.17	9.48 - 10.74	7.30 - 8.50
Iron $^{+++}$	0.046- 0.239	0.010- 0.056	0.110- 0.160	0.050- 0.110
Hardness	8.0 - 10.4	12.50 - 15.55	9.40 - 12.20	13.30 - 15.00
Calcium	2.40 - 2.80	3.00 - 4.10	2.00 - 3.04	2.96 - 3.52
Magnesium	0.34 - 0.83	1.22 - 1.37	1.07 - 1.26	1.35 - 1.60
Ammonia Nitrogen	0.053- 0.079	0.016- 0.169	0.017- 0.046	0.017- 0.052
Nitrate Nitrogen	0.002- 0.0066	0.002- 0.004	0.001- 0.005	0.004
Nitrite Nitrogen	0.114- 0.337	0.069- 0.162	0.065- 0.098	0.077- 0.12
Phosphate	0.012- 0.103	0.069- 0.088	not done	0.031
Sulfate	not done	2.28 - 2.81	2.21 - 2.50	2.50 - 3.05
pH	7.0	6.8 - 7.0	6.7 - 6.9	6.8 - 6.9
Silicon Dioxide	8.68 - 9.54	8.34 - 9.71	8.59 - 10.13	8.39 - 8.77
Temperature (°C)	28.0 - 29.5	21.0 - 23.0	11.0 - 14.5	19.0 - 20.5
B.O.D.	0.79 - 2.01	0.48 - 1.37	0.76 - 1.07	0.55 - 0.75
Turbidity	204.0 -548.0	50.0 -120.0	110.0 -140.0	34.3 - 52.0

Chemicals	Aug.-Sept. 1955	May, 1956	May, 1960	September, 1960
	Variation on a Survey			
Alkalinity (m.o.)	20.4 - 26.8	15.8 - 18.6	14.7 - 17.9	16.2 - 17.4
Chloride	2.8 - 3.6	3.2 - 4.2	6.1 - 7.0	5.3 - 5.9
Carbon Dioxide	6.8 - 8.0	3.6 - 5.8	4.8 - 10.6	4.7 - 6.2
Dissolved Oxygen	8.62 - 9.42	7.74 - 8.96	7.19 - 8.11	6.34 - 6.90
Iron $^{+++}$	0.006- 0.024	0.010- 0.037	0.447- 0.720	0.144- 0.238
Hardness	14.6 - 16.6	13.0 - 15.1	18.1 - 21.9	16.4 - 18.0
Calcium	3.60 - 5.84	2.72 - 3.36	3.28 - 3.84	3.70 - 4.36
Magnesium	1.31 - 1.65	1.31 - 1.81	2.06 - 3.33	1.31 - 1.80
Ammonia Nitrogen	0.008- 0.010	0.004	0.001	0.026- 0.047
Nitrate Nitrogen	0.001	0.001- 0.002	0.002- 0.003	0.004- 0.005
Nitrite Nitrogen	0.150- 0.203	0.144- 0.232	0.207- 0.385	0.094- 0.115
Phosphate	0.028- 0.044	0.047- 0.059	0.088- 0.469	0.022- 0.075
Sulfate	2.62 - 2.96	2.53 - 4.42	5.67 - 8.26	10.80 - 11.02
pH	6.7 - 6.8	6.8 - 6.9	6.5 - 6.8	6.8 - 6.9
Silicon Dioxide	7.85 - 8.18	7.388- 7.510	14.40 - 14.64	7.16 - 7.42
Temperature (°C)	24.3 - 26.6	19.0 - 22.9	20.8 - 24.2	24.8 - 27.5
B.O.D.	0.26 - 1.16	0.46 - 1.06	1.07 - 1.40	0.75 - 0.94
Turbidity	23.4 - 33.9	118.0 -171.0	44.85 - 53.13	26.10 -165.30

*All results are given in ppm--except pH and temperature.
From Patrick, Cairns, and Roback (1967)

TABLE 4

	High Flow				Low Flow					
Station	1956	1960	1961	1962	1957	1960	1961	1962	1963	1965
Algae										
1	105	93	87	86	103	85	101	60	87	84
2L*	88	82	80	81	95	84	87	76	87	78
2R	78	93	74	93	87	84	98	83	89	77
3	104	97	77	62	93	83	78	73	81	73
Protozoa										
1	85	53	42	58	68	79	42	51	51	69
2L	39	59	65	51	33	52	27	59	46	58
2R	45	33	39	33	20	45	47	46	50	67
3	83	68	56	56	58	87	53	49	52	64
Invertebrates										
1	24	15	22	23	29	21	31	24	22	26
2L	14	13	14	17	28	15	18	19	13	17
2R	17	12	20	14	21	15	17	19	16	16
3	15	21	24	19	26	19	30	22	27	21
Insects										
1	91	71	81	74	104	81	81	74	69	65
2L	70	53	64	60	77	65	62	57	56	37
2R	41	58	59	53	52	56	51	48	53	42
3	85	76	60	63	93	90	72	66	59	57
Fish										
1	18	30	29	23	28	33	29	29	23	29
2**	24	27	22	27	34	30	29	33	26	20
3	18	24	21	24	30	29	24	29	24	23

*Left bank facing downstream (i.e. below PEPCO outfall).

** Since fish move about more freely than the other organisms, no attempt was made to divide collections from station 2 into right and left banks.

Table 5a

Station 1

Water characteristic	Series 1*	Series 2	Series 3	Series 4
Alkalinity, P	7.6	6.0	8.0	5.0
Alkalinity, MO	112.4	109.0	102	94
Cl	31.6	29	29	27
Hardness, total (as $CaCO_3$)	162.4	172	162	157
Hardness, calcium (as $CaCO_3$)	106	114	112	107
Hardness, magnesium (as $CaCO_3$)	56.4	58	50	50
Ca	42.4	45.6	44.8	42.8
Mg	13.7	14.1	12.15	12.15
pH	8.3	8.5	8.5	8.5
Fe (total dissolved)	0.01	0.02	0.01	0.04
NH_3 - nitrogen	0.0074	<0.001	<0.001	<0.001
NO_2 - nitrogen	0.0065	0.0015	0.0015	0.0027
PO_4	0.064	0.006	0.05	0.1
SO_4	101	110	101	101
SiO_2	2.0	1.6	1.5	1.66
Turbidity	22	28	77	42
Total solids	338	394	378	342
Volatile matter	90	96	106	112
Fixed residue	248	298	272	230
Specific conductivity (in mhos)	4.64×10^{-4}	4.95×10^{-4}	4.80×10^{-4}	4.57×10^{-4}
Transparency	Bottom	Bottom	Bottom	Bottom
Temperature (in °C)	24.9	24.8	26	25.5
NO_3 - nitrogen	0.150	0.052	0.088	0.059

*Series 1 samples were collected at all stations on the same day. Other series were collected on subsequent days.

Table 5a (cont.)
Station 2

Water characteristic	Series 1	Series 2	Series 3	Series 4
Alkalinity, P	10.4	6.0	5.0	3.0
Alkalinity, MO	90.6	98.0	103.0	78.0
Cl	32.0	27.0	26.0	20.0
Hardness, total (as $CaCO_3$)	129.4	152.0	155.0	117.0
Hardness, calcium (as $CaCO_3$)	99.2	102.0	104.0	82.0
Hardness, magnesium (as $CaCO_3$)	30.2	50.0	51.0	35.0
Ca	39.7	40.8	41.6	32.8
Mg	7.3	12.5	12.4	8.5
[illegible]	8.7	8.3	8.45	8.1
Fe (total dissolved)	0.016	0.044	0.01	0.04
NH_3 - nitrogen	0.0074	<0.001	<0.001	<0.001
NO_2 - nitrogen	0.0015	0.0024	0.0052	0.0123
PO_4	0.05	0.018	0.07	0.1
SO_4	90	90	90	68
SiO_2	0.84	1.68	2.1	2.94
Turbidity	46	53	41	404
Total solids	336	330	334	406
Volatile matter	116	100	106	110
Fixed residue	220	230	228	296
Specific conductivity (in mhos)	4.40×10^{-4}	4.44×10^{-4}	4.42×10^{-4}	3.38×10^{-4}
Transparency	2'1"	1'6"	1'11"	6"
Temperature (in $^\circ$ C)	LB RB 31.5 30.7	LB RB 28 26.5	LB RB 32.8 28.2	LB RB 31.5 27.40
NO_3 - nitrogen	0.062	0.05	0.172	0.046

Table 5a (cont.)
Station 3

Water characteristic	Series 1	Series 2	Series 3	Series 4
Alkalinity, P	9.8	7.0	8.0	3.0
Alkalinity, MO	87.0	91.0	88.0	80.0
Cl	26.0	27.0	26.0	22.0
Hardness, total (as $CaCO_3$)	140.0	144.0	147.0	124.0
Hardness, calcium (as $CaCO_3$)	86.0	99.0	98.0	85.0
Hardness, magnesium (as $CaCO_3$)	54.0	45.0	49.0	39.0
Ca	34.4	39.6	39.2	34.0
Mg	13.1	10.9	11.9	9.5
pH	8.7	8.5	8.45	7.8
Fe (total dissolved)	0.016	0.01	0.01	0.03
NH_3 - nitrogen	0.021	0.033	<0.001	0.026
NO_2 - nitrogen	0.0013	0.0013	0.0013	0.0148
PO_4	0.04	0.022	0.056	0.154
SO_4	92	80	91.5	66
SiO_2	1.0	1.36	2.4	0.16
Turbidity	48	52	92	380
Total solids	320	294	348	390
Volatile matter	108	96	110	102
Fixed residue	212	198	238	288
Specific conductivity (in mhos)	4.30×10^{-4}	4.0×10^{-4}	4.80×10^{-4}	3.71×10^{-4}
Transparency	1'6"	1'9"	1'0"	3"
Temperature (in $^{\circ}$ C)	28.8	25.5	27.2	26.2
NO_3 - nitrogen	0.039	0.062	0.104	0.319

TABLE 5b.

	Station 1 Transect Left Bank to Right Bank					
	1	2	3	4	5	6
6:00 AM	25.5	25.5	25.5	25.5	25.5	25.5
Noon	26.5	26.5	26.5	26.5	27.0	27.0
3:00 PM	27.0	27.0	27.2	27.2	28.0	28.2
6:00 PM	25.5	25.2	25.2	25.5	25.0	25.0

	Station 2 Transect Left Bank to Right Bank					
	1	2	3	4	5	6
6:00 AM	30.0	30.0	29.5	28.2	28.2	27.5
Noon	31.6	32.6	30.0	31.6	31.0	29.5
3:00 PM	34.5	33.9	31.0	33.2	32.1	31.5
6:00 PM	31.6	32.2	30.0	28.9	28.2	27.6

	Station 3 Transect Left Bank to Right Bank					
	1	2	3	4	5	6
6:00 AM	28.2	28.9	28.9	28.2	28.9	27.5
Noon	28.9	28.9	28.4	27.5	28.4	27.5
3:00 PM	30.0	30.0	30.0	29.5	28.9	28.9
6:00 PM	28.2	28.2	27.5	28.2	28.2	28.9

Table 6 Flow and temperature change of cooling water at generating plants at time of surveys, 1963 (from Squire, 1967)

Generating plant	Flow (g.p.m.)	Temperature (°F.)		
		In	Out	Rise
Redondo Beach:				
January 16	310,000	56	75	+19
February 4	267,000	58	77	+19
Alamitos:				
January 16	512,000	--	--	--
Haynes plant	96,000	57	78	+21
Edison plant	416,000	57	78	+21
February 4	355,000	--	--	--
Haynes plant	90,000	59	80	+21
Edison plant	265,000	61	80	+19
Huntington Beach:				
January 16	264,000	56	78	+22
February 4	416,000	60	80	+20
Carlsbad (Encina plant):				
January 16	150,000	56	68.5	+12.5
February 4	149,400	58	77	+19

Table 7 Increases over ambient temperatures on two surveys (from Squire, 1967)

Outfall area	Temperature increase above above ambient (°F.)		Difference (°F.), Survey 1 to Survey 2
	Survey 1	Survey 2	
Redondo Beach	4.2	4.0	-0.2
Alamitos	17.0	20.0	+3.0
Huntington Beach	7.2	6.5	-0.7
Carlsbad-Encina	8.0	4.0	-4.0

Cairns papers

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