MEASUREMENT OF WATER QUALITY THROUGH A NATIONAL SAMPLING NETWORK

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I am pleased to participate in this, the 122nd annual meeting of your American Statistical Association. I am sure that the need for statistical data on which to base man's progressive social, economic, health and welfare requirements is as old as civilization itself. Nevertheless, it came as no small surprise to me that this organization has existed since the year 1840. I know that you and your predecessors -- in your workings with industry, with government, and with organizations and institutions of many kinds -- have contributed much to the growth and development of America. In all probability, basic data such as only the professional statistician can provide, will continue to be in short supply as long as mankind is still inquisitive about the Earth and the Universe in which he lives.

Today, as you see on your programs, I am to speak to you on "The Measurement of Water Quality Through a National Sampling Network."

Background and Present Status of the Water Resource

Water resources development in the United States, encompassing all sectors of society, is truly in the "big business" category, presently involving an expenditure of about $10 billion a year. The federal budget for this fiscal year for water resources investigations and research alone totals $79.6 million, a 24 percent increase over 1962. Fifteen government agencies or departments are involved.

The Federal program which I represent is that of water supply and pollution control, administered by the Public Health Service and its parent agency, the Department of Health, Education, and Welfare.

And now, let us review briefly the background and present status of the water resource itself.

Since the turn of the century, while our population has a little more than doubled, there has been an eight-fold increase in the use of water. Our population, now in excess of 185 million, is using water at the rate of 325 billion gallons a day. Water use is expected to double by 1980 and triple by the year 2000. It goes without saying that as water is used, more liquid wastes are created. There is now nearly six times as much waste -- pollution -- in our rivers, lakes and streams as 60 years ago.

The wise management of our water resource has assumed a position of number one importance. Prominently involved is the abatement, control and prevention of pollution. While sanitary engineers have long recognized and repeatedly voiced the need to protect the quality of our Nation's waters, the public-at-large has been slow to heed the warning and accept the responsibility. The urgency of the need is quite evident when we measure the potential available water supply against projected water requirements for municipal, industrial, agricultural, and recreational use. (These predictions are shown in Figure 1).

Here the complexity of the situation becomes immediately obvious. First, it is clear that reuse of water is unavoidable. Even now, for example, the waters of the Ohio River are used 3.7 times during periods of low flow before they join the Mississippi. Similarly, in the Mississippi River just below St. Paul, more than 10 percent of the flow has recently been through the sewers of Minneapolis or St. Paul one day in 20.

Secondly, criteria for water quality must be developed on a basis which is equitable to all water users. President Kennedy has succinctly stated our national goal as one "to have sufficient water sufficiently clean in the right place at the right time to serve the range of human and industrial needs."

Virtually every use of water, whether for cooling an industrial process or carrying away land drainage, etc., impairs its quality to some extent. This in turn reduces its value to the next user. The expanding need for water, therefore, emphasizes the necessity of preserving its quality as demand rapidly approaches a final limit of supply.

More and more we are finding that water pollution is affected by new factors. In earlier years we were dealing largely with problems of pollution resulting from man's body wastes and from sewage-like industrial wastes. These, and their effects on water, have for the most part been well defined. We have known for years, for example, that waters receiving domestic wastes undergo organic enrichment which results in the production of large quantities of algae, eliminates fish, and destroys the usefulness of the water for recreation, domestic supply, and other purposes.

Today the streams are being invaded by many new and unfamiliar types of wastes to which we might apply the term "persistent," products largely of the new technologics of the past 20 years. Among those with which we are most concerned are synthetic organic chemicals (such as household detergents and agricultural pesticides) and radioactive materials.

These newer wastes, together with residual materials remaining after treatment of conventional wastes, are raising questions as to just what is happening to the quality of the Nation's waters. These questions are coming from water works operators, agriculturists, recreational groups, conservationists and public officials. The growing importance of water supplies to meet municipal, industrial and agricultural demands, makes it necessary that we know and are able to predict the quality of water much more precisely than we do today.

Defining water quality becomes a most difficult concept. How clean is clean to water's multiple users? And at what point in its role of waste carrier does a river's water become "dirty" to each user? There are many water users, and to each, water quality may have a different meaning. Moreover, the natural mineral and organic content of waters differs from one part of the country to another. Whatever the variations in water quality, its management will be increasingly important to obtaining maximum use from our available water resources.

To carry out such management, basic data on water quality is essential. The Congress recognized this need in the Federal Water Pollution Control Act of 1956 when it gave to the Public Health Service the responsibility to "collect and disseminate basic data on chemical, physical and biological water quality and other information insofar as such data or other information relate to water pollution and the prevention and control thereof." This, the legislation states, is to be done in cooperation with other Federal, State, and local agencies.

The National Water Quality Network

The National Water Quality Network was established in 1957 as a part of the over-all basic data program of the Public Health Service in response to the charge of the Congress. The Network has grown from 51 stations in its first year of operation to 125 stations located on major waterways of the country, with plans for eventual expansion to about 300 stations. Participants include more than 100 local water, sewage or other public utilities, health departments, industries, and universities, State water pollution control agencies, and resident engineers of federal reservoirs. Active local participation is important in this operation. It assures maximum development of all information valuable both locally and nationally. The State and local agencies perform most of the conventional chemical analyses and collect water samples for the more complex examinations. The Public Health Service, in turn, performs the more complex determinations and makes the results available to the participants. In addition, the consultation, training facilities, and other resources of the Public Health Service are available to the cooperating agencies.

The basic data program as a whole, is designed to assemble, examine, and interpret the facts which enable water pollution control agencies and others concerned to determine the scope and character of problems to be solved. It is this last function of the Public Health Service basic data program which I would now like to discuss with respect to water quality.

Objectives

The objectives of the National Water Quality Network are:

1) To maintain continuous intelligence on the nature and extent of pollution affecting water quality.

2) To determine trends in water quality as affected by: (a) water pollution control activities; (b) water resource development activities; and (c) water use and reuse.

3) To provide data on water quality useful in the development of comprehensive water resources programs.

4) To provide data which will guide State, interstate and other agencies in their water pollution control programs, and in the selection of sites for legitimate water uses.

5) To provide data of likely importance to epidemiological and toxicological studies.

Scope of Analytical Activities

Only after careful screening of needs in water resource development was the pattern set for analyses of water samples. Of interest presently in the water quality picture are more than 15 physical and chemical parameters, including radioactivity, plankton populations, coliform organisms and a dozen or more biochemical, chemical, and physical measurements, such as color turbidity, temperature, alkalinity, hardness, dissolved oxygen, etc. Certain of these -- radioactivity, coliform organisms, etc., for example -- are analyzed weekly, others monthly and semi-monthly. Determinations are made also about twice during each year for trace elements in composited samples.

Organic chemicals are adsorbed on activated carbon from about 5,000 gallons sampled over about a week's period each month. In the laboratory the organic materials are extracted from the carbon and separated into about 10 fractions, with specific identifications made where possible.

A rapidly developing area of water quality analysis is that of biology. Plankton have been counted and identified, along with protozoa and certain bacteria, including coliform organisms. Expansion into the determination of fish populations and benthic organisms is under way.

This systematized, continuing collecting of basic data is thus providing the most complete picture we have ever had of the quality of our surface waters.

Programs are also under way to provide dependable electronic measuring and recording equipment to monitor several parameters pertaining to water quality at certain stations. This program will provide a more complete picture of the water at those stations than is now available, but will also provide vast quantities of data which must be reduced to usable form.

This brings us to the important role you, the statisticians, play -- the processing of data to make it usable and understandable.

Data Handling

With but five years of data available from our as yet limited number of stations, we can make only limited determinations of trends and correlations as yet. But, of course, we must be working to sort and solve the problems which must be overcome to enable complete analyses of figures.

Defining water quality is one major task confronting us. What is the quality of our Nation's waters? Is it improving or degrading? Simple questions, but the answers, unfortunately, are far from simple, since no two water users have the same concept of water quality (Figure 2). Domestic users, for example, are concerned with the bacterial purity of their water supply; steel manufacturers are not. High pressure boiler use cannot tolerate a high degree of hardness in water; photographic processors, on the other hand, are concerned not at all with this aspect of the water chemistry. Turbidity is acceptable in low pressure boiler feed water, but not so in most textile manufacturing. Sulfates in water are of little importance to the domestic user, but are certainly unwanted by the pulp and paper manufacturer and must be considered by the farmer irrigating his crops.

Thus, the defining of water quality depends very much on the different water uses. Also, any analysis of water quality must include the natural elements present in waters, and these may vary greatly geographically and geologically. (Figure 3). New Englanders, for example, accustomed to crystal clear recreational waters, may look askance at midwesterners swimming in waters green with algal bloom. Economics may enter the picture, as in certain areas where hard waters affect the use of soap. It has been determined that the savings in the cost of soap will pay for softening of water above 150 ppm hardness.

Selection of sampling location. Care must be taken to locate the Water Quality Network sampling stations where they can continuously provide representative samples of the stream water, and where dependable local assistance can be enlisted in collecting and analyzing samples for the desired parameters. Sampling locations must also satisfy one or more of three criteria: (a) Major waterways used for public water supply, propagation of fish and wildlife, recreational purposes, and agricultural, industrial, and other legitimate uses; (b) Interstate, coastal, and international boundary waters; (c) Waters on which activities of the Federal Government may have an impact.

A site which might answer one requisite, may fail in another. For example, in the lower Mississippi River from Memphis to New Orleans, there are no locations where proper local assistance can be had at sites providing ideal sampling conditions otherwise. Flood is a major problem here, and in those locations where this problem has been overcome, questions exist as to the effects of tributary streams on the collected sample.

The maintenance of usable data presents questions. In what quantities should specific data be collected? How significant are they in the over-all assembly? The chemist, the biologist, and the engineer jointly must decide the importance of present analyses, when to abandon old or begin new analyses. But only the statistical analyst himself can cope with problems involving too-sparse data or the accumulations of large quantities of unprocessed data. The latter may be expected to grow rapidly as automatic instrumentation is installed to monitor water quality.

Constant evaluation of laboratory techniques is important to the successful operation of the National Water Quality Network. Two questions arise in this connection: (a) What is the most dependable technique of analysis for a given parameter, and (b) is the performance of all laboratories such that the data should be published for use by other organizations?

A basis for these evaluations is provided by the Analytical Reference Service of the Public Health Service's Training Program at the Robert A. Taft Sanitary Engineering Center in Cincinnati. It prepares samples for analysis by various interested laboratories throughout the United States, including those participating in the Network. The results are evaluated for laboratory performance and dependability of methods on the basis of the known contents of the samples. Table I shows one such evaluation involving the occurrence of several metals in water samples. Other direct evaluations of techniques are carried out by the Water Quality Section and by the Research Branch of the Division of Water Supply and Pollution Control.

The statistics obtained from analyses made by participating laboratories are presented graphically (Figure 4). These include the standard deviation from the amount of substance added and a 50 percent range. Each laboratory receives a summary report of results. If a participating laboratory falls short of the acceptable limit of accuracy set by our chemists, the laboratory is alerted and corrective suggestions offered to it.

The utilization of water quality data is, of course, the ultimate aim of the Public Health Service's sampling Network. Analyses of data for trends, cycles, unusual values, ecological correlations, and epidemiology directed toward a better understanding of our national water resource is our specific task.

A computer program is being developed to analyze trends, cycles and unusual values. Variations in data from one sample to the next and from year to year may make difficult the detection of such trends and cycles, although some data do lend themselves to such analysis. Figure 5, for example, shows the cyclic nature of plankton population at two stations on the Yellowstone and Columbia Rivers. It also shows upward trends in plankton populations at two stations on the Illinois and Mississippi Rivers. Such elegant and well-defined data are not available at all Network stations, however.

Our data may be interpreted on levels of: (1) the single station, (2) the single main stem of a river, (3) the basinwide system, or (4) the nationwide picture.

Whereas the Figure 5 data demonstrate the cyclic nature of plankton populations found at some stations, and trends found at others, in Figure 6 we see a striking example of a trend in the chloride data collected at Yuma, Arizona.

Plankton data similar to that of Figure 5, but for two stations on the Potomac River, are shown in Figure 7. The plankton populations at the upstream station, Williamsport, are lower and less variable than at the Great Falls Station, which demonstrates a high degree of variability and frequent high populations.

A different type of data presentation is made in Figure 8 for the green alga, Scenedesmus, in the Missouri River.

Populations of coliform bacteria, for years accepted as indicators of fecal contamination, are presented in Figure 9 for the Missouri and Mississippi Rivers. It may be noted that the Missouri enters the Mississippi at St. Louis.

Radioactivity analysis best illustrates data interpretation for the Nation as a whole. Depicted in Figure 10 are the quarterly medians of 47 National Water Quality Network stations operated since the beginning of the Network. Statistics have been applied to test significant changes in radioactivity at some stations, but have not as yet been applied to the data of Figure 10.

Conclusion

It is obvious to a group such as yours that the engineering profession -- and the sanitary engineers in particular -- are faced with a severe problem of defining water quality, of understanding the factors influencing this quality, and of predicting future needs. This appraisal is a great responsibility. The very health of the Nation -- both physical and economic -- is at stake. Our methods of measurement of water quality must be increased in number, improved in sensitivity, and expertly translated into terminology which will give the public adequate information on how clean or how soiled our streams and lakes may be.

The statistician with an understanding of biology and chemistry can definitely contribute to the solution of our many problems. It is urgent that improved approaches to data-handling as well as interpretation be developed continuously in order that the needs of health agencies, industrial groups, conservation interests, and ultimately, the individual citizen can be satisfied.

References

(1) Analytical Reference Service, Public Health Service, U.S. Department of Health, Education, and Welfare. "Analytical Reference Service - Water Minerals No. 3" (1961)

(2) Crow, James F. "Mechanisms and Trends in Human Evolution" Daedalus 90:416-431 (1961)

(3) Kroner, R. C., Ballinger, D. G., and Kramer, H. P. "Evaluation of Laboratory Methods for Analysis of Heavy Metals in Water" J. A. W. W. A. 25:117-124 (1960)

(4) U.S. Senate, Select Committee on National Water Resources "Water Quality Management" in Water Resources Activities in the United States, Print No. 24, (February, 1960) p. 9

(5) U.S. Senate, Select Committee on National Water Resources "Water Supply and Demand" in Water Resources Activities in the United States, Print No. 32, (August, 1960)

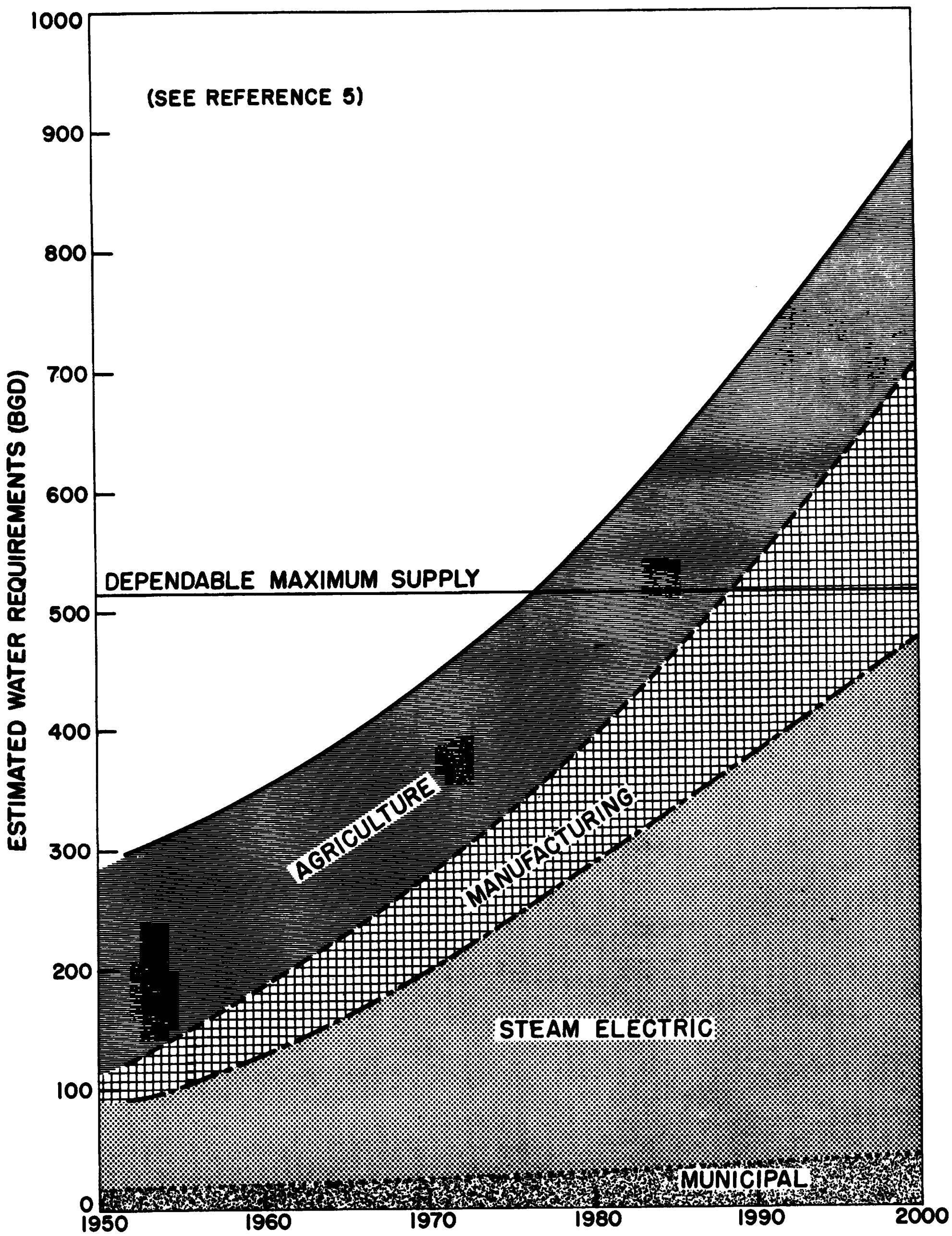
(6) Water Quality Criteria. State Water Pollution Control Board, Sacramento (1952)

TABLE I

(After Kroner et al, Reference 3)

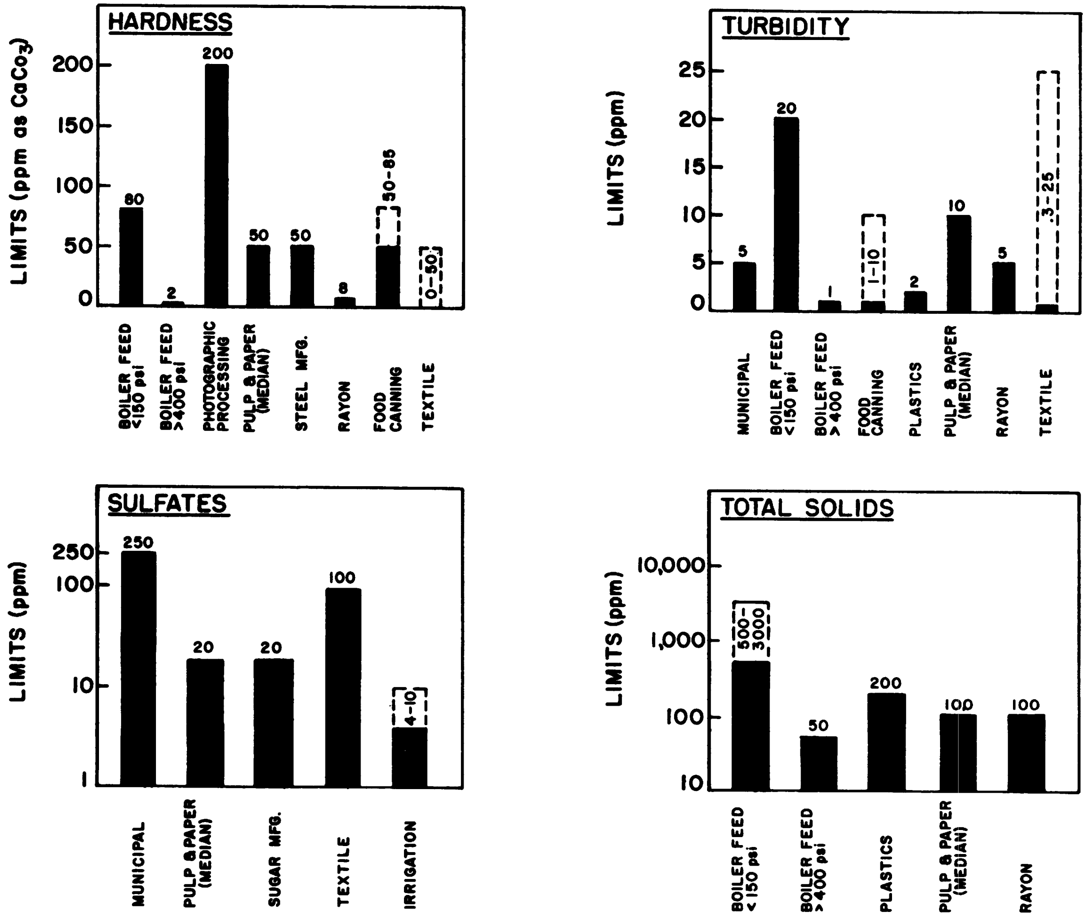
Determination	Method	No. of Laboratories Reporting	Amount Added mg/l	Avg. of Amounts Observed mg/l	Standard Deviation From Amount Added mg/l	Standard Deviation From Amount Added percent
Iron	all methods	17	0.55	0.55	0.126	22.3
	o-phenanthroline	9		0.55		
	bypyridyl	4		0.57		
	tripyridyl	1		0.50		
	thiocyanate	3		0.57		
Copper	all methods	14	0.56	0.60	0.204	36.4
	carbamate	8		0.58		
	cuprethol	5		0.62		
	dithizone	1		0.56		
Manganese	all methods	17	0.20	0.20	0.100	50.0
	periodate	8		0.17		
	persulfate	8		0.23		
	other	1		0.23		
Aluminum	all methods	12	2.00	3.44	1.880	94.0
	aluminon	9		3.47		
	hematoxylin	1		2.52		
	other	2		3.75		
Cadmium	all methods	7	0.16	0.18*	0.061*	38.1
	dithizone	6		0.17		
	polarograph	1		0.25		
Lead	all methods	14	0.12	0.13*	0.40*	33.3
	dithizone	13		0.13		
	polarograph	1		0.18		
Chromium	diphenylcarbazide**	14	0.15	0.13	0.041	27.3
Zinc	dithizone**	11	7.47	7.73	0.979*	13.1

* One atypical result not used in calculation
** Only method used



PROJECTED WATER NEEDS FOR MAJOR WATER USERS IN THE UNITED STATES

FIGURE I



VARIATIONS IN WATER QUALITY NEEDS OF INDUSTRY AND MUNICIPALITY

FIGURE 2

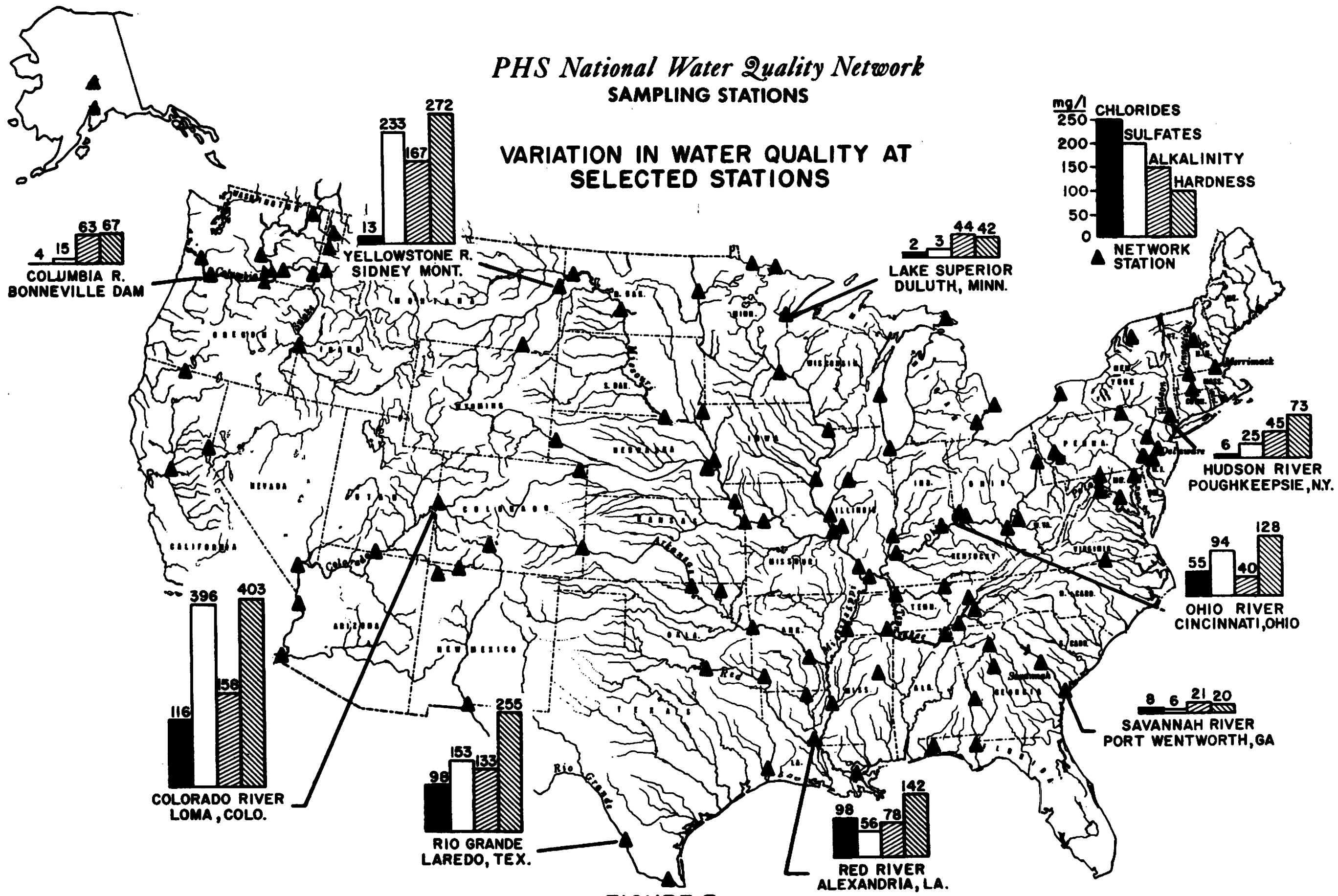
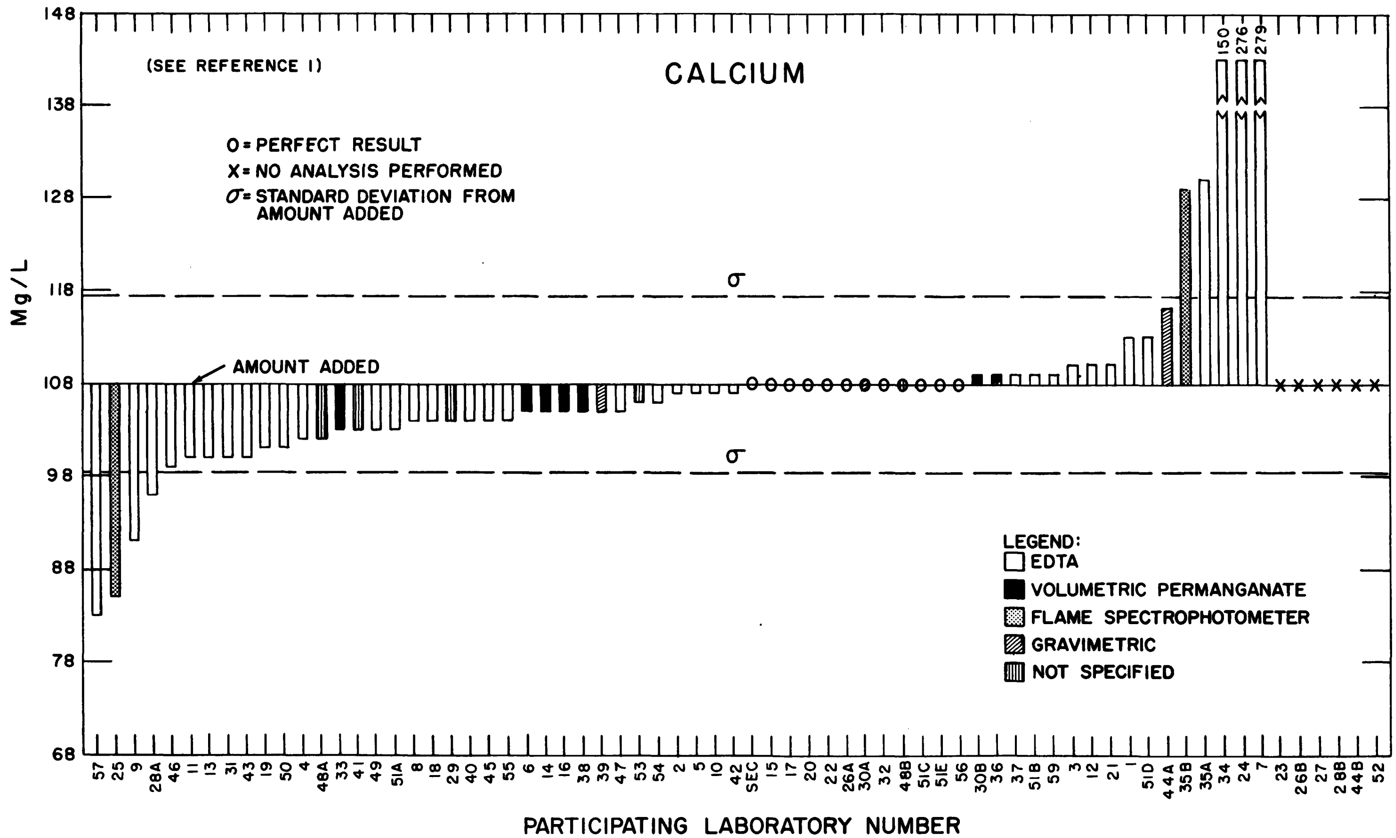
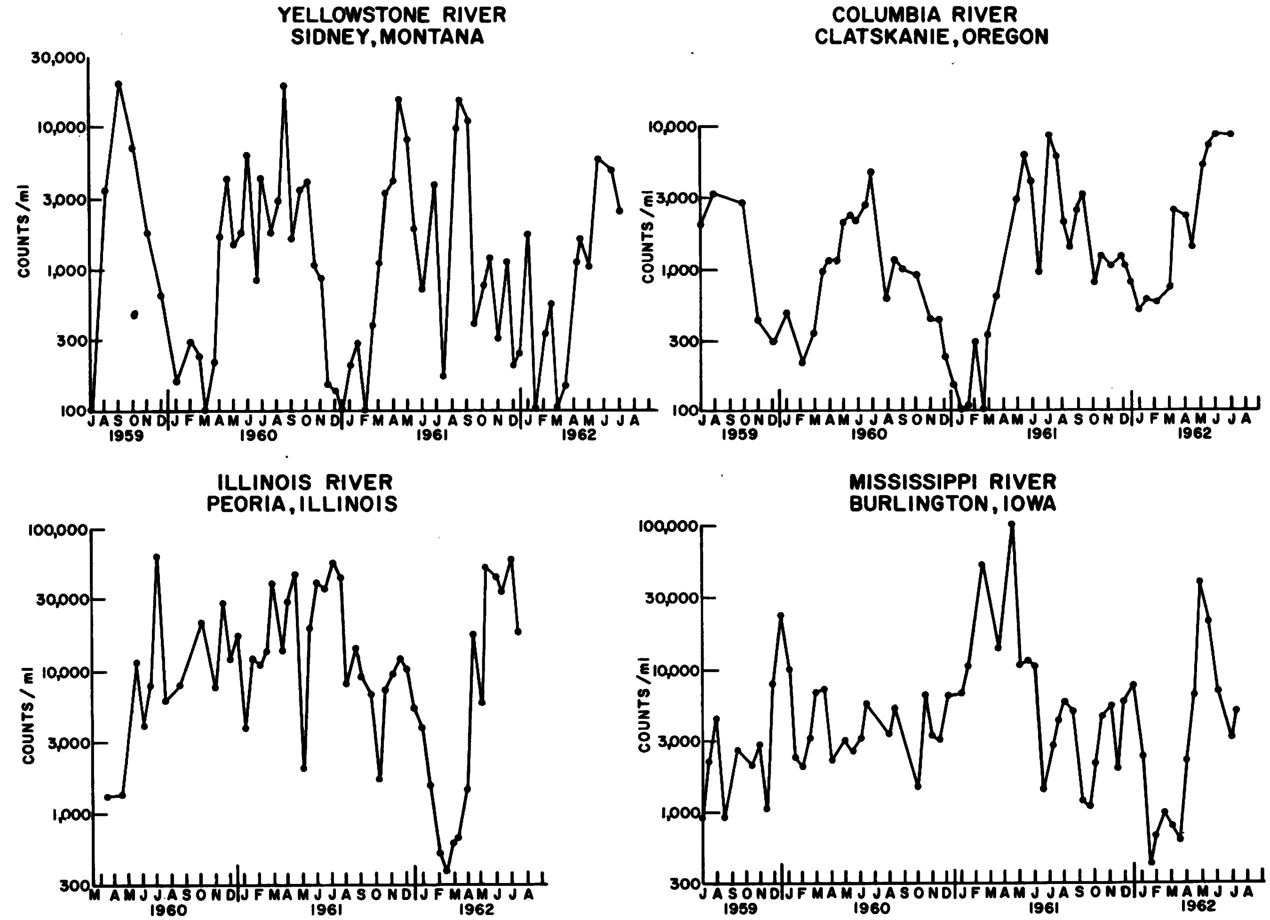

PHS National Water Quality Network
SAMPLING STATIONS
VARIATION IN WATER QUALITY AT SELECTED STATIONS
mg/l
250
200
150
100
50
0
CHLORIDES
SULFATES
ALKALINITY
HARDNESS
NETWORK STATION
4 15 63 67
COLUMBIA R. BONNEVILLE DAM
13 233 167 272
YELLOWSTONE R. SIDNEY MONT.
2 3 44 42
LAKE SUPERIOR DULUTH, MINN.
6 25 45 73
HUDSON RIVER POUGHKEEPSIE, N.Y.
55 94 40 128
OHIO RIVER CINCINNATI, OHIO
8 6 21 20
SAVANNAH RIVER PORT WENTWORTH, GA
116 396 158 403
COLORADO RIVER LOMA, COLO.
98 153 133 255
RIO GRANDE LAREDO, TEX.
98 56 78 142
RED RIVER ALEXANDRIA, LA.

FIGURE 3

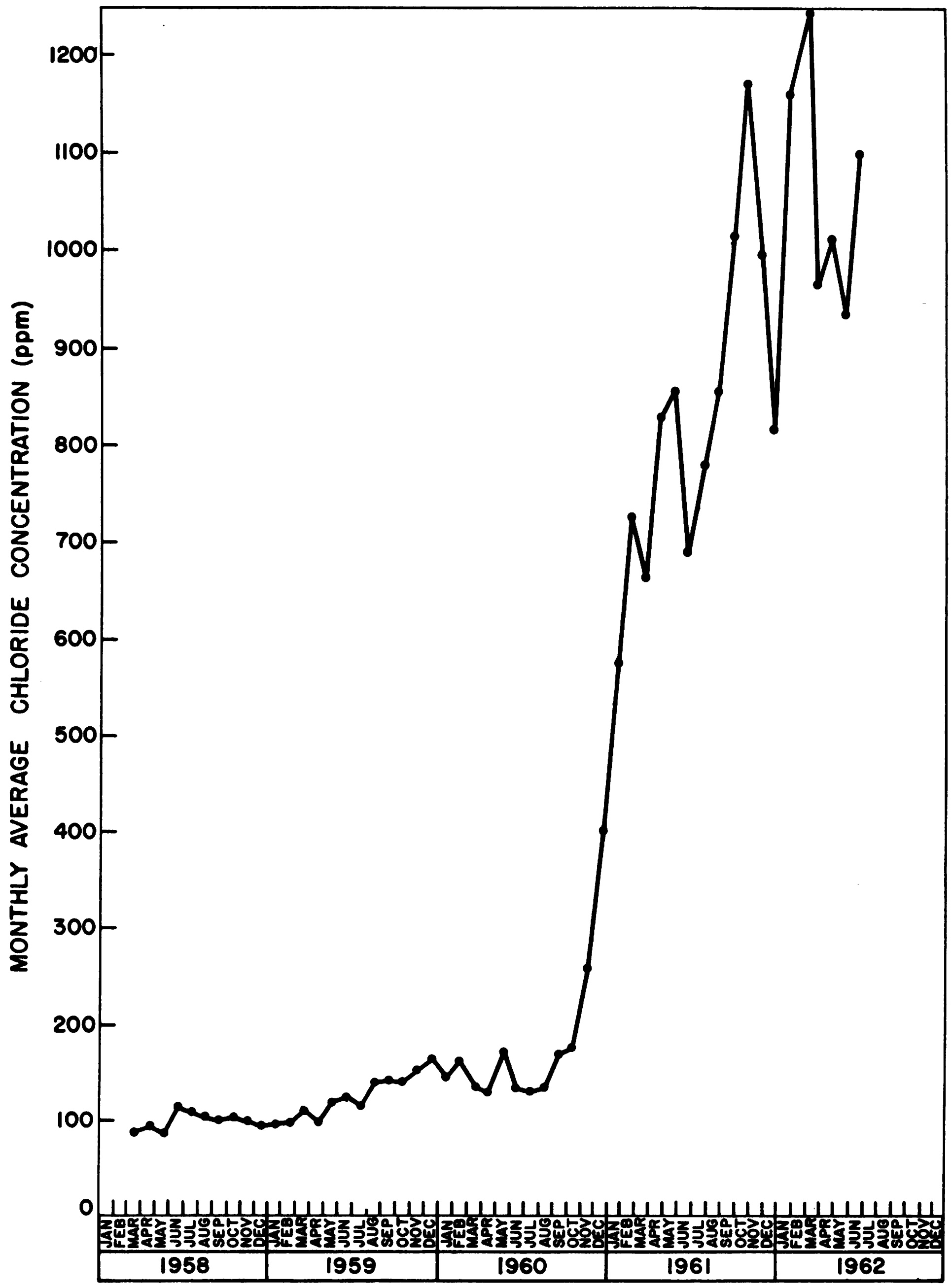


ANALYTICAL REFERENCE SERVICE

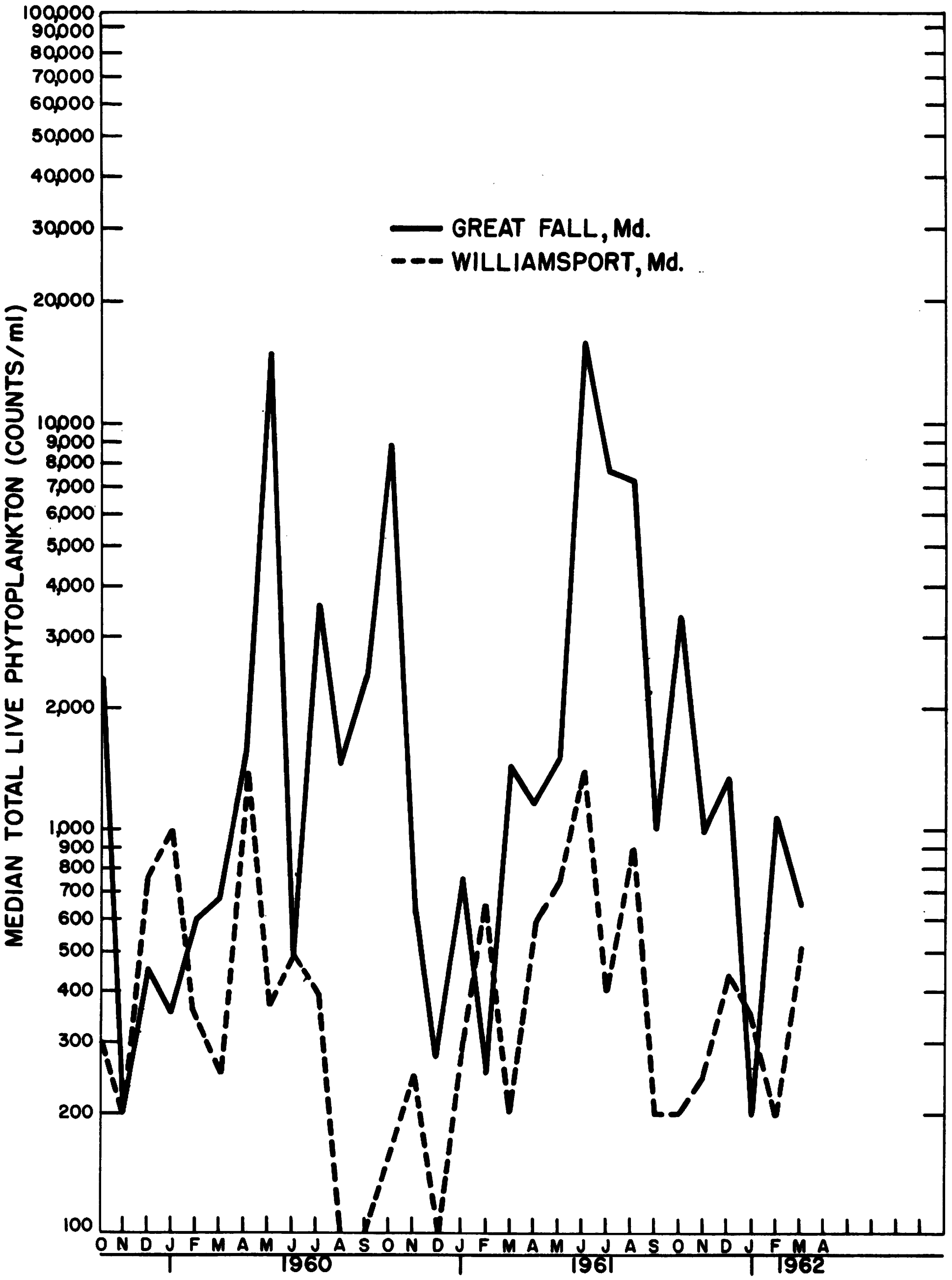
FIGURE 4



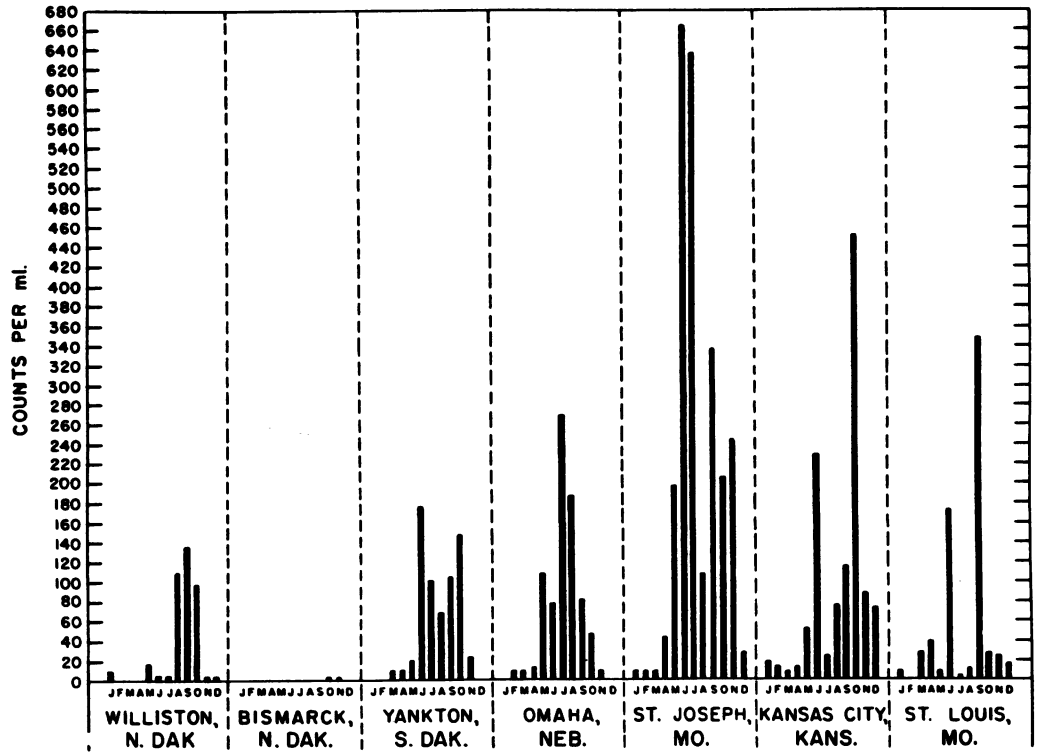
CYCLES AND TRENDS
TOTAL LIVE PHYTOPLANKTON COUNTS
FIGURE 5



COLORADO RIVER AT YUMA, ARIZONA
CHLORIDE VS TIME
FIGURE 6

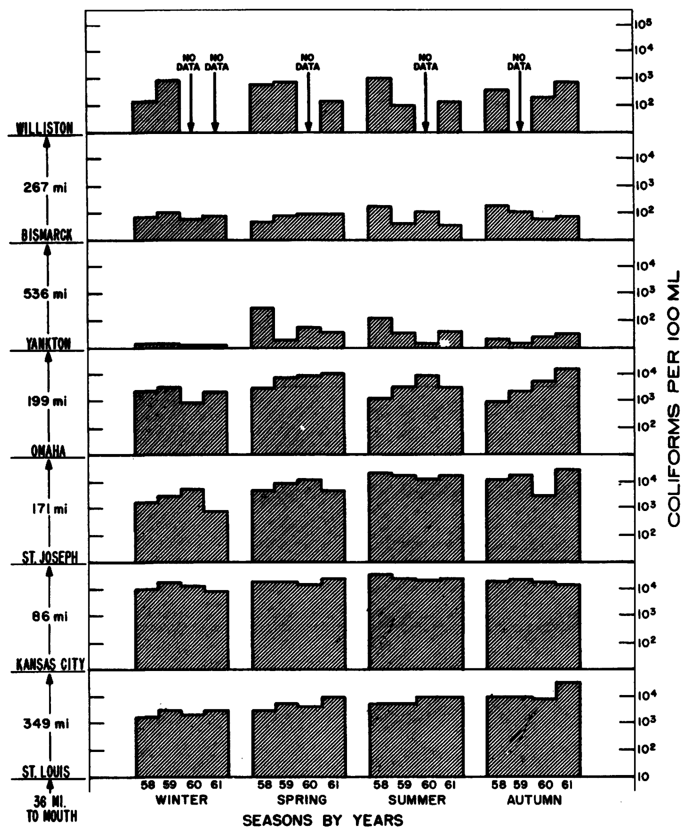


POTOMAC RIVER
MEDIAN MONTHLY TOTAL LIVE PHYTOPLANKTON
FIGURE 7

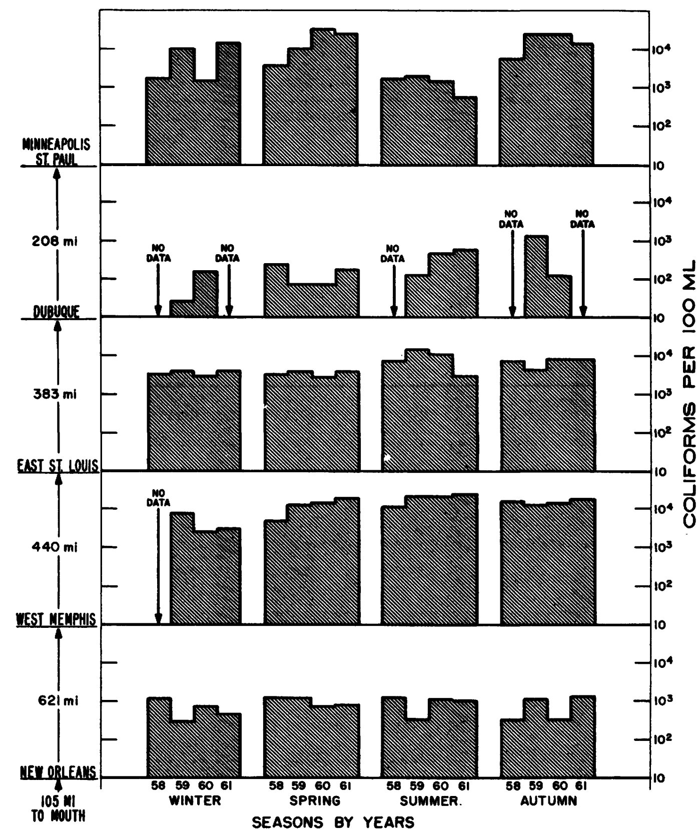


SCENEDESMUS
AVERAGES FOR 1958, 1959 AND HALF OF 1960
MISSOURI RIVER

FIGURE 8

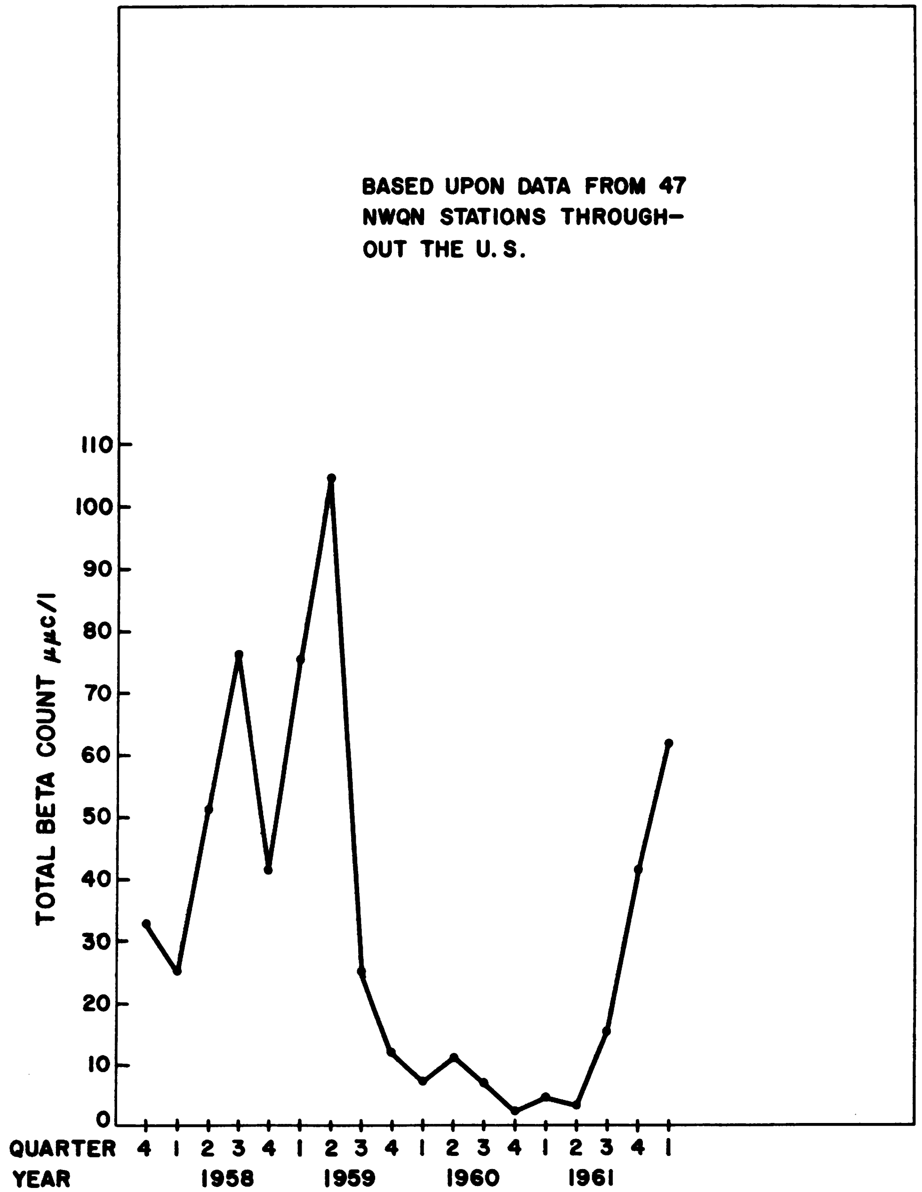


SEASONAL COLIFORM MEDIANS
MISSOURI 1958-1961



SEASONAL COLIFORM MEDIANS
MISSISSIPPI 1958-1961

FIGURE 9



MEDIAN QUARTERLY TOTAL BETA RADIOACTIVITY
IN THE U.S.

FIGURE 10