BACTERIAL-QUALITY OBJECTIVES

for the Ohio River

A guide for the evaluation of sanitary condition of waters used for potable supplies and recreational uses.

OHIO RIVER VALLEY
WATER SANITATION COMMISSION

414 WALNUT STREET   CINCINNATI 2, OHIO

June 1, 1951

To the Chairman and
Members of the Commission:

This is the final report of bacterial-quality objectives for the Ohio River, which you adopted on April 4, 1951 and ordered published. The report sets forth the objectives for both water supply and recreational uses, the manner in which the objectives are to be interpreted, and the background for their validity.

In large measure this report is the work of Harold W. Streeter, U. S. Public Health Service (retired) who now serves the Commission in a consultant capacity. Mr. Streeter, an international authority on water-quality investigations has been studying Ohio River conditions since 1914. Drawing upon this experience and supplementing it with new information gathered by the Commission and its signatory states, Mr. Streeter prepared findings that were scrutinized by your Engineering Committee and other authorities over a period of a year.

The Engineering Committee recommended adoption of these objectives since they provide a sound basis for the Commission to reach decisions on acceptable limits and control of bacterial contamination. Heretofore, the task was complicated by a wide divergence of viewpoints and standards throughout the nation.

Respectfully submitted,

Edward J. Cleary

EDWARD J. CLEARY
Executive Director
and Chief Engineer

Bacterial-Quality Objectives
for the Ohio River

Adopted by the

OHIO RIVER VALLEY WATER SANITATION COMMISSION

on the basis of findings reported by

Harold W. Streeter, Consultant

and approved by members of the Engineering Committee

C. W. Klassen, Chairman
Fred H. Waring
Earl Devendorf
F. Clark Dugan
B. A. Poole
H. E. Moses
M. LeBosquet
W. W. Towne
Edgar Landenberger
O. Lloyd Meehean
Harry K. Gidley
Richard Messer

June 1, 1951

TABLE 1 — SUMMARY OF CERTAIN STATE AND REGIONAL BACTERIAL QUALITY STANDARDS FOR SOURCES OF WATER SUPPLY.

State or Region	Class	Units	Limiting Coliform Numbers per 100 Ml	Remarks
New York	A-1 & A-2	Mo. Av. MPN	50	1
	A-4	Mo. Av. MPN	5,000 and not over 20% samples above 5,000.	2
New England	A	MPN	50	1
Tenn. Valley	I	Geom. Av. MPN	50	1
Authority	II	Geom. Av. MPN	5,000	2
	III	Geom. Av. MPN	20,000	3
Tennessee (state)		Av. MPN	5,000	4
West Virginia	AA	Mo. Av. MPN	100	5
	A	Mo. Av. MPN	1,000	5
	B	Mo. Av. MPN	10,000	3
Indiana	- -	Max. MPN	5,000	
Washington		Av. MPN	50	1
Potomac River	A	Mo. Av.	50	1
Commission	C	Mo. Av.	5,000	2
Incodel	Zone 1	Av.	10% not over 100	5
		Max.	10,000	
	Zone 2	Av.	25% not over 100	2
		Max.	10,000	
Ohio River	Desirable	Mo. Av.	50	1
Committee	Desirable	Mo. Av.	5,000	2
(House Doc.	Doubtful	Mo. Av.	5,000 - 20,000	3
266)	Unsuitable	Mo. Av.	Over 20,000	
U. S. P. H. S.	II	Mo. Av.	50	1
Recommenda-	III	Mo. Av.	5,000	2
tions		Max.	20% over 5,000	
(Bull. 296)				
	IV	Mo. Av.	Over 5,000	2, 3
		Max.	5% over 20,000	

Remarks: 1—Chlorination 2—Filtration and chlorination 3—Auxiliary treatment 4—General sanitation 5—Good sources

OBJECTIVES summarized:

As a guide in the establishment of treatment requirements for sewage discharged in the Ohio River, and as a yardstick for evaluating sanitary conditions in waters used for potable supplies and recreational purposes, the Ohio River Valley Water Sanitation Commission on April 4, 1951, adopted these bacterial-quality objectives:

Water Supply Uses—The monthly arithmetical average "most probable number" of coliform organisms in waters of the river at water intakes should not exceed 5,000 per 100 ml in any month; nor exceed this number in more than 20 percent of the samples of such waters examined during any month; nor exceed 20,000 per 100 ml in more than 5 percent of such samples.

Recreational Uses—For bathing or swimming waters, monthly arithmetical average "most probable number" of coliform organisms should not exceed 1,000 per 100 ml during any month of the recreation season; nor exceed this number in more than 20 percent of the samples examined during any such month; nor exceed 2,400 per 100 ml on any day. For non-bathing or non-swimming waters, the monthly arithmetical average "most probable number" of coliform organisms should not exceed 5,000 per 100 ml in any month of the recreational season, nor should exceed this number in more than 20 percent of the samples examined during any such month.

The limits for potable supply sources are premised on the desirability of a return to normal water-treatment methods (coagulation, sedimentation, rapid-sand filtration, and pre - and/or post-chlorination) with a minimum of chlorine residuals in the finished water, in order to insure palatability as well as bacterial safety of water supplies drawn from the river. Too many water treatment plants must now resort to auxiliary processing as a regular practice because of excessive pollution loads. It cannot be denied, however, that the availability of such facilities for emergency use is highly desirable.

Recommendations for recreational waters are tentative, pending further knowledge of the epidemiology of bathing-water sanitation, and are intended to provide reasonable safeguards to bathers along the river against more serious water-borne diseases. For recreational uses not involving bathing or swimming, a bacterial-quality goal at the water supply level is recommended.

It is recommended that the improved methods of coliform-bacteria enumeration employed in the Commission's Ohio River water quality survey of September, 1950, be adopted as standard procedure for future routine tests in connection with bacterial-quality investigations.

As an aid in the interpretation of these objectives and the manner in which they are to be applied, see the next section for detailed explanation.

INTERPRETATION and APPLICATION

Application of bacterial-quality objectives for the Ohio River involves evaluation of existing pollution levels with reference to those which should be attained to meet potable supply and recreational requirements. Such an evaluation — in terms of coliform-bacterial densities — cannot be expected to be precise in the same degree that is possible with chemical analyses of the river water.

Methods now available for enumerating bacteria of the coliform group are subject to errors far beyond those of chemical determinations, or even of biochemical tests such as "biochemical oxygen demand". This fundamental fact should be kept in mind when interpreting and applying bacterial-quality objectives expressed in terms of "most probable numbers" of coliform organisms. Experienced judgment and common sense, together with a thorough knowledge of local conditions affecting sewage pollution, are essential to a rational application of these objectives.

Averages and single results—According to an estimate by Velz, the upper 95 percent confidence limit for the result of a single-coliform test with three tubes planted in each dilution is 3.6 times the MPN determined from the test. (Velz, C. J., Inservice Training Course lecture, March 14-15, 1949, University of Michigan, School of Public Health, Ann Arbor, Mich.)

If the MPN resulting from the test were 2,300 per 100 ml. there is a 95 percent probability that the true number of coliform organisms in the sample would range up to, but not exceed, 8,300 per 100 ml. An average of 25 results would theoretically narrow the range to one-fifth of that for a single result, bringing the upper 95 percent confidence limit to about 72 percent above the observed mean of the 25 results. This illustrates the statistical advantage of averages versus individual results with regard to their stability and range of error.

Sampling effect—Another source of error in evaluating coliform density in river waters is due to sampling. For ordinary catch-sampling in a well-mixed stream, this error may run 15-20 percent for a single sample. Where the stream is not well mixed across a section, the error may run considerably higher, especially if samples are collected at single mid-stream points. This latter error is variable and practically impossible to evaluate, except by direct measurement in a particular situation. Sampling errors generally are compensating; their range may be greatly reduced by averaging. They probably are of a lower order than those involved in the coliform determination itself.

In the Commission's Ohio River water quality survey of September, 1950, results from coliform tests made on daily samples were obtained for a period of two weeks at 36 sampling points, of which 27 points were located in the Ohio River, and nine points at the mouths of principal tributaries. Methods followed in these tests, carefully standardized by the USPHS Environmental Health Center at Cincinnati, involved planting three tubes in each of three or more dilutions, arranged in decimal series. Results of the standard confirmed test were reported from the survey; 24-hr and 48-hr presumptive results were also recorded. A separate report on this survey has been prepared by the Commission. Reference here is only to a section of the coliform results, which have provided excellent illustrative material for application of bacterial-quality objectives.

Period averages and daily maximums—A summary of the period-average and daily-maximum confirmed results of the coliform tests at each sampling point, together with the percentages of days on which the coliform MPN exceeded 5,000 and 20,000 per 100 ml, respectively, is given in Table 2. A plot of the period-averages at the various sampling points, with ordinates representing the corresponding percentages of samples in which MPN exceeded 5,000 per 100 ml, is given in Fig. 1. A similar plot for the percentages of samples showing MPN's exceeding 20,000 per 100 ml is also given. For those sections of the two curves within an average MPN range up to 20,000, trends of plotted points follow nearly straight lines, and the correlation coefficient in each case is over 0.90, indicating a high degree of correlation in this range.

Inspection of Table 2 shows that average coliform MPN was less than 5,000 at only four sampling points (Nos. 5, E, 26, and 27), though it exceeded this figure only slightly at a fifth point (No. 9). At these five points the frequency of daily samples exceeding 5,000 MPN was 25 percent or less, averaging 14 percent, and the frequency exceeding 20,000 MPN was less than 10 percent, averaging 5 percent.

It is noted that with an average coliform MPN of 5,000 (Fig. 1) intersections of the two curves at this vertical show 20 percent and 5 percent, respectively, as frequency of individual MPN's exceeding 5,000 and 20,000. These intersections have provided a basis for adjusting the "over-run" frequency allowances made in connection with the bacterial-quality objectives recommended for potable supply requirements. They reflect more accurately the natural run of variability in the river's coliform content when measured by the improved method of routine tests followed in the survey of September, 1950.

The maximum daily coliform MPN recorded at any of the five sampling points above noted was 23,000 per 100 ml, being 9,300 at two of them, and 23,000 at the other three points. It thus appears that at average-coliform levels of 5,000 or below, natural variability in the Ohio would tend to limit the daily maximum MPN to about 23,000. Within the range of expected error this approximates the 20,000 level marking the safe-load limit for water-filtration plants using auxiliary treatment.

A further study of the ratios of maximum-to-average MPN's recorded in Table 2 brings out some interesting points concerning the general run of these ratios, and a few divergences from this trend. At all except five of the 36 sampling points, the maximum-to-average ratio was less than 6.0, and at 23 of the points, was less than 5.0. At the five points where these ratios were exceeded, divergence was found to be due to a single exceptionally high daily result in each case, exerting a marked influence on the period average. Although these departures from the general trend of the ratios were a small minority, they raise an important ques-

TABLE 2 — AVERAGE AND DAILY MAXIMUM RESULTS OF COLIFORM DETERMINATION IN OHIO RIVER WATER QUALITY SURVEY — SEPTEMBER, 1950.

Sampling Point No.	Confirmed Coliform MPN Average	Confirmed Coliform MPN Maximum	Ratio Max/Avg	MPN Greater than: 5000/100 ml days	MPN Greater than: 5000/100 ml %	MPN Greater than: 20000/100 ml days	MPN Greater than: 20000/100 ml %
A	24,500	75,000	3.1	11	92	7	58
B	88,700	930,000	10.5	7	58	3	25
1	81,700	230,000	3.0	12	100	12	100
C	14,400	43,000	3.0	8	67	4	33
2	9,600	43,000	4.5	6	50	1	8
3	8,000	23,000	2.9	5	42	2	17
4	15,500	93,000	6.0	4	36	3	25
5	4,400	23,000	5.2	2	17	1	8
6	6,400	23,000	3.6	3	25	2	17
D	321,000	930,000	2.9	12	100	11	92
7	18,400	43,000	2.4	7	58	5	42
8	7,900	43,000	5.5	4	33	1	8
E	3,800	9,300	2.4	3	25	0	0
9	5,300	23,000	4.3	2	17	1	8
10	11,100	43,000	3.9	3	25	6	50
11	40,800	230,000	5.6	7	58	5	42
12	39,900	150,000	3.8	10	83	5	42
13	70,000	430,000	6.2	12	100	10	83
F	162,000	930,000	5.8	12	100	11	92
14	40,900	230,000	5.6	10	83	6	50
15	76,000	430,000	5.7	6	50	4	33
G	192,000	930,000	4.9	8	67	5	42
16	210,000	930,000	4.4	9	75	8	67
17	94,000	430,000	4.6	12	100	11	92
H	11,700	75,000	6.4	3	25	2	17
18	44,400	230,000	5.2	8	73	6	55
19	211,000	2,300,000	10.9	8	67	4	33
20	156,000	290,000	1.9	12	100	12	100
21	14,700	43,000	2.9	9	75	6	50
22	28,000	93,000	3.3	11	92	9	75
23	12,100	43,000	3.6	7	58	3	25
I	29,500	93,000	3.2	9	75	6	50
24	15,100	43,000	2.9	9	75	4	33
25	7,600	23,000	3.0	4	33	2	17
26	3,300	9,300	2.8	1	8	0	0
27	2,500	4,300	5.6	0	0	0	0

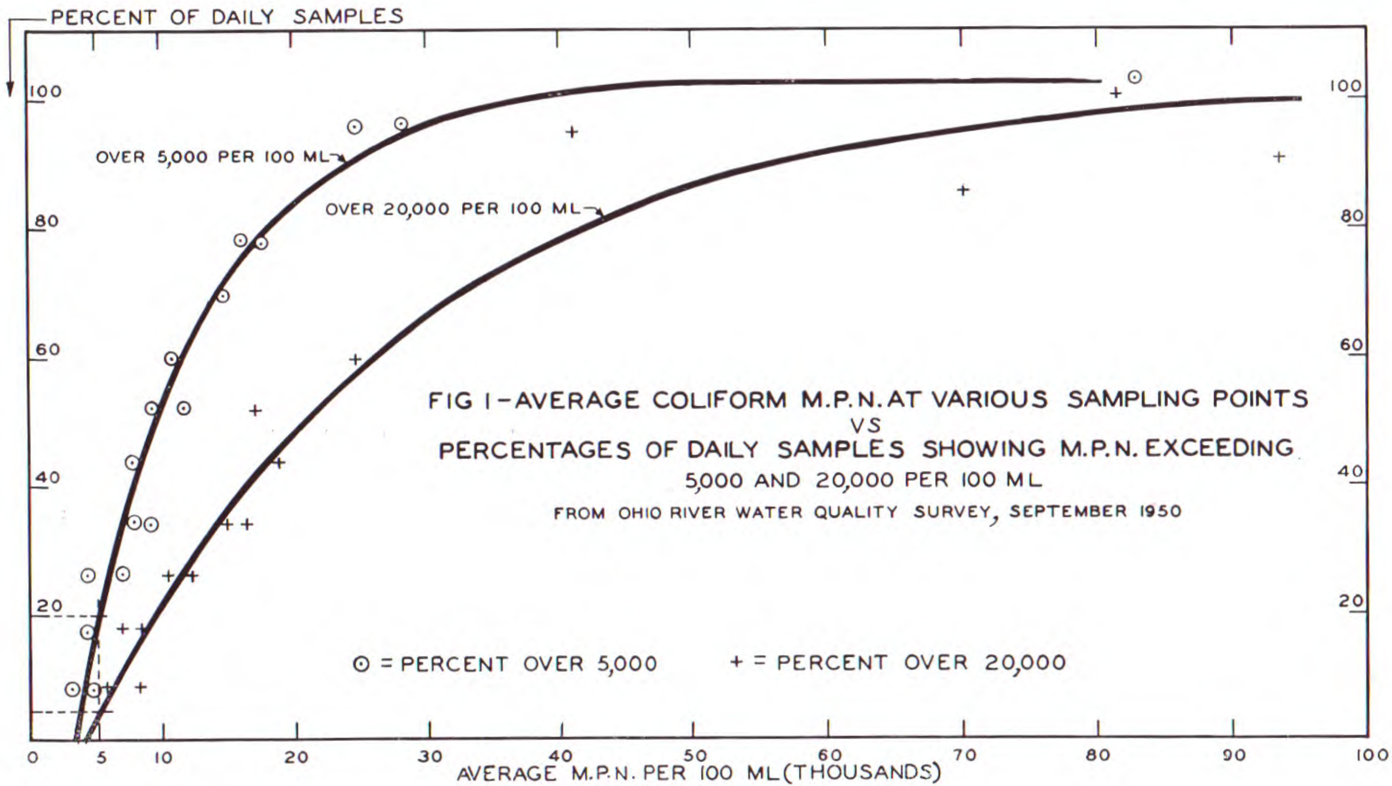

FIG 1 – AVERAGE COLIFORM M.P.N. AT VARIOUS SAMPLING POINTS VS PERCENTAGES OF DAILY SAMPLES SHOWING M.P.N. EXCEEDING 5,000 AND 20,000 PER 100 ML

FROM OHIO RIVER WATER QUALITY SURVEY, SEPTEMBER 1950 tion as to the application of water-supply objectives to situations of this kind. A single high result, far out of line with the others, may exert an undue influence on the average at a given point. It tends to show an average water condition materially worse than otherwise would be indicated.

At three of the five points in question, average coliform MPN's were so high, even excluding single maximum results, that quality of the river water at these points would fail to meet an objective of 5,000 per 100 ml by a wide margin. At the other two points, exclusion of single high results would bring period average only slightly above the objective level. In the first case, it would be immaterial, for all practical purposes, whether or not high results were discarded, as the evaluation would be substantially the same in either event.

No rational conclusion in the second case could be reached until an analytical check had been made to determine whether the exceptionally high result recorded at each point was due to error in the test, or whether its occasional recurrence was normally to be expected at that point. Local sources of pollution might be revealed by a sanitary survey of the immediate drainage area. Any wide departure from the normal maximum-to-average ratio would call for a thorough check on the point in question before any final judgment could be reached.

Recreational waters—Application of bacterial-quality objectives to waters used or intended to be used for recreation involves the same general principles and raises the same questions of interpretation as those arising for water-supply objectives. In this case it would seem that wide departures in daily maximum MPN's from the average run of the data might have greater public health significance for natural bathing waters because of the direct exposure of bathers without the intervention of any artificial purification process. For this reason it has been thought expedient in revising the bathing-water objective, to provide a limiting maximum, subject as it may be to the possibility of wide errors in routine determination. In this case judgment should be exercised in applying such a maximum, lest a bathing water of generally good sanitary quality be unjustly condemned and its recreational values thereby sacrificed.

A check should be made on the coliform-enterococci ratio in accordance with the recommendations of Scott and Clark.

Waters draining agricultural lands—Where the sanitary survey shows a water intake or a bathing area to be definitely unaffected by some source or sources of sewage pollution, as in streams draining solely agricultural lands, the coliform limits herein recommended should be interpreted with considerable latitude.

Need for standard coliform test—A final point to be emphasized in the application of the objectives is the desirability of a concerted effort on the part of the signatory states to bring about at the earliest time practicable the adoption of a standard method of routine coliform tests for Ohio River and its tributary waters based on the same procedures as followed in the Ohio River Commission water quality survey.

This method would involve planting three tubes in each sample dilution, with a sufficient range of dilutions (at least three) to insure an accurate determination of the "most probable manner" in each sample. The standard "confirmed" test should be made on all samples, as prescribed in Standard Methods. Variations in the ratio of confirmed results to those obtained from 24-hr and 48-hr presumptive tests in connection with the September survey were sufficiently wide to suggest that it would be inadvisable to depend on either of these two presumptive tests for comparable results at all stream points.

BACKGROUND and VALIDATION

by Harold W. Streeter, *Consultant*
Ohio River Valley Water Sanitation Commission

In a communication received from the Commission's executive director, under date of March 6, 1950, I was requested to review "available information and practice on the use and validity of bacterial-quality standards as related to water supply and recreational requirements", and "to prepare a report and submit recommendations for the establishment of bacterial-quality objectives for the Ohio River". This report deals with conclusions reached from such a study, and explains the reasons for such conclusions. It follows the general outline of an interim report made to the Engineering Committee of the Commission at its meeting on July 11, 1950, and is modified to incorporate further data.

The study followed two general lines of inquiry:

(1) A review of representative state and regional standards currently proposed to meet the requirements of the two stream uses indicated in the reference; and

(2) An analysis of available research and observational data bearing on the fundamental bases of current standards, and their application to conditions of pollution and water uses in the Ohio River. In this connection, particular attention has been given to the practical aspects of the problem, as viewed from the standpoint of the long-range plans and policies which are understood to motivate the Commission's program for establishing effective pollution control both in the Ohio River and in its tributary streams.

In carrying out the study, advantage has been taken of interchanges in views with the Commission staff, with Mr. M. LeBosquet and his associates in the U. S. Public Health Service and with Mr. F. H. Waring, chief engineer of the Ohio State Department of Health, with whom frequent meetings have been held in connection with another project touching somewhat closely the problems of the Ohio River. These conferences, together with the views of the Engineering Committee obtained at its July 11, 1950 meeting, have been of much value to me in orienting my viewpoint with the general policies of the Commission. Special acknowledgement is also made to Mr. LeBosquet for his kindness in loaning files containing valuable information on stream standards, and also for his helpful advice. Thanks are also due to Messrs. F. M. Middleton and H. F. Clark of the Environmental Health Center at Cincinnati for their kindness in collecting certain bacteriological data for me while visiting water treatment plants along the Ohio River, and also

to Mr. Waring for making available the files at his office containing annual summaries of similar data as reported during past years from plants in Ohio located on the river.

Because of the difference between bacterial-quality requirements for water supplies and for recreational water uses, especially for bathing, this study has been divided into two parts, each dealing separately with its own phase of the problem. In the section of the report which immediately follows, attention will be confined to water supply requirements, and the bacterial-quality objectives which have been and may be established in order to meet such requirements.

Water Supply Objectives

The history of bacterial-quality standards to meet water supply requirements dates back for some thirty-five years in the United States to the International Joint Commission standard, which was adopted in 1914 on recommendation by a board of consulting sanitary engineers headed by the late George W. Fuller. This standard provided in effect that the yearly average coliform bacteria index in the international boundary waters of Canada and the United States as delivered for treatment should not exceed 500 per 100 ml. In recommending this standard the board pointed out that the index would be expected to exceed this limit at times during the year, and to be less at other times. The standard was based on an assumed efficiency of coliform bacterial removal of 99.6 percent by the average filtration plant treating these waters, and the production of an effluent containing not over 2.0 coliform bacteria per 100 ml., the upper limit then provided in the U. S. Treasury Department drinking water standard.

During the period of 1915 to 1916, the U. S. Public Health Service began a series of observational studies of the efficiency of water treatment plants which, after being discontinued because of World War I, were resumed in 1924 and continued through 1929. These studies covered a year's observation of the performance of 31 representative municipal water filtration plants, including 10 plants on the Ohio River, and five year's operation of a large-scale experimental filtration plant at Cincinnati, equipped with modern treatment devices and designed in two parallel sections throughout, so that any two different methods or combinations of treatment could be observed under the same raw water and other conditions. The results of these investigations, published in a series of reports, provided the only available information on the efficiency and limitations of various combinations of water treatment at that time, and have served as the basis for bacterial-quality standards for sources of treated water supplies in many of our states up to the present time.

Within the limits of observational error, it was found that the average water filtration plant of the rapid-sand type, with postchlorination to low residuals (0.05 - 0.30 ppm by the OT test), could deliver an effluent meeting the bacterial requirements of the 1925 drinking water standard (average coliform index not exceeding 1.0 per 100 ml) from raw waters containing an average of not over 5,000 coliforms per 100 ml. For relatively short periods of time, such as a month, this average would not ordinarily be exceeded by a degree sufficient to vitiate its applicability as a working limit, though for longer periods, such as a year, or several months, variations above the average would be greater in degree, and sometimes too high for safety.

In connection with the same series of studies, the effects of certain auxiliary measures of water treatment on the overall efficiency of bacterial removal were investigated. These measures included prechlorination and multi-stage coagulation-sedimentation, both of which have been in use, either separately or in combination, at some plants on the Ohio River. It was found that prechlorination and double-stage sedimentation, when added to normal filtration treatment, would permit higher average numbers of coliform bacteria in the raw water and enable plants thus equipped to take care of temporary overloads of bacterial pollution, ranging up to 20,000 coliform bacteria per 100 ml. or thereabouts. Thus two general levels of permissible raw water pollution were established observationally, the lower one applicable to normal filtration with low-residual postchlorination, and the higher one to the same treatment reinforced by auxiliary measures such as above described, providing a safety factor, when needed, to offset peak loads on the normal filtration process. This was the general concept of the proper function of auxiliary treatment at that time, as an adjunct to normal filtration.

With increased sewage pollution of the Ohio River, and the concomitant problem of industrial wastes pollution, the role of auxiliary treatment has changed gradually from that of a temporary safety measure to one of continuous integration with the treatment process as a whole. This step has brought about a chain of circumstances, ranging from increased chlorine residuals through and after treatment to measures such as aeration, activated carbon treatment, chlorine dioxide treatment, and "breakpoint" chlorination, designed to deal with tastes and odors resulting in part from intensified chlorination, and in part from increased sewage and industrial pollution. Multi-stage coagulation-sedimentation, together with pre-settling, also have been resorted to in an effort to meet increasing bacterial loads.

The past twenty-five years has thus been a record of a continuing struggle to deal with this problem at the water intake, with consequent deterioration in the quality of water supplies except for bacterial content, which has been held down mostly within safe limits as defined by current drinking water standards. With this historical background in mind, a brief review of state and regional bacterial-quality standards for sources of water supply, together with a somewhat more detailed review of the present bacterial efficiencies of a few representative water treatment plants on the Ohio River studies some twenty-five years ago, will follow in the order just named.

State and Regional Standards

In connection with this study, a review has been made of eleven state and regional standards proposing bacterial-quality requirements for sources of water supply. In Table 1 (page 4) is given a summary of these requirements, as taken from the latest source material available. These are the only standards of this character found among the laws and regulations of some forty-odd states relating to the control of stream and lake pollution. A majority of them, it will be noted, are based on recommendations for regional or general pollution control, only five of them having been drawn up for individual states. Eight of the eleven standards named are set up as parts of a classification of streams according to various water uses. In two cases (New England's Class A and Washington's general standard), bacterial-quality limits set for sources of water supply have been based evidently on requirements for waters treated by chlorination alone. In one case (Tennessee), the standard recommended is indicated as a general one for streams of the state, including those used for water supplies after normal filtration treatment. In eight of the standards, a limit of 5,000 coliform bacteria per 100 ml. is given for waters subjected to normal filtration-postchlorination treatment.

In seven of these eight cases, the standard is given as an average, and in one case (Indiana), as a maximum.

In all of the eleven standards, the coliform group of bacteria is taken as the index organism, and is expressed numerically either in terms of the "most probable number", or unspecified. In one standard (T.V.A.) the geometric mean is used rather than the arithmetic mean. In two of the standards (New York and U.S.P.H.S. recommendations), an over-run above 5,000 coliforms per 100 ml. is limited to 20 percent of samples tested, and in the latter case, an over-run above 20,000 per 100 ml., to 5 percent. This is a wise provision in standards expressed as long-term averages, as it places a definite limit on variations above the average. It should take account, however, of the natural variability of a stream or lake in this respect, as otherwise an upper limit may be set which cannot be controlled.

In reviewing these standards, the recurrence of the figure, 5,000 per 100 ml., suggests the influence of the U. S. Public Health Service's studies of the 1920's. It is significant in this connection that this standard has stood for a period of nearly twenty-five years where it has been used, and has in fact gained in favor with the years, having been incorporated into some of the more recent standards. The reason for this survival of an old standard probably lies mainly in the fact that it has served its purpose well, and also that little change has occurred in the basic processes of water filtration since it was originally recommended, though some of them, such as chlorination and multi-stage sedimentation, have been intensified, as previously noted, where excessive raw water pollution has forced such additional defensive measures. That only two of the ten standards reviewed have mentioned a higher coliform limit as permissible with auxiliary treatment suggests that in a majority of cases a definite reservation exists concerning any compromise with a standard which assumes more than normal filtration treatment as a desirable practice. This is a highly significant fact, which should not be lost sight of in the preesnt situation of water treatment along the Ohio River.

Efficiency of Filtration Plants

In view of the marked increase in pollution of raw water supplies in general along the Ohio River during the past twenty-five years, and the consequent necessity for reinforcement of the filtration plants treating these raw waters, an important aspect of this study has been to compare the present bacterial efficiency of a few representative plants along the river with that which was observed at the same plants some twenty-five years ago in connection with the survey previously mentioned. It has been possible to obtain comparable data from only six of the ten plants previously studied, namely, at East Liverpool, Steubenville, Huntington, Ironton, Cincinnati, and Louisville. From records of these six plants, monthly average coliform results for one year from each plant during the period of 1945-1949 have been compared with those obtained at the same plants for a year during the period of July, 1923 through June, 1924, in connection with the U.S.P.H.S. surveys. For the recent period, 1945-49, the years selected have not been in all cases the same, because it has been desired to avoid years in which any material change in treatment has beenmade.

At all of the plants included in this review, coliform enumerations are expressed in terms of the "indicated number" (Phelps index), and in all except the final effluent samples, are determined from fermentation tests with single-tube plantings in decimal series dilutions. As this is the same procedure as was followed in the routine coliform tests in 1923-1924, the results obtained at that time are directly comparable with those at the present time, making some allowance for minor changes in the methods followed in making confirmatory tests. In final effluent and distribution tap samples, the standard test in five 10-ml. portions is the rule, with additional single-tube plantings in 1 ml. in some cases. In general, enumerations of coliform bacteria in raw and other samples up to the final effluent are based on the standard presumptive test. In the final effluent and tap samples, the results are in some cases expressed in terms of the "gas-former" index (48-hour gas), presumptive index (24-hour gas), and confirmed index. In such cases, an opportunity is thus afforded to compare the final results in these three terms.

Of the six plants selected for study, all except the Ironton plant now use high chlorine residuals. At Cincinnati, "breakpoint" prechlorination has been added recently in an endeavor to minimize objectionable tastes and odors. At Ironton, chlorine residuals have remained at less than 0.2 ppm, which is about the same level as in 1923-1924. At the other five plants, residuals have been increased from about the same levels as at Ironton 25 years ago until they now range from 0.3 to 0.8 ppm or more. In some cases an effort is made, through the addition of ammonia, to maintain chloramine residuals throughout the distribution system. In general, tastes and odors in the treated water supplies have been considerably more serious in recent years than they were in 1923-1924, when the major cause of such troubles was the occasional presence of phenols in the river.

It is somewhat difficult to determine whether the intensified difficulties in respect to tastes and odors have been due mainly to increased industrial wastes pollution, increased sewage pollution, or both combined, together with the necessity of using much higher chlorine residuals. Probably all of these elements have exerted some influence. It seems quite likely that if industrial pollution were completely eliminated as a causitive factor in the present taste and odor problem, this problem would still continue to exist in those sections of the river where sewage pollution is high, if only for the reason that intensified chlorination would still be necessary in order to combat sewage pollution at the water intakes.

The exception at Ironton is notable because unusual coagulation-sedimentation facilities, together with the fact that this plant is still working at an output well below its designed capacity, have enabled this plant to meet increased bacterial loads without resorting to heavy chlorination. Incidentally, it is understood that taste and odor troubles have been somewhat less acute at Ironton than in most of the other water supplies along the river, though industrial wastes pollution has caused some increase in these difficulties.

In Table 3 is given a tabulation of the comparative annual average numbers of coliform bacteria recorded in the raw water and final effluent at each plant during the year 1923-1924 and during one year of the 1946-1949 period. Also shown are the same results for each plant during the poorest month of the year, when the confirmed coliform index averaged the highest in the plant effluent. Except at Ironton, it is noted that yearly average coliform numbers have increased measurably in the raw water during the 25 years since 1923-24. It is not clear why this exception at Ironton should exist, unless it may be due to the combined influence of the high dam at Gallipolis, and the effect of the pool above Dam 26, which would tend to retard the lateral diffusion of pollution from Huntington and cause it to follow more closely the left bank of the river. This is borne out by the fact that the yearly average coliform index at Ashland had increased from 11,500 per 100 ml. in 1923-24 to 30,000 per 100 ml. in 1949. In the last

TABLE 3—AVERAGE INDICATED NUMBERS OF COLIFORMS PER 100 ML. IN RAW AND FINAL CHLORINATED EFFLUENT WATERS OF SIX OHIO RIVER FILTRATION PLANTS DURING ONE-YEAR PERIODS.

Plant	Year	Annual Average		Poorest Month Average		% of Raw in Effluent	
		Raw	Effluent	Raw	Effluent	Annual	Poorest Month
E. Liverpool	1949	3300	0.05	8600	0.30	.0015	.0035
	1923-24	2680	.40	3890	1.30	.015	.033
Steubenville	1946	640	.06	4630	.40	.0094	.0086
	1923-24	330	.20	210	.60	.061	.290
Huntington	1947	2260	.04	1510	.13	.0018	.0086
	1923-24	2370	.80	5280	1.60	.034	.030
Ironton	1945	6200	.02	3270	.17	.0003	.0052
	1923-24	14900	.01	19100	3.40	.00007	.018
Cincinnati	1945	4360	.08	8550	.32	.0018	.0037
	1923-24	2980	.50	9910	2.0	.017	.020
Louisville	1949	4570	.14	8900	1.0	.0031	.011
	1923-24	2220	.10	2300	.30	.0045	.013

Note: Raw water numbers based on presumptive tests; effluent numbers on confirmed test.

two columns of Table 3 are shown the percentages of raw water coliforms observed in the final effluents of the six plants during the recent period, as compared with those recorded during the period 1923-24. It is also to be noted that despite the increased bacterial loads during the more recent periods, the average coliform content of the final effluents has been lower than during the period 1923-24. This trend is reflected in the lower percentages of raw water coliforms remaining in the final effluents, as compared with 1923-24.

That this increased bacterial efficiency is due almost wholly to more intensified chlorination is suggested by the results shown in Table 4, in which the average coliform numbers and their residual percentages observed in the unchlorinated filtered effluents of four plants during periods between 1945 and 1949 are compared with those observed in 1923-24. In these four cases direct comparison is possible because the filtered effluent samples during both periods represent the purification efficiencies accomplished by each plant without chlorination. Such a comparison has not been possible with the other plants on the river because of prechlorination not practiced in 1923-24, or because the filtered effluent samples were not directly comparable during the two periods.

It will be noted that two of the four plants show slightly greater, and two of them, slightly lower efficiencies of coliform removal during the two periods. In all cases no marked improvement in filtration process efficiency in itself is indicated. This evidences that the over-all gain in bacterial efficiency of filtration processes along the river during the past 25 years has been accomplished very largely through the more liberal application of chlorine, and not through any material improvement in those features of filtration plant design and operation which in themselves would tend to bring about augmented bacterial efficiencies.

TABLE 4—COMPARATIVE NUMBERS AND PERCENTAGES OF COLIFORMS REMAINING IN UNCHLORINATED FILTER EFFLUENTS OF FOUR OHIO RIVER FILTRATION PLANTS.

Plant	Year	Coliforms per 100 Ml. Raw	Filtered	% of Raw in Filtered
Ironton	1949	5770	0.29	.005
	1923-24	14900	1.6	.011
Portsmouth	1949	2250	3.6	.11
	1923-24	3490	1.7	.05
Cincinnati	1945-48	4330	6.2	.14
	1923-24	2980	3.4	.11
Louisville	1947-49	3400	20.0	.59
	1923-24	2220	17.0	.77

In order to show somewhat more graphically the overall increase in bacterial removals effected by intensified chlorination, the figures given in Table 3 have been utilized to estimate, on the basis of the observed efficiencies, the maximum average coliform numbers in the raw waters as delivered to each of the six plants which would permit the delivery of final effluents containing an average coliform content of not over 1.0 per 100 ml., the limit set by the current drinking water standard, during each of the two periods covered in Table 3. This has been done by the simple process of dividing the number of raw water coliforms by the corresponding number recorded in the final effluent, thus giving the raw water content which would yield a number of 1.0 per 100 ml. in the effluent if the same bacterial removal efficiency should hold at the higher level.

This procedure is of course an approximation, but appears to be justified for purposes of estimate because previous studies have indicated that in general, the bacterial removal efficiency tends to increase with the bacterial loading on a treatment process up to a point where it levels off, and then remains fairly constant at higher loads. In the case at hand, except at Steubenville, where the bacterial load is relatively low in the raw water, the tendency for plant efficiencies to reach a fairly stable level would be expected to be attained at average coliform densities above 2,000 per 100 ml. or thereabouts, which density is exceeded by all of the raw waters except at Steubenville during both of the two periods studied.

On a yearly average basis, the raw water coliform limits thus estimated are shown to range from 11,000 to 66,000 (omitting the result for Ironton as being far out of line with the others), and to average 38,000 during the periods of 1945-49. During the period 1923-24, they ranged from 1,500 to 22,200, averaging 6,500, a figure which incidentally was not far from the coliform limit found for the average Ohio River plant in the U.S.P.H.S. studies carried out at that time. During the poorest months of the two periods, the estimated coliform limit in the raw waters averaged 18,000 for 1945-49, and 4,200 for 1923-24, the latter of which again was not far from the limit observed for the average Ohio River plant at that time.

In this connection it should be noted, however, that during these poorest months the efficiency of three of the six plants studied was such that their estimated limiting average coliform load would tend to approximate 10,000 per 100 ml., ranging from 8,900 to 11,600. Although this indicated load limit doubtless could be increased by more

TABLE 5—ESTIMATED AVERAGE INDICATED NUMBERS OF COLIFORMS IN RAW WATERS OF SIX OHIO RIVER FILTRATION PLANTS GIVING NOT OVER 1.0 PER 100 ML. IN FINAL EFFLUENTS.

(Based on average efficiencies during one-year periods)

Plant	Average Annual		Poorest Month	
	1945-49	1923-24	1945-49	1923-24
E. Liverpool	66000	6500	29000	3000
Steubenville	11000	1500	11000	350
Huntington	56000	2960	11600	3300
Ironton	310000*	140000*	19000	5600
Cincinnati	62000	6000	29000	4960
Louisville	33000	22000	8900	7700
Average	38000	6500	18000	4200

(*) Omitted from average.

highly intensified chlorination, it is nevertheless a significant indication that under conditions of normal operation, with the relatively high chlorine residuals being carried, occasional months occur in which the average plant efficiencies are shown to deteriorate to the extent indicated. (See Table 5)

Discussion

In interpreting the foregoing data, the following indications are noteworthy:

1. Increasing sewage pollution of the river has brought about a general need for augmenting treatment facilities in order to offset increased bacterial loads at the water intakes.

2. This has been accomplished for the most part by adding prechlorination to existing filtration facilities, and by carrying much higher chlorine residuals through the treatment process to the distribution system. Complete plant reconstruction has been undertaken only in two cases, though strengthening of certain stages of treatment has been carried out at several plants.

3. A general increase has been noted in the bacterial efficiency of practically every plant along the river, though most of them have shown a tendency for lowered efficiency during occasional months, sometimes under unusually heavy average bacterial loads, and at other times, under unfavorable conditions, which apparently occur more frequently during periods of marked seasonal changes, though not necessarily closely related to such changes.

4. On the basis of yearly average efficiencies, all except one of the plants studied can produce effluents of average drinking water bacterial quality from estimated raw water coliform bacteria loads ranging above 30,000 per 100 ml., and averaging roughly 40,000. As yearly average data tend to mask significant lapses in the bacterial efficiency of practically every plant studied, they may be considered only as indicating general trends in comparison with average efficiencies observed in 1923-24.

5. On the basis of performances observed during the poorest months of single years, by which is meant the months when the coliform numbers in the final effluents averaged the highest during the year, a somewhat different picture is shown. In this case, the estimated safe limit of coliform loading

would tend to center around 10,000 per 100 ml. for a significantly large proportion of the plants studied. This limit would represent that which could be handled safely under more adverse conditions of plant operation, but with existing facilities for high-residual chlorination. It would not provide in all cases a working factor of safety, though in others a fairly liberal margin in this respect would prevail.

Bacterial-Quality Objectives

In establishing bacterial-quality objectives for the Ohio River to meet water supply requirements, a distinction should be made between those which are tolerable and those which are desirable. From the standpoint of tolerance, a limiting average coliform density of 10,000 per 100 ml. would be adequately safe, but would involve the continued dependence on intensified chlorination as an integral part of every water filtration plant. This in turn would entail a continuance of existing difficulties with unpalatability in water supplies derived from the river, largely as the result of the need for carrying high chlorine residuals into the distribution systems. Although such a condition might be tolerated during emergencies, and treatment plants should be equipped to meet them, it cannot in my opinion be considered as a desirable situation permanently, from the standpoint of the nearly three millions of people who depend on the river as their only source of domestic and industrial water supply.

It has been shown conclusively that normal filtration processes, with low-residual or "marginal" chlorination, can deliver both safe and palatable effluents from raw waters containing monthly average numbers not exceeding 5,000 per 100 ml., provided of course that such waters are free from taste-producing industrial pollutants. In view of plans now underway to reduce and ultimately eliminate all harmful industrial pollution from the Ohio River, a return to normal filtration methods would be a highly desirable concomitant of such a development.

It therefore is recommended that pollution-control measures along the Ohio River and in its tributaries be aimed to meet an ultimate bacterial-quality objective such that the monthly arithmetical average "most probable number" of coliform bacteria in the river at all water supply intakes will not exceed 5,000 per 100 ml. in any month; nor will exceed this figure in more than 20 percent of the samples of raw water examined during any month; nor will exceed 20,000 per 100 ml. in more than 5 percent of such samples.

In making this recommendation, the month has been taken as the period of the average for two reasons. First, it is the shortest common period for reporting bacterial results which will permit a fairly stabilized average to be taken. Secondly, it usually is based on at least 25 daily results from individual tests, and thus involves a range of statistical error which is roughly one-fifth or less the expected error of an individual coliform result. In view of the very large errors of individual results which have been shown to be involved in the ordinary MPN determination, it would be highly unwise, in my opinion, to base any limiting standard on a single maximum expressed in such terms. The month appears to be the best compromise between a period which is either so short as to involve large errors of measurement, or so long that seasonal and other natural variations in the coliform content of a stream would exert an undue influence on an average.

Use of an arithmetic average has been followed in stating this objective because the main statistical reason for using a median, or a geometric mean, namely, a definite pattern of logarithmic skewness in the frequency distribution of individual results, has not been found in the normal trend of these results when taken over periods as short as a month, though various degrees of skewness, highly irregular in pattern, have been noted in some months and at some points, owing to the effect of a few high results. Moreover, in the case at hand, every individual result has its significance in showing the average condition of a stream during short periods of time; hence any tendency to suppress the full effect of even a few high results would tend to distort the true significance of an average, where the public health is so vitally concerned, and where, as in the Ohio River, sewage pollution dominates every situation.

Provision of "over-run" frequency controls in the objective as stated is designed to place a definite limit to the frequency of high results above those which would normally be expected as being due to natural variance in the stream content, at average levels not exceeding 5,000 per 100 ml. A slight revision in these "controls" has resulted from an analysis of the results of the Commission's Ohio River Water Quality Survey of Sept., 1950, in which improved methods of coliform enumeration were followed.

As a rough guide in estimating the degree of reduction in bacterial pollution to meet such an ultimate objective, an analysis has been made of a ten-year record of monthly average raw water coliform densities reported at ten water filtration plants during the years 1926-1935, inclusive. This study has indicated that under normal stream conditions in the Ohio River, an average coliform density of 5,000 per 100 ml. may not be expected to be exceeded in any month of the year if the yearly average coliform density is held within an upper limit of 2,000 per 100 ml. Referring to Table 3, it will be noted that the yearly average coliform densities recorded at the six intakes listed in the table were slightly more than twice this limit at Cincinnati and Louisville during 1945 and 1949, respectively, somewhat over three times the limit at Ironton in 1945, about 65 percent higher at East Liverpool in 1949, very slightly higher at Huntington in 1947, and lower at Steubenville in 1946. At Ashland, Kentucky, however, where the reported raw water coliform index averaged 30,000 per 100 ml. in 1949 (the highest along the river), a reduction of nearly 95 percent in the bacterial load would be required. The excessive load on this plant is quite evidently due to the influence of sewage pollution from the Huntington district, which apparently tends to follow the left bank of the river downstream.

The foregoing recommendation may be criticized on the ground that it is unduly conservative, because it fails to credit the increased bacterial efficiencies which have been developed at the sevral Ohio River filtration plants in a continued effort to combat increased raw water pollution. The provision of added facilities to accomplish this purpose has been an expensive undertaking, and represents a very considerable investment. Some plant supervisors are honestly convinced that the bacterial-quality standards of past years are outmoded, and should be modified so as to take account of the greater bacterial efficiencies of water treatment processes made possible by intensified chlorination, and other auxiliary measures of reinforcement.

In this writer's opinion, the answer to these arguments rests in the simple fact that water consumers along the river are not obtaining the consistently palatable water supplies to which they are entitled, despite the ingenious and costly methods which have been developed in an effort to combat such unpalatability. As the only major change in water treatment has been intensification of chlorination, the inference seems quite clear that this practice lies at the root of present difficulties, though doubtless aggravated by the effects of certain industrial pollution. Reduction of bacterial loads in accordance with the objectives herein recommended would go far to obviate the necessity of heavy chlorination, and thus make it possible, with the improved chlorination techniques of recent years, to produce even more palatable water supplies than were being delivered some 25 years ago.

Pending the time when adequate pollution control has become established in the river and its tributaries, a monthly average coliform number not exceeding 10,000 per 100 ml. in any month should serve the purpose of maintaining reasonably safe water supplies, though at the price of continuation of present practices of intensified chlorination. If sewage pollution of the river could be brought within the boundaries of such a temporary standard, it is possible that at plants equipped with improved coagulation-sedimentation facilities, some reduction in the present high level of chlorine residuals could be effected, and in some cases carried to a level of "marginal" chlorination, as has been done at the Ironton plant during the past 25 years, despite heavy bacterial loads in the raw water. Although a monthly average coliform load up to 10,000 per 100 ml. doubtless could be carried without undue difficulty at practically every Ohio River filtration plant with present equipment, an objective at this level would serve only as a temporary expedient, and in my opinion would not afford a permanent solution of the problem.

Recreational Water Objectives

The approach to considering bacterial-quality objectives to meet recreational requirements is quite different, and in some respects more difficult, than that of water supply requirements. In this case, no background of systematic observation and experiment exists, except a few studies of bathing beaches such as have been made in Connecticut and California, correlating known sanitary conditions with bathing water quality. Although some recent studies instituted by the U. S. Public Health Service have made a more direct approach to the problem by undertaking to correlate bathing water quality with the incidence of water-borne diseases among the bathing population, these studies are still in progress, and may require some time before definite results will be available. In Illinois, a novel approach has been made through a study aimed to correlate sanitary surveys with coliform-enterococcus levels in lake waters. Further results of this study will merit the closest attention, and likewise those of the U.S.P.H.S. Meanwhile it is possible only to review existing standards proposed in several states and regional areas, and attempt to appraise their public health significance as applied to streams like the Ohio River.

In Table 6 is given a summary of 11 state and regional standards for bathing and recreational waters. In five of these standards are parts of classification schemes for natural waters used for different purposes. In 9 of the 11 standards, a limiting coliform bacterial density of 1000 per 100 ml. is given, either as an average or as a maximum. This, in fact, is the most recurrent figure appearing in the standards, and may well be taken as a base line for discussion. For desirable bathing waters, preferred coliform densities range from 50 to 100 per 100 ml. as averages, especially where classification of bathing waters has been adopted or proposed. Between this level and that of 1,000 per 100 ml. seems to be an intermediate zone, in which many stream and lake waters of relatively low degrees of pollution fall. Current bacteriological surveys of some 25 bathing beaches along the Ohio shore of Lake Erie have disclosed a considerable number of beaches comparatively free of local pollution falling into this intermediate class on the basis of their average coliform bacteria counts.

TABLE 6 — SUMMARY OF BACTERIAL-QUALITY REQUIREMENTS FOR BATHING WATERS IN CERTAIN STATE AND REGIONAL STANDARDS

State or Region	Class	Units	Limiting Coliform Numbers per 100 Ml.
New York	B-1	Av. MPN	1000
		Max. MPN	2400
New England	B	Max. MPN	1000
Connecticut	A	Av. MPN	0 - 50
	B	Av. MPN	50 - 500
	C	Av. MPN	500 - 1000
	D	Av. MPN	Over 1000
Tennessee Valley Authority	I	Geom. Av. MPN	50
	II	Geom. Av. MPN	1000*
West Virginia	AA	Mo. Av. MPN	100
	A	Mo. Av. MPN	1000*
Potomac River Commission	B	Av. MPN	50 - 500
		Max. MPN	1000
Indiana	—	Max. MPN	1000
Washington	—	Av. MPN	50
A.P.H.A. Joint Comm. (1948)	—	Av. MPN	1000
		Max. MPN	2400
Ohio R. Committee (House Doc. 266)		Av.	100
		Max.	1000
California		Av. MPN	1000
		Max. MPN	20% samples over 1000

(*) Also for general recreation.

For waters devoted to general recreational pursuits other than bathing, only a few standards have been found in which coliform bacterial requirements are specified. The Tennessee Valley Authority indicates in its recommended standard a limiting average coliform MPN (geometric mean) of 1,000 per 100 ml. for Class II waters, stating that such waters should be good for general recreation. West Virginia's coliform standard for Class A waters also indicates 1,000 per 100 ml. as suitable for general recreation. The Tennessee (state) standard does not specify whether its general coliform limiting average level of 5,000 per 100 ml. also applies to recreational waters, and hence is omitted from Table 6. The New England, Potomac River Commission, Indiana, and Ohio River Committee standards give a coliform density of 1,000 per 100 ml. as a maximum for bathing waters. Among the standards allowing densities in excess of this amount, New York (state) specifies a maximum of 2,400 per 100 ml., and California a frequency of 20 percent above 1,000 which is the limiting average for both of these standards.

It thus appears that in the very few cases where a general recreational standard is given, it is at the same average level as that of a majority of the bathing water standards (i.e. 1,000 coliforms per 100 ml.). A fairly logical reason for this in some cases would be that in general, recreational uses of streams and lakes, especially for camping, picnicking, etc., tend to merge to a considerable extent with bathing uses, as in many cases people will seek for such purposes water areas where bathing is permissible, even if only incidentally to other recreational pursuits. For some types of recreation, notably boating, bacterial-quality requirements should be definitely less stringent than for bathing, as in such cases little or no hazard of human ingestion of the water is involved. Thus along the Ohio River it is common to observe active boating in sections of the river where the quality of the water would permit bathing. For this particular activity, a common-sense view would seem to be that it could be readily pursued, with practically no hazard, in natural bodies of water which in general are fit sources of filtered water supplies, that is, which average not over 5,000 coliform bacteria per 100 ml.

With reference to bathing water standards, special mention has been made of a study by the Illinois Department of Public Health concerning the relation between sanitary surveys and the coliform-enterococcus levels in a lake pollution investigation. In a paper presented in October, 1949 by Scott and Clark*, the authors, from a statistical study of coliform-enterococcus ratios as correlated with a "relative pollution factor" ranging numerically from 1 to 5, concluded that in areas subject to sewage pollution, a satisfactory water would contain: (a) coliform MPN less than 700 if enterococci is 23 or more, or (b) coliform MPN 700 or over, but less than 2,400, if enterococci is less than 23 (all expressed per 100 ml.). In areas not subject to sewage pollution, a satisfactory water would contain: (a) coliform less than 2,400, if enterococci is 23 or more, or (b) coliform MPN over 2,400, but less than 7,000, if enterococci is less than 23. In setting up this scale, the authors in effect have taken an enterococci MPN level of 23 per 100 ml. as the dividing line between significant sewage pollution and pollution resulting from birds, rodents, and land wash.

In a paper given before the American Society of Civil Engineers in January, 1950, Cox** has reviewed the public health significance of bacteriological findings in natural bathing waters. He notes the efforts of bacteriologists to develop more specific tests for fecal bacteria, including tests for "sewage streptococci", indicating that in his view these investigations have not yet developed any tests more specific or of public health significance than the standard plate count and the test for coliform organisms. He concludes that bacterial tests should serve only as a general guide, forming part of the information pertaining to any given bathing beach, and that bacterial standards for natural waters used for bathing cannot be placed on a precise quantitative basis as disclosing the intrinsic quality of the water, or certain public health safety for the bathers. He indicates approval of beach waters in the New York City area if epidemiological data pertaining to bathers, and the sanitary survey, are both satisfactory, and the average coliform content of the water is not in excess of 2,400 per 100 ml., except when the other two criteria justify the use of the lower average of 240 per 100 ml. Cox also points out the well-known distinction between the types of infections con-

*Scott, R. M. and Clark, E. S. Correlation of the Sanitary Survey and the Coliform-enterococcus Levels in a Lake Pollution Investigation. Presented at the Society of Illinois Bacteriologists meeting, Springfield, Illinois, Oct. 13, 1949.

**Cox, C. R. Acceptable Standards for Natural Waters Used for Bathing. Presented before Sanitary Engineering Division, A.S.C.E., January, 1950.

tracted from natural bathing waters and those of artificial swimming pools, the latter including skin, mucous membrane, and other bather-to-bather infections, whereas the former usually are intestinal, resulting from ingestion of the water by bathers.

These two studies, though somewhat contradictory to each other in their specific findings, are illuminating in expressing trends of recent thought on the subject of bathing waters. According to both studies, coliform densities ranging up to 2,400 per 100 ml., or even higher if sewage pollution is known to be absent, are not necessarily out of line with good sanitation, though a rigid interpretation of the Illinois findings would tend to limit the coliform densities to something less than 1,000 if definite evidence of sewage pollution is present.

In connection with the present investigation, a study has been made of the possibility of utilizing the findings of Kehr and Butterfield* several years ago as a rough check on the rationality of various proposed bathing water standards, as viewed from the standpoint of water-borne disease hazards. Without going into their study in detail, it may be noted here that they derived from a number of studies in England, Indonesia, and California, where the successful enumeration of both coliforms and typhoid and para-typhoid organisms was carried out in sewage and sewage-polluted waters at the time of outbreaks of these enteric diseases, a correlation between the morbidity rates from typhoid fever in different areas and the ratios of E. coli to E. typhosa in the sewage and sewage-polluted waters of the areas. Although present typhoid morbidity rates in the Ohio Valley are extremely low, the rates for certain other enteric diseases, such as dysentery and diarrhea-enteritis, are sufficiently high to indicate a carrier reservoir which might be a factor in bathing water sanitation.

According to the U. S. Census mortality reports for various diseases, the average typhoid mortality rate for seven Ohio River states in the years 1945-47 was 0.4 per 100,000 (as compared with a rate of 0.2 per 100,000 in the U. S. registration area). Assuming a morbidity:mortality ratio of 10 to 1, this would indicate a morbidity rate of 4 per 100,000, or 0.04 per 1,000. From Kehr and Butterfield's curve, the corresponding ratio of E. typhosa: E. coli in the sewage and sewage-polluted waters of such an area would be 6 E. typhosa per million coliforms, or about 170,000 coliforms for each E. typhosa organism. This of course is an extremely low infection ratio for typhoid fever, but nevertheless measurable according to the Kehr-Butterfield results.

In order to apply these data to an evaluation of the typhoid hazard in bathing waters of an area, it is necessary to assume the average volume of water ingested per bather per day. For purposes of estimate, let this volume be assumed as 10 ml., which probably would be high for trained swimmers, and low for children. Now let:

R = the number of coliforms per single E. typhosa in the bathing water.

B = the number of bathers per day.

V = the volume of water, in ml. ingested per bather daily.

C = the average coliform content of the bathing water per ml.

Then the chance of exposure (P_e) of (B) bathers to a single E. typhosa on any day is:

$$P_e = BVC/R$$

and the exposure interval, in days, between successive ingestions of a single organism is:

$$I_e = 1/P_e = R/BVC$$

*Kehr, R. W. and Butterfield, C. T. Notes on the Relation Between Coliforms and Enteric Pathogens. Public Health Reports, Apr. 9, 1943. Reprint No. 2469.

For illustration, let us assume R = 170,000; V = 10 ml., and C = 10 per ml., or 1,000 per 100 ml. Then the chance that a single bather would be exposed to ingestion of one E. typhosa organism would be:

$$P_e = 1/1{,}700$$

During a 90-day bathing season, *if he bathes every day*, his risk of exposure would be 90/1700, or 1/19. If he bathes every other day, the risk then will be 1/38.

Butterfield and Kehr estimated that about 2 percent, or one out of every 50 persons exposed to ingestion of a single E. typosa organism, actually contract the disease. On this basis, it may be estimated that our bather's risk of contracting typhoid fever during a 90-day season would be $1/19 \times 50$, or 1/950, a very remote hazard.

From estimates compiled from surveys of water-borne diseases by Wolman and Gorman*, and by Eliassen and Cummings**, it appears that water-borne diarrhea-enteritis morbidity rates tend to average about 20 times those of typhoid fever. In the seven Ohio River states, the ratio based on mortality records was 22 to 1 during the years 1945-47.

If the ratio of 20 : 1 be applied to the typhoid risk for an individual bather, his risk of contracting diarrhea-enteritis during a 90-day season would be 20/950, or about 1/50. This again is a rather remote hazard.

If similar estimates are made for groups of bathers, it must first be assumed that every bather of a group bathes regularly every day, or that a certain proportion of the group bathes daily. For a group of 100 regular bathers, the typhoid risk under the conditions assumed above thus would be about 1/10 for a 90-day season. For the same group, the diarrhea-enteritis risk would be about 2/1 during a 90-day season, again assuming each member of the group to bathe regularly every day. This is of course a tangible hazard, though reduced in proportion to the percentage of the group bathing each day.

When viewed from the standpoint of calculable risk, a bathing water coliform standard of 1,000 per 100 ml. or thereabouts would seem to involve no great hazard for the individual bather, or even for moderate sized groups of bathers. From the computations shown above, it can be readily estimated that a water meeting this standard should provide a high degree of protection for groups of several hundreds of people against typhoid infections, and reasonable protection for smaller groups against diarrheal diseases. Moreover, a standard at this level is probably the most stringent one which could be met in the Ohio River under any conditions of pollution which can be visualized during the near future, even with some degree of pollution control established. Pending the outcome of future epidemiological studies of bathing waters, it probably would be the most logical tentative objective at which immediate measures of pollution control could be aimed. If adopted as a tentative objective, however, it should be properly safeguarded against excessive "over-run", both in degree and in frequency.

It is therefore recommended that for bathing and other recreational requirements other than boating, a bacterial-quality objective be established tentatively for the Ohio River under the following conditions:

Waters suitable for this purpose should show a monthly arithmetical average "most probable number" of coliform bacteria, not exceeding 1,000 per 100 ml. in any month of the normal bathing

*Water-borne Outbreaks in the United States & Canada 1930-1936. AP.H.A. Annual Year Book, Vol. 20, No. 2.

**Analysis of Water-borne Outbreaks, 1938-45. Jour. Am. W. W. Assoc., May, 1948.

season, nor exceeding this number in more than 20 percent of the samples examined during any such month; nor exceeding 2,400 per 100 ml. on any day.

For general recreational purposes not involving the use of the river waters for bathing or swimming, a monthly average "most probable number" of coliform bacteria not exceeding 5,000 per 100 ml., nor exceeding 5,000 per 100 ml. in more than 20 percent of the samples examined during any month of the recreation season, is recommended as a minimum bacterial-quality requirement.

As to the significance of the term "average" as used in this recommendation, it is intended to mean the ordinary arithmetic average. This is done not to exclude, or minimize, the full effects of wide deviations from the average which in the case at hand are believed to be of definite public health significance.

The above recommendations are a compromise between that which would be desirable and that which is administratively practicable. They represent the best judgment of this reviewer after considering the problem from several different angles.

OHIO RIVER VALLEY WATER SANITATION COMMISSION

AN INTERSTATE AGENCY

ESTABLISHED JUNE 30, 1948