OHIO RIVER

Pollution-Abatement Needs

Cincinnati-Cairo Stretch

These findings on treatment requirements for maintaining oxygen and bacterial-quality objectives form part of the comprehensive plan of the . . .

OHIO RIVER VALLEY
WATER SANITATION COMMISSION

OHIO RIVER VALLEY WATER SANITATION COMMISSION

An interstate agency representing Illinois, Indiana, Kentucky, New York, Ohio, Pennsylvania, Virginia and West Virginia.

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OHIO RIVER VALLEY
WATER SANITATION COMMISSION

414 WALNUT ST. CINCINNATI 2, OHIO

To the Chairman and
Members of the Commission

A staff study has been completed relating to water-quality conditions in the Cincinnati-Cairo stretch of the Ohio River and directed toward determining requirements for the treatment of sewage. Findings from this study have been reviewed by your engineering committee and it has approved the conclusions reached.

This report sets forth the findings and the recommendations for treatment. Since the latter calls for a degree of treatment higher in some places than the minimum specified in the compact, the Commission authorized at its meeting of October 7, 1953 the conduct of a public hearing in accordance with procedures outlined in Article VI of the compact. The hearing will be held in Louisville, beginning on December 8. Members of the hearing board are: Kentucky commissioner Henry Ward, chairman; Indiana commissioner Joseph L. Quinn, and Illinois commissioner W. H. Wisely

Evaluation studies and preparation of the report were assigned to Harold W. Streeter, staff consultant. He was assisted in the development and compilation of data by Robert K. Horton, sanitary engineer. Illustrations were made by Elmer Rohmiller, staff assistant.

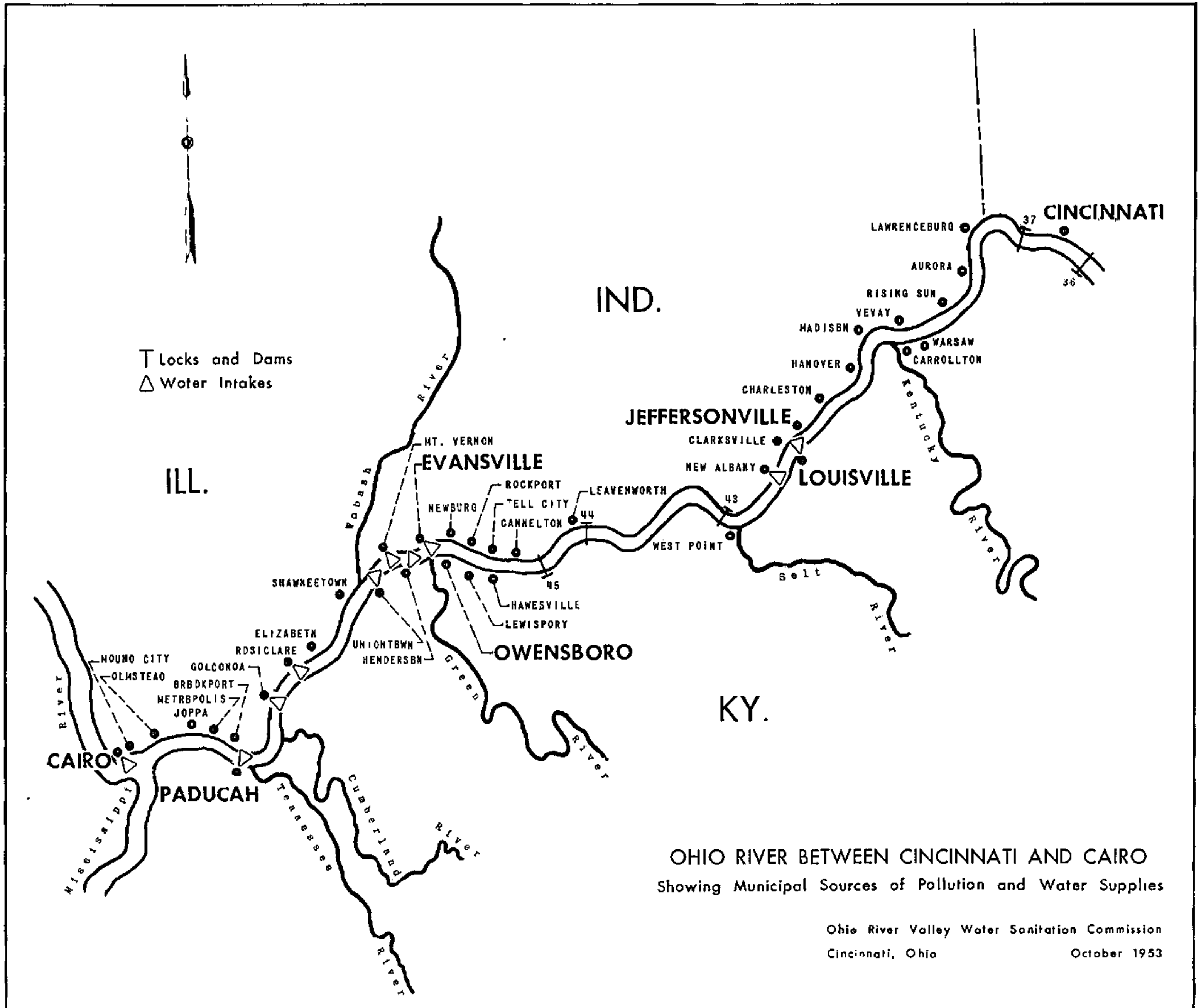
Respectfully submitted,

Edward J. Cleary

EDWARD J. CLEARY
Executive Director
and Chief Engineer

November 1, 1953
Cincinnati, Ohio

Contents



OHIO RIVER BETWEEN CINCINNATI AND CAIRO

Showing Municipal Sources of Pollution and Water Supplies

Ohio River Valley Water Sanitation Commission

Cincinnati, Ohio — October 1953

OHIO RIVER POLLUTION–ABATEMENT NEEDS

Cincinnati–Cairo Stretch

RECOMMENDATIONS

This investigation has been made for the purpose of evaluating pollution conditions resulting from the discharge of sewage into the Ohio River between Cincinnati (Dam 37) and Cairo Point (near the junction of the Ohio and Mississippi rivers). It has been directed toward the determination of sewage-treatment requirements necessary to maintain satisfactory sanitary conditions in the river, as provided in Article I of the Ohio River Valley Water Sanitation Compact.

Article I of the Compact pledges the eight signatory states to take such action that the waters within the compact district shall be placed and maintained in satisfactory sanitary condition, available for use as public and industrial water supplies, suitable for recreational purposes, capable of maintaining fish and other aquatic life, free from nuisance, and adaptable to other legitimate uses. The sewage-treatment requirements recommended in this report are intended to achieve these objectives. As in previous reports dealing with other stretches of the Ohio River, dissolved oxygen conditions and bacterial quality in terms of coliform bacterial densities in the river have been considered in this report as primary indicators of sanitary conditions.

It is recommended that the following standard of treatment, subject to revision as changing conditions may require, be established for all sewage from municipalities or other political subdivisions, public or private institutions or corporations, discharged or permitted to flow into that stretch of the Ohio River extending from Dam No. 37, located about ten miles below Cincinnati and being 483.2 miles downstream from Pittsburgh, to Cairo Point, located at the confluence of the Ohio and Mississippi Rivers and being 981.0 miles downstream from Pittsburgh:

(1) Substantially complete removal of settleable solids; and

(2) Removal of not less than forty-five percent of the total suspended solids; and, in addition

(3) Treatment of all sewage discharged into that section of the river extending from Mile Point 750 (miles below Pittsburgh) to Mile Point 803 so as to provide for reduction in coliform organisms in accordance with the following schedule:

Not less than 85 percent reduction during the months May through October.

Not less than 65 percent reduction during the months November through April.

PURPOSE and SCOPE

This report is the fourth of a series concerned with treatment requirements for wastes discharged to the Ohio River. The purpose of the report is to present findings on sewage pollution conditions in a 500-mile stretch of the river extending from Cincinnati to Cairo, and to submit recommendations for corrective measures that can be considered at a public hearing.

The recommended measures apply only to the control of sanitary sewage discharges as referred to in the second paragraph of Article VI of the Compact. Requirements as to the control of pollution from industrial waste discharges will be detailed in subsequent reports.

The section of the Ohio River with which this investigation deals may be defined as that extending from Dam No. 37, located about ten miles below Cincinnati and being 483.2 miles downstream from Pittsburgh, to a point near Cairo, Ill. (known as Cairo Point) located at the confluence of the Ohio and Mississippi Rivers and being 981.0 miles below Pittsburgh.

Eleven municipalities in this stretch obtain their water supplies directly from the Ohio River. The total population thus served is estimated as being approximately 650,000 (see Table I).

In evaluating conditions in this stretch of the river, it has been necessary to consider the effects of wastes discharged to the river in the Cincinnati pool (mile 460.9 to mile 483.2). These wastes constitute a major part of the total pollution load imposed on the lower half of the Ohio River. This investigation has taken into account the present influence of such discharges on quality conditions, and also the effects that might be expected once these discharges are treated in accordance with already-established requirements.

Wastes discharged into the Cincinnati-Cairo stretch of the Ohio River (including those discharged in the Cincinnati pool) have a total population equivalent in terms of bio-chemical-oxygen-demand (BOD) of 3,550,400. The total sewered population is 1,373,200. These figures are estimated as of the year 1950. Major sources of pollution are shown in Table II.

Sewage-treatment requirements have been evaluated with reference to the need for establishing and maintaining quality conditions in the Ohio River that will satisfy general requirements of the Compact as set forth in Article I. This has meant that consideration be given to the following three criteria of water quality:

(1) a dissolved oxygen content suitable for normal aquatic life, natural-purification processes, and other legitimate uses;

(2) a bacterial quality suitable for water supplies; and

(3) a bacterial quality suitable for recreational uses, including bathing.

These criteria are the same as those dealt with previously in the reports on the Huntington-Cincinnati and Pittsburgh-Huntington stretches of the river, titled "Ohio River Pollution-Abatement Needs - Huntington-Cincinnati Stretch", dated February 1952; and "Ohio River Pollution-Abatement Needs - Pittsburgh-Huntington Stretch" dated March 1953.

The present investigation has involved a study of existing oxygen-demanding loads imposed on the river, and a determination of maximum allowable loads at critical points and with critical stream flows. It also has included a study of coliform-bacteria concentrations at or near certain waterworks intakes for which reliable data have been available, the conditions under which these concentrations exceed quality objectives adopted by the Commission, and the corrective measures that should be applied to upstream sewage discharges to bring these concentrations within the adopted limits.

Finally, the investigation has concerned itself with areas that might lend themselves to recreational uses, and the extent to which sewage treatment will be necessary in order to utilize such areas during the recreation season. In this latter connection the degree of recreational benefit that will result from sewage-treatment measures aimed only at protecting water supplies also has been considered.

Basic information on pollution loads has been obtained from the Ohio River Pollution Survey Report (House Document 266, 78th Congress) ; from the most recent available data in the U. S. Public Health Services "Inventory of Water and Sewage Facilities"; from the 1950 U. S. Census report ; from surveys made by the Commission, and from available records of raw-water quality at waterworks intakes, including data collected by the Water Users Committee of the Commission.

HYDROMETRIC DATA

Discharge records for the U. S. Geological Survey gages at Louisville, Ky. and Metropolis, Ill. were used as the basis for flow-probability studies. These gages are located in the upper and lower sections of the Cincinnati-Cairo stretch, and they provide the longest continuous records of any of the gaging stations on the Ohio River in this stretch. For intermediate points, flow estimates have been based on drainage area ratios as referred to Louisville or Metropolis.

From these records the following data were tabulated for each year from 1934 to 1949, 1949 being the latest year for which final flow records are available: Minimum daily flow, minimum weekly flow, minimum two-week flow, and minimum (calendar) monthly flow. These data are shown in Table III. From the tabulation it will be noted that the various minimum flows recorded during the 16-year period are as follows:

	Louisville	Metropolis
Minimum day	4,090	20,600
" week	6,400	27,000
" two-weeks	6,880	30,000
" month	8,590	35,000

Flow adjustment for reservoir operation

The recorded flows given in Table III have been adjusted to show the effect of low-flow regulation from multiple-purpose reservoirs in the upper watershed of the Ohio River. Adjustments have been made in accordance with procedures followed in previous investigations on the Pittsburgh-Huntington and Huntington-Cincinnati stretches of the Ohio River.

Adjusted flows are shown in Table IV. The months during which low-flow increases may be expected are June through October.

In making these adjustments, consideration has been given only to those reservoirs already in operation, or to those now under construction. No allowance has been made for reservoirs which have been proposed, but construction of which is uncertain.

Reservoirs providing low-flow regulation and the amount of flow increase from each are detailed in Table V. The values of flow increase shown in the tabulation are believed to be conservative. This information has been supplied by the Ohio River Division of the U. S. Corps of Engineers.

Drought-flow probabilities

On the basis of adjusted flow records, (Table IV), studies were made to determine the probability of droughts of varying severity. These studies were made in accordance with Gumbel's statistical theory of extreme values. Results of these studies are shown in Table VI.

Critical flow duration

For the evaluation of oxygen conditions the minimum weekly-average flows have been used, as representing approximately the time of passage of pollution through the critical sections of the river below the major sources of pollution, such as the Cincinnati and Louisville areas, where oxygen depletion is greatest.

In the studies of bacterial conditions from Cincinnati to Cairo, the calendar monthly average flows have been used. The reason in this case is that the bacterial-quality objectives adopted by the Commission are expressed in terms of average coliform bacterial concentrations during a calendar month.

Time of flow

Time-of-flow data used in the analysis of oxygen and bacterial conditions in the river were obtained from a Commission report entitled "The Ohio River Estimates of Time-of-Flow", prepared by Edgar Landenberger of the U. S. Corps of Engineers and a member of the Commission's engineering committee. Mr. Landenberger's work is based on hydrometric observations made in connection with the 1939-40 Ohio River Pollution Survey of the U. S. Public Health Service (House Document 266, 78th Congress).

In this report, Mr. Landenberger developed a graphical method for showing times-of-flow from points of origin in three sections of the Ohio River by a series of slope-lines plotted on a horizontal river mileage scale, and with ordinates representing time-of-flow in hours. The general slope of each line is determined by the total time-of-flow through the section corresponding to a given discharge as indicated by the reading at a reference gage sensitive to changes in flow. (The basic method is described in Mr. Landenberger's report).

In the present case, however, the Ohio River discharge curves used by Mr. Landenberger have been utilized (rather than tributary reference-gage readings) as being more directly correlated with times-of-flow especially in low stages of the river.

Stream temperature

Stream temperature data for these investigations were obtained from the Ohio River Pollution Survey report of the U. S. Public Health Service (House Document 266), and from results of current surveys by the Commission's Water Users Committee at certain waterworks intakes. For seasonal periods, stream temperatures have been averaged by months during such periods

OXYGEN CONDITIONS

Sources of pollution

Estimated biochemical-oxygen-demand (BOD) loads discharged into the river between Cincinnati and Cairo are shown in Table II for the years 1940 and 1950. The table also gives the 1940 and 1950 census and estimated-sewered populations for each major source of sewage pollution.

No attempt has been made to list all individual sources of pollution, such as isolated industrial plants, or smaller unsewered or partially sewered communities. The data for the main sources listed include, however, both sewage and industrial waste loads discharged either through municipal sewers, or directly into the river, so far as available information is at hand. Population equivalents of waste loads have been estimated on the basis of 0.25 lb. of total first-stage biochemical oxygen demand (BOD), or 0.17 lb. of 5-day BOD, per capita daily.

In compiling Table II, the 1940 and 1950 census populations were taken from the reports of the U. S. Census Bureau. The 1940 sewered populations and population equivalents were derived from data published in House Document 266, 78th Congress, Part II, Table OH-3, page 212. The 1950 sewered populations and population equivalents were estimated in part from the 1940 figures, adjusted for changes in census population, and in part from additional information furnished by the states of Indiana, Kentucky, and Illinois.

As shown in Table II, about 90 percent of the total census population located on the river between Cincinnati and Cairo is resident in these main centers: Cincinnati, Louisville and Evansville. The Cincinnati area, with a population of 628,381, made up 48 percent; the Louisville area, with 419,065, 32 percent; and Evansville, with 128,636, 10 percent.

On the basis of population equivalents, the Cincinnati area contributed 55 percent of the total BOD load; the Louisville area, 34 percent; and Evansville, 6 percent. From these figures it is apparent that sewage and industrial pollution from the other communities, amounting to less than 10 percent of the total, is a comparatively small element in the total BOD load.

Oxygen profiles

The trend of dissolved oxygen in the river under summer low-flow conditions is shown in Figure 1 by the lower profile. This profile is based on load data shown in Table II, and has been drawn at the minimum weekly average river flow occurring once in ten years (7,410 cfs at Louisville gage), and at a river temperature of 25 degrees Centigrade. The upper profile shows the effect of a uniform 35% reduction in BOD.

These profiles have been calculated by means of the oxygen sag formula, adjusting the BOD load at each successive source of pollution. Although it does now show the absolute dissolved-oxygen minimum points below Cincinnati and Louisville, it indicates them approximately at Lawrenceburg and Dam 43 (mile 633.2), respectively. In computing the profiles, allowance has been made for residual BOD in the river above Cincinnati.

It will be noted that the effect of the BOD load discharged at Evansville is small as compared with the effects of loads from Cincinnati and Louisville, reflecting both the lesser Evansville load and the greater volume of river flow at this point.

The profiles take no account, however, of the deoxygenating effect of sludge deposits in the river, which would tend to reduce the dissolved oxygen levels to somewhat lower amounts than shown in the lower profile immediately below major sources of pollution, during and following prolonged low stages of the river. This deoxygenating effect was shown in the results of river examinations carried out in the Commission-sponsored survey of the river in September, 1950. It has not been included in the calculations for the profile because of the presumption that the accumulation of organic sludge deposits will be to a large extent eliminated if the minimum Compact requirements for the removal of settleable solids from all sewage discharged into the river are met.

From the profiles it is evident that the only serious sources of oxygen depression in the river during summer low-flows are immediately below Cincinnati and Louisville, where definite oxygen-sag curves are formed. Below Dam 45 (mile 703.0), where oxygen recovery is in progress, the trend of the profiles is shown to be upward towards an oxygen saturation value of 8.3 parts per million (ppm) at 25 degrees centigrade, which is practically reached near the mouth at Cairo. This general picture has been confirmed by the observations carried out by the U. S. Public Health Service in 1940, and by the average results of the tests made in September, 1950, in the latter case with the exception above noted.

Because of the fact that the major part of the BOD load discharged to the river originates at Cincinnati and Louisville, a special study has been made of the minimum dissolved-oxygen values to be expected below each of these two sources of pollution under summer drought-flow conditions, both with and without treatment. In this connection it should be noted that treatment requirements already established for the Cincinnati area call for BOD reductions up to 65 percent as needed, depending on flow conditions. For the Louisville area, it has been assumed that treatment in accordance with minimum Compact requirements will result in a 35 percent reduction in the total BOD load from the area.

Minimum oxygen levels

Calculations of minimum dissolved oxygen content were made for two summer low-flow conditions, one being the 10-year minimum weekly average flow and the other, an extreme drought flow such as occurred during the summer and fall of the year 1930. In making these calculations, the oxygen-sag formula was used, with rates of reaeration based on the results of a series of measurements made in the river between Cincinnati and Louisville during the U.S.P.H.S. survey of 1930, when the river was in pool stage from May through November; probably the longest and best series made in this section of the river under low-flow conditions. Rates of deoxygenation were based on the "normal rate" corrected to a stream temperature of 25 degrees Centigrade. The initial oxygen saturation deficiency assumed was 2.0 parts per million above each city, but no allowance was made for residual BOD at these points, as it was desired to show the effects of BOD loads from each city alone.

The results of the calculations may be summarized briefly as follows:

Cincinnati	10-yr Min.		1930 Drought	
Flow	7,230 cfs		4,920 cfs	
	Initial BOD ppm	Minimum D.O. ppm	Initial BOD ppm	Minimum D. O. ppm
Without treatment	12.5	2.5	18.5	0.0
With 35% BOD reduction	8.1	4.3	12.0	2.7
With 50% BOD reduction	6.2	5.0	9.2	3.8
With 65% BOD reduction	4.4	5.8	6.5	4.9
Louisville				
Flow	7,410 cfs		6,000 cfs	
Without treatment	7.4	4.6	9.1	3.8
With 35% BOD reduction	4.8	5.6	5.9	5.1

In the above tabulation it is shown that 35 percent of BOD reduction at Louisville would be expected to accomplish approximately the same results in minimum dissolved-oxygen control as would 65 percent reduction at Cincinnati under the same flow and temperature conditions. It also is indicated that with a 10-year minimum weekly average flow, 50 percent of BOD reduction would be required at Cincinnati to maintain a 5 ppm minimum dissolved oxygen content, and 65 percent reduction at an extreme drought flow as of the year 1930. At Louisville, it would appear that 35 percent of BOD reduction from primary treatment of all sewage from that area should maintain satisfactory oxygen conditions below that district.

At Louisville, the situation with 35 percent of BOD reduction would be roughly similar to that at Cincinnati with reductions up to 65 percent, on the basis of comparable increases in population at the two cities. Population increase at Cincinnati has been estimated at 16 percent for the year 1960 and 31 percent for 1980, over the 1950 population (see Cincinnati Pool Report). Thus with an increase of 31 percent in total BOD load up to 1980, a sustained BOD reduction of 35 percent should permit the maintenance of an average minimum oxygen level of about 5 ppm with a 10-year minimum weekly flow of 7,410 cfs, and an average level of slightly over 4 ppm with an average drought flow of 6,000 cfs. These average levels would provide, however little margin of safety to cover daily variations below 4 ppm.

Conditions between Louisville and Cairo

In the section of the river extending from below Louisville to Cairo, the BOD loads discharged to the river, excepting at Evansville, are small compared to those from the Cincinnati and Louisville areas. The trend of the profile shown in Figure 1, together with the observations made in the two surveys of the river previously mentioned, would suggest that with primary sewage treatment in effect at all sources of direct pollution along this section, and with treatment up to 65 % at Cincinnati, it should be possible to maintain minimum dissolved-oxygen levels well above 4 to 5 ppm at all points with any normally expected increase in sewered populations up to the year 1980.

In connection with the 1940 observations in the river, it was noted that the 5-day BOD values in the lower section of the river were somewhat higher than could be accounted for as originating in direct sources of sewage pollution at various distances upstream. This probably was due in part to the effect of BOD brought in by the tributaries, and possibly also by the transition of biochemical oxidation into the nitrification phase, which would tend to bring about increases in observed BOD unrelated to any immediate sources of pollution.

This same phenomenon has been consistently observed in other long stretches of the river receiving little direct pollution, and it has been marked by evidences of nitrification such as an increase in nitrites and nitrates. The possibility also exists that in these long and relatively unpolluted sections of the river, the effects of BOD originating in land wash from agricultural areas may be more apparent than in those sections where the effects of direct sewage pollution are prevalent. It has been previously noted that the flushing of organic sludge deposits accumulated in pooled sections of the river would also tend to increase the BOD load and cause measurable temporary decreases in oxygen content, as was noted in the September 1950 survey immediately following a sharp general rise in the river. Probably each of these several factors exert their influence at one time or another. They are important in evaluating oxygen conditions in any stream, and particularly in a long river such as the Ohio, with its highly variable flow pattern and the marked contrasts in pollution conditions in its different sections.

BACTERIAL CONDITIONS

As previously noted, sewage pollution in this stretch of the river is dominated by the influence of the three large centers of population at Cincinnati, Louisville and Evansville. So far as bacterial conditions are concerned, however, the effects of a few smaller communities located close to downstream sources of water supply cannot be ignored, as the protection of public water supplies taken from this stretch is the primary aim of corrective sewage treatment at all points.

The largest two sources of sewage pollution, Cincinnati and Louisville, are fortunately situated in relation to downstream water supplies. The nearest water supply now taken from the river below Cincinnati is that of Louisville, some 130 miles by river from Cincinnati. At Louisville, though sewage from the upper part of the city now is discharged into the river above the New Albany intake, it is understood that this situation will be corrected when the sewage of the entire city has been collected and treated at a point below the Falls, and thence discharged into the river. After this program has been completed, the nearest water intake below the Louisville outfall will be that of Evansville, nearly 200 miles downriver. The combined forces of dilution and self-purification over long distances of river mileage will afford in themselves a high degree of protection to downstream water supplies from the effects of pollution from these two major population centers.

The most critical section of the river involving close proximity of water supplies to sources of pollution is between Owensboro and Henderson. The center of this zone is Evansville, the third largest city in the Cincinnati-Cairo stretch. Only ten miles below Evansville is Henderson, which takes its water supply from the river, and some 35 miles upstream is Owensboro, a city of about 34,000 people, which does not take its water supply from the river but discharges its sewage into it. Thus within a river distance of roughly 50 miles are two important sources of pollution, and two equally important sources of water supply. Within a distance of 50 miles below Evansville are four public water supplies, including those of Henderson and Mt. Vernon. The most hazardous situation in this section is that of Henderson, because of its close proximity to Evansville.

Coliform densities at waterworks intakes

The only recent comparable data bearing on the bacterial quality of the river at waterworks intakes have been records at Louisville and Evansville, supplied by the Commission's Water Users Committee, and at Cairo, which have been furnished by the Illinois Sanitary Water Board. These records are based on routine coliform tests with triplicate plantings in each sample dilution, and are expressed in terms of "most probable numbers" (MPN). In Table VII is a summary of these results covering a 30-month period, from July, 1950 through December, 1952, together with concurrent monthly average river flows (provisional) furnished by the U. S. Geological Survey through the District Office at Louisville.

In Figures 2, 3, and 4 are shown plots of the data in Table VII, with flows as abscissae and coliform MPN's as ordinates, using logarithmic scales in order to bring the plots within a convenient range. In each chart results for the months of May-October are designated by circles and results for the months of November-April by triangles, the former representing the summer-fall season, and the latter the winter-spring months with generally lower stream temperatures and higher flows.

In each chart, the general trend of the points indicates increased coliform densities with higher flows, though this trend is less well-defined at Cairo, probably because of the disturbing influence of backwater from the Mississippi River and of the large tributaries entering the Ohio just above Cairo.

During the 30-month period of the record, the monthly average coliform MPN exceeded 5,000 per 100 ml. in 14 out of 26 months at Louisville; in 12 out of 24 months at Evansville; and in 8 out of 29 months at Cairo. The highest monthly average MPN values were 14,000 per 100 ml. at Louisville; 16,200 at Evansville; and 12,100 at Cairo. These figures indicate a somewhat similar level and distribution of bacterial pollution at the Louisville and Evansville intakes, but a lower level at Cairo, where self-purification has been augmented by dilution from the large tributaries, the Cumberland, Tennessee and Wabash Rivers.

It will be noted in the charts that in almost every month at both Louisville and Evansville the coliform MPN exceeded 5,000 per 100 ml. with river flows greater than 100,000 cfs, and at Cairo, with flows greater than 200,000 cfs, these higher flows usually occurring during the winter-spring months. During the summer low-flow months, coliform densities at all three of the intakes have in general been lower than the 5,000 per 100 ml. objective adopted by the Commission for sources of water supply. In a few of these months, notably at the Louisville intake, average coliform densities have been lower than the Commission's bathing water objective of 1,000 per 100 ml.

Computed and observed coliform profiles

In order to show the general trend of coliform densities throughout the entire stretch of the river, a series of computed profiles has been drawn for different river flows characteristic of summer and winter conditions. These profiles are similar to those previously drawn for other stretches of the river and shown in preceding reports on the Pittsburgh-Huntington and Huntington-Cincinnati sections.

The method of computation has been the same as previously. Coliform densities in the river below each source of pollution have been based on summer and winter per capita contributions of coliforms, as determined from measurements made previously by the U. S. Public Health Service and converted to concentration units by applying the river flow. Rates of "die-away" in the river between successive pollution sources have been determined by applying summer and winter curves originally developed by the U. S. Public Health Service from three years' continuous observations during 1914-1916, and checked by later observations covering shorter periods.

In Figures 5 and 6 are shown coliform profiles drawn for the same average flows that prevailed during two periods in 1940-1941, one in summer and the other in winter, when the U. S. Public Health Service carried out coliform-bacteria observations at a number of points between Cincinnati and Cairo (House Document 266, Part II). The average river flow during the summer period was 42,500 cfs at Louisville, and during the winter period was 85,000 cfs at the same point. For comparison with the profiles, the averages of coliform densities observed in the U. S. Public Health Service survey have been plotted in the charts at their proper locations along the river. Also added are observed averages at the Louisville and Evansville intakes reported by the Water Users Committee for months of comparable flow conditions in 1950-52 (these being designated by triangles).

With one or two exceptions, particularly in the winter profile, good agreement is shown between the profiles and the observed coliform densities at various points, the deviations from the profiles being mostly within the limits of observational error. The agreement thus shown, as in previous plots of the same kind, may be taken as indicating that coliform profiles thus drawn should indicate with a fair degree of accuracy the trend of coliform densities throughout the stretch under the average flow and seasonal conditions assumed.

The advantage of these profiles as drawn lies in the fact that they are not subject to temporary disturbing influences from external sources, and hence tend to reflect the trend of coliform densities in the river as affected solely by sources of pollution located directly on the river. The only assumption involved as to tributary pollution is that the bacterial quality of the tributary waters is equal to that of the main river at their point of discharge;

this in effect being consistent with the provisions of the Compact. The non-prevalence of this condition at present probably accounts in part for the deviations of the observed coliform densities from the profiles in Figures 5 and 6.

Coliform densities at critical flows

In Figure 7 (upper profile) is shown a coliform profile drawn for summer conditions at the 10-year minimum monthly average drought flow of 11,100 cfs at Louisville, which is about 25 percent of the summer average flow for which the profile in Figure 5 was drawn. This flow represents an average which would be expected to occur during only one month in ten years; hence it is an extreme drought condition in which the concentrations of coliform bacteria immediately below sources of pollution would be at a maximum. Because of the long times of flow in the river coinciding with this flow, the forces of natural purification at summer temperatures are likewise at a maximum, and their effect is shown by the great improvement in bacterial quality between Cincinnati and Louisville, and between Louisville and Evansville, despite the marked effect of Owensboro in the latter section.

In the river section below Mt. Vernon, a marked improvement is shown, except for the influence of Paducah. Between Owensboro and Mt. Vernon is a sustained "hump" in the profile, which indicates the effect of the three sources of pollution in this section, especially at the Henderson intake, where a coliform density of about 30,000 per 100 ml. would be expected.

In Figure 8 (upper profile) is a winter profile drawn for an assumed flow of 100,000 cfs at Cincinnati, with downstream flows proportionate to increased total drainage areas. In this case the combined effect of lowered river temperatures and shortened times of flow is apparent in the section between Cincinnati and Louisville, though a natural decrease from 70,000 to 10,000 per 100 ml. or about 85 percent is indicated. In the Owensboro-Mt. Vernon section, bacterial conditions are indicated as being somewhat better than under summer flows, with added dilution more than offsetting lowered self-purification, though the combined influence of pollution from Owensboro and Evansville at the Henderson intake is still apparent.

Bacterial-reduction treatment needed

A study of the profiles in Figures 5 and 7 indicates that under summer low-flow conditions, a reduction of 35 percent in coliform bacterial densities, which has been assumed as resulting from primary sewage treatment alone without disinfection, should afford protection to all water supplies in the Cincinnati-Cairo stretch except between Owensboro and Henderson, where a reduction up to 85 percent would be necessary in order to protect water supplies in this section, and particularly at Henderson, the most critical point in the stretch. The degrees of treatment above indicated would be sufficient to provide limited areas of bathing water quality near Tell City and Paducah, and water suitable for other recreational uses in several sections aggregating about 200 miles in length.

The assumption that primary sewage treatment without disinfection may be expected to reduce the coliform bacteria content of raw sewage by about 35 percent merits further comment at this point. In their book on Sewage Treatment, Imhoff and Fair indicate coliform bacteria reductions ranging from 25 to 75 percent for primary treatment alone. Results from the Cleveland Westerly primary treatment plant have shown average coliform reductions well over 35 percent during the past few years, and during the summers of 1927-31 averaged 30 percent, with individual seasonal averages ranging up to 43 percent. On the other hand some daily results from 24-hour composite samples collected primarily for chemical analysis at seven Illinois plants during July and August, 1951 have shown little or no reduction in coliform bacteria from primary treatment alone. These results are not very conclusive, however, because of the limited period covered by them, and because they were based on samples composited over 24-hour periods, during which time marked changes in bacterial content could occur. Provisionally, at least, it would appear that the 35 percent reduction assumed is fairly reasonable for the purpose of estimate.

With winter flows of 100,000 cfs or upwards (Figure 8), indications are that a 35 percent reduction in coliform loads should be sufficient to protect all water supplies in the Cincinnati-Cairo stretch except between Owensboro and Henderson, where a reduction up to 65 percent would be needed. Although the profile in Figure 8 shows that a 35 percent reduction in the coliform load at Cincinnati would fail by a narrow margin to meet the Commission's water-quality objective at the Louisville intake, this margin is so small as to indicate that the present plan of sewage treatment for the Cincinnati area as provided in Treatment Standard No. 1 should be able substantially to meet this objective at existing population loads (1950-52) without additional bacterial-reduction treatment.

It should be pointed out, however, that any material future increase in coliform loads from the Cincinnati area probably would result in failure to meet the objective at Louisville by increasing amounts and with greater frequencies. If and when this situation should develop from an increase in sewered population within the Cincinnati area, provision for added bacterial-reduction treatment of all sewage from this area will be required. The same principle, though to a lesser degree, also would hold for treatment of sewage from the Louisville area, particularly during the winter months of higher flows.

CONCLUSIONS

The following conclusions have been reached from this study of oxygen and bacterial conditions in the Cincinnati-Cairo stretch of the river as affected by direct sewage pollution from 1950 sewered populations:

1. Oxygen conditions are critical only in river sections extending immediately below Cincinnati and to a lesser extent, below Louisville, these conditions being most critical at minimum summer drought flows. In all other sections of the river below Dam 44, oxygen recovery is well established, and should remain in this state under all flow conditions except for some future increase in pollution loads at points now undetermined.

2. BOD reductions in the Cincinnati area in accordance with requirements already established, together with reductions up to 35 percent at all other points (including Louisville), such as may be expected to result from primary treatment of all sewage according to minimum compact requirements, should insure the maintenance of satisfactory oxygen conditions throughout the stretch under all flow conditions with normally expected population increases along the river for the next 20 or 25 years.

3. Bacterial conditions in this stretch of the river, though dominated by the influence of Cincinnati, Louisville and Evansville so far as immediate effects are concerned, are most critical with respect to water supplies in the Owensboro-Henderson section, because of the proximity of the Henderson water supply to the sewer outfalls of Evansville and Owensboro. The long river distances below Cincinnati and Louisville to the nearest sources of water supply tend to mitigate the immediate effects of pollution from these two population centers, so far as their influence on the quality of downstream water supplies is concerned. Below Henderson, the combined effects of tributary dilution at high flows and those of self-purification at low flows, tend to

provided natural protection to water supplies in this section under existing pollution loads, when aided by bacterial reductions to be expected from primary treatment of sewage in accordance with minimum compact requirements.

4. Thirty-five percent reduction in the number of coliform organisms present in raw sewage (such as might be expected from primary sewage treatment) should provide sufficient protection to water supplies under present pollution loads if applied in all river sections except from Owensboro to Henderson. Between Owensboro and Henderson the following reductions in coliform organisms are needed in order to provide adequate protection to water supplies: 85 percent reduction during May through October, and 65 percent reduction during November through April. Any future material increase in existing bacterial loads on the river at Cincinnati will necessitate degrees of bacterial reduction higher than 35 percent in that area, particularly at winter flows exceeding 100,000 cfs.

5. Treatment in accordance with paragraph (4) above should provide water of bathing quality in limited areas above Tell City and Paducah during the bathing season, and should provide water suitable for other recreational uses in these and other areas aggregating about 200 miles of river length (see Figure 7).

TABLES and FIGURES

Table No.

Figure No.

Table I - Municipal water supplies taken from the Ohio River between Cincinnati and Cairo

Municipality	State	Location of intake (miles below Pittsburgh)	Population Served 1950 (estimated)	Municipality	State	Location of intake (miles below Pittsburgh)	Population Served 1950 (estimated)
Louisville	Ky.	601	405,000	Morganfield	Ky.	844	3,000
New Albany	Ind.	608	28,800	Rosiclare	Ill.	891	1,800
Evansville	Ind.	792	140,000	Golconda	Ill.	903	700
Henderson	Ky.	803	18,000	Paducah	Ky.	934	33,800
Mt. Vernon	Ind.	829	6,000	Cairo	Ill.	977	12,000
Uniontown	Ky.	840	400				
						Total----	649,500

Table II - Estimated BOD loads discharged to the Ohio River between Cincinnati and Cairo (loads shown include industrial discharges)

Point	State	Miles below Pittsburgh	Census population		Estimated Sewered population		Estimated BOD load in population equivalents	
			1940	1950	1940	1950	1940	1950
Dam 36		461						
Bellevue,	Ky.		28,154	28,887				
Dayton and Ft. Thomas					60,800	61,700	67,800	68,800
Newport	Ky.	470	30,631	31,044				
Covington	Ky.	471	62,018	64,452	77,800	80,600	141,600	146,500
Cincinnati	Ohio	474	455,610	503,998	512,000	566,000	1,569,400	1,736,000
Dam 37		483						
Lawrenceburg	Ind.	493	4,413	4,806	2,500	5,900	71,900	71,800
Aurora	Ind.	497	4,828	4,780	1,200	4,500		4,500
Madison	Ind.	558	6,923	7,506	7,100	9,130	18,900	20,500
Jeffersonville-Clarksville	Ind.	603	13,879	20,590	12,500	18,500	14,100	29,000
Louisville	Ky.	604	319,077	369,129	304,300	378,000	906,900	1,050,000 *
New Albany	Ind.	609	25,414	29,346	18,300	26,400	40,600	40,800
Tell City	Ind.	727	5,395	5,735	3,500	4,000	4,700	5,000
Owensboro	Ky.	756	30,245	33,651	25,600	32,000	64,400	71,600
Evansville	Ind.	792	97,062	128,636	103,300	110,700	191,200	229,400
Henderson	Ky.	804	13,160	16,837	11,000	17,000	14,000	18,000
Mt. Vernon	Ind.	829	5,638	6,150	4,200	3,100	6,000	5,160
Paducah	Ky.	935	33,756	32,828	29,000	29,500	39,600	39,600
Metropolis	Ill.	944	6,287	6,093	4,200	4,200	4,200	4,200
Cairo	Ill.	981	14,407	12,123	12,000	12,000	12,000	12,000

* Estimated 1953 load is 1,162,000

Table III - Minimum recorded river flows at Louisville and Metropolis gages

Year	Louisville gage: minimum recorded flow (cfs)				Month of minimum flow	Metropolis gage: minimum recorded flow (cfs)				Month of minimum flow
	Day	Week	2-Weeks	Month		Day	Week	2-Weeks	Month	
1934	4,900	8,890	10,100	16,200	July	29,500	31,100	41,800	59,400	Sept.
1935	10,600	12,600	13,200	16,800	Oct.	24,800	28,400	30,900	38,600	Oct.
1936	6,150	8,000	8,370	15,000	Sept.	26,900	31,000	35,900	41,500	Aug.
1937	4,090	9,710	10,700	33,400	Sept.	47,800	53,000	55,300	87,800	Sept.
1938	4,600	9,040	10,300	12,300	Oct.	23,700	31,000	31,500	41,800	Oct.
1939	5,200	6,400	7,740	8,590	Sept.	25,200	27,300	29,700	35,000	Sept.
1940	7,200	10,100	10,900	12,900	Oct.	31,800	36,900	38,900	43,000	Oct.
1941	5,360	7,390	8,460	16,200	Oct.	20,600	27,000	30,000	44,500	Oct.
1942	15,200	19,900	27,600	33,700	Sept.	54,000	64,100	71,500	92,300	Oct.
1943	5,300	6,430	6,880	12,400	Oct.	48,000	50,900	52,400	54,900	Oct.
1944	9,120	9,580	10,000	13,400	Aug.	32,700	44,800	45,500	54,100	Aug.
1945	10,700	14,500	16,400	34,300	July	55,700	63,400	65,800	103,000	Aug.
1946	5,500	7,910	9,970	11,000	Sept.	51,700	58,300	59,800	62,700	Sept.
1947	9,730	12,400	14,600	16,000	Oct.	41,100	48,000	49,900	53,700	Oct.
1948	5,780	11,500	12,800	17,600	Sept.	42,500	52,400	55,600	58,400	Sept.
1949	11,000	15,600	17,400	18,900	Oct.	62,000	76,900	77,200	95,800	Sept.

Table IV - Minimum recorded river flows adjusted for reservoir operation (Louisville and Metropolis gages)

Year	Louisville gage: minimum adjusted flow (cfs)				Metropolis gage: minimum adjusted flow (cfs)			
	Day	Week	2-Weeks	Month	Day	Week	2-Weeks	Month
1934	6,310	10,300	11,500	17,600	30,900	32,500	43,200	60,900
1935	12,000	14,000	14,600	18,200	26,200	29,800	32,300	40,100
1936	7,560	9,410	9,780	16,400	28,300	32,400	37,400	42,900
1937	5,500	11,100	12,100	34,800	49,200	54,400	56,700	89,200
1938	5,670	10,100	11,300	13,300	24,800	32,100	32,600	42,900
1939	6,270	7,460	8,810	9,660	26,300	28,400	30,800	36,100
1940	8,270	11,200	12,000	14,000	32,900	38,000	39,900	44,100
1941	6,430	8,460	9,540	17,300	21,700	28,100	31,000	45,600
1942	16,300	21,000	28,700	34,800	55,100	65,200	72,600	93,400
1943	6,200	7,330	7,780	13,400	48,900	51,800	53,300	55,800
1944	9,820	10,300	10,700	14,100	33,400	45,500	46,200	54,800
1945	11,400	15,200	17,100	35,000	56,400	64,100	66,500	104,000
1946	6,200	8,610	10,700	11,800	52,400	59,000	60,500	63,400
1947	10,400	13,100	15,300	16,800	41,800	48,700	50,600	54,400
1948	5,980	11,700	13,000	17,800	42,700	52,600	55,800	58,600
1949	11,200	15,800	17,600	19,200	62,200	77,100	77,400	96,000

Table V - Increases in river flow resulting from operation of multiple-purpose reservoirs

Name of reservoir	Date of completion	Minimum flow increase (cfs)	Increase added to flows of record: Date of records	Increase (cfs)
Tygart	1938	340	Prior to 1938	1,410
Berlin	July 1943	170	1938 to July 1943	1,070
Mosquito Creek	April 1944	200	July 1943 to April 1944	900
Youghiogheny	1948	500	April 1944 to 1948	700
			1948 to 1953	200
East Branch Clarion	January 1953	200		
	Total	1,410		

Table VI - Probability of drought flows at Louisville and Metropolis gages (based on adjusted flow records)

Drought Severity	Louisville gage				Metropolis gage			
	Minimum Daily	Minimum Weekly	Minimum 2 Week	Minimum Calendar Month	Minimum Daily	Minimum Weekly	Minimum 2 Week	Minimum Calendar Month
Most probable drought	7,230	11,300	12,300	17,600	39,000	45,800	50,300	56,700
Once in 5 years	6,150	8,720	9,720	13,300	27,900	33,400	35,800	44,100
Once in 7 years	5,880	8,080	9,080	12,200	25,200	30,300	32,300	41,000
Once in 10 years	5,610	7,410	8,420	11,100	22,400	27,200	28,600	37,800
Once in 15 years	5,300	6,680	7,690	9,900	19,300	23,700	24,500	34,300
Once in 20 years	5,090	6,160	7,180	9,050	17,100	21,200	21,700	31,800

Table VII - Coliform densities and stream flows at Louisville, Evansville and Cairo waterworks intakes (Coliform data are monthly averages. Louisville and Evansville data supplied by Commission's Water Users Committee; Cairo data supplied by Illinois Sanitary Water Board.)

Month	Louisville		Evansville		Cairo	
	Av. Flow Thousand cfs	Coliforms MPN per 100 ml.	Av. Flow Thousand cfs	Coliforms MPN per 100 ml.	Av. Flow Thousand cfs	Coliforms MPN per 100 ml.
1950						
July	89.6	2,650	105.0	8,400	205.0	9,710
August	37.0	880	43.4	6,100	150.0	3,850
September	95.1	12,000	112.0	16,200	278.0	8,600
October	41.3	1,980	47.3	4,850	127.0	5,170
November	132.0	14,000	154.0	13,600	268.0	11,100
December	266.0	12,300	312.0	10,200	496.0	12,800
1951						
January	286.0	11,600	335.0	11,300	580.0	8,520
February	357.0	6,000	419.0	9,400	726.0	12,100
March	284.0	5,480	333.0	4,120	664.0	8,210
April	243.0	6,740	284.0	2,840	572.0	1,230
May	120.0		141.0	5,480	252.0	1,200
June	91.7		107.0	6,000	179.0	1,510
July	49.7		58.4	3,300	165.0	770
August	16.0		18.7		84.3	120
September	16.6		19.5		80.5	440
October					61.8	250
November	64.7		76.0		197.0	2,780
December	213.0	7,050	250.0		606.0	4,800
1952						
January	313.0	8,600	367.0		640.0	3,700
February	288.0	7,500	338.0	4,600	680.0	4,500
March	273.0	4,100	320.0	7,500	586.0	3,360
April	176.0	3,200	203.0	3,400	452.0	2,150
May	158.0	7,700	185.0	12,700	257.0	2,260
June	58.0	1,500	67.0	4,800	183.0	2,200
July	24.3	610	28.4	1,400	84.8	280
August	21.3	150	25.0	1,810	64.0	810
September	15.0	860	17.6	820	53.2	2,900
October	13.6	104	16.0	580	49.4	1,500
November	20.7	760	25.5	6,600	53.4	2,080
December	57.3	3,200	67.3	1,860		
1953						
January	150.0	5,800	176.0			
February	144.0	6,000	170.0			
March	192.0	6,400	225.0			

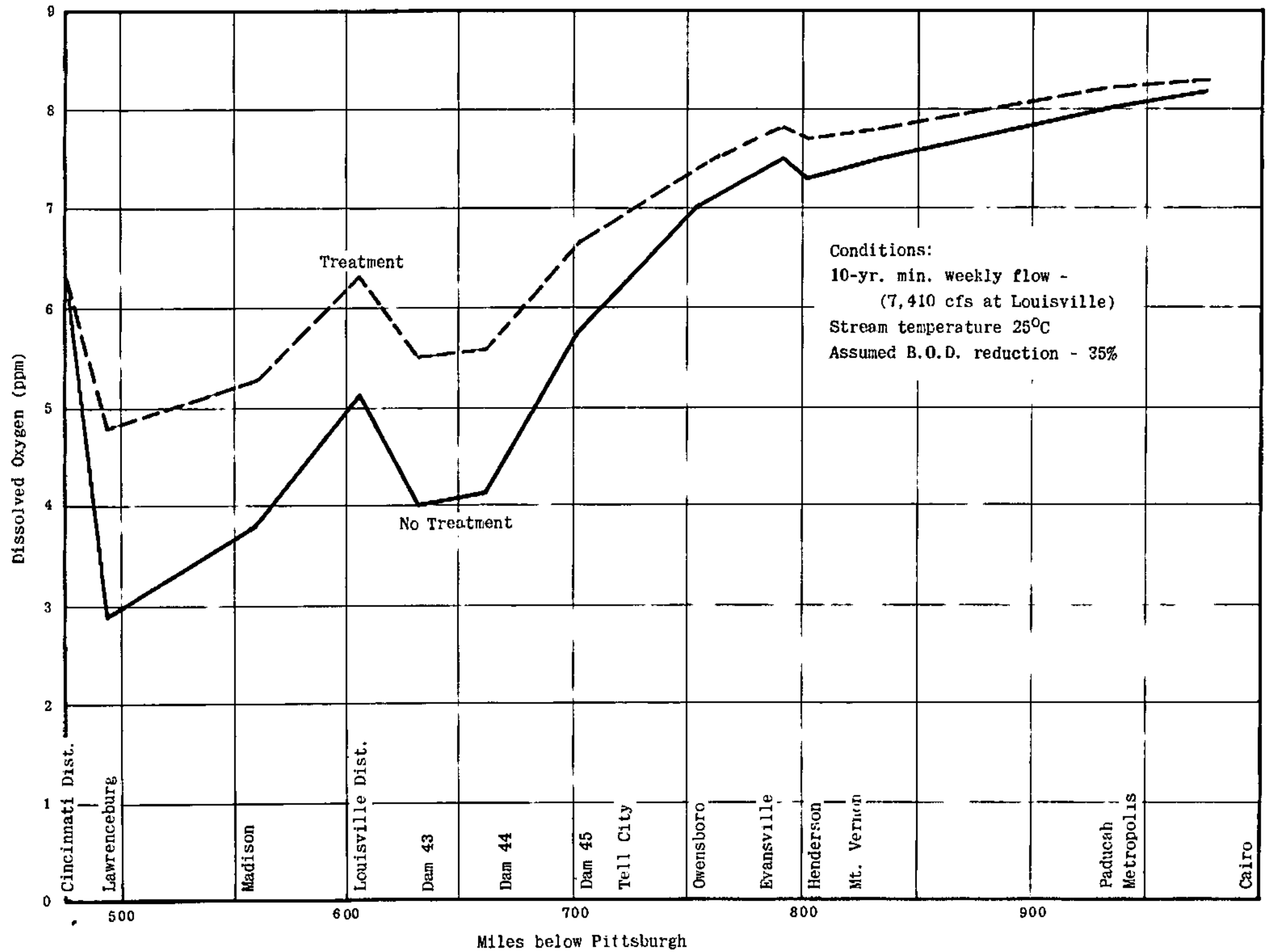


FIG. 1 - DISSOLVED OXYGEN PROFILES in Ohio River between Cincinnati and Cairo

September 1953

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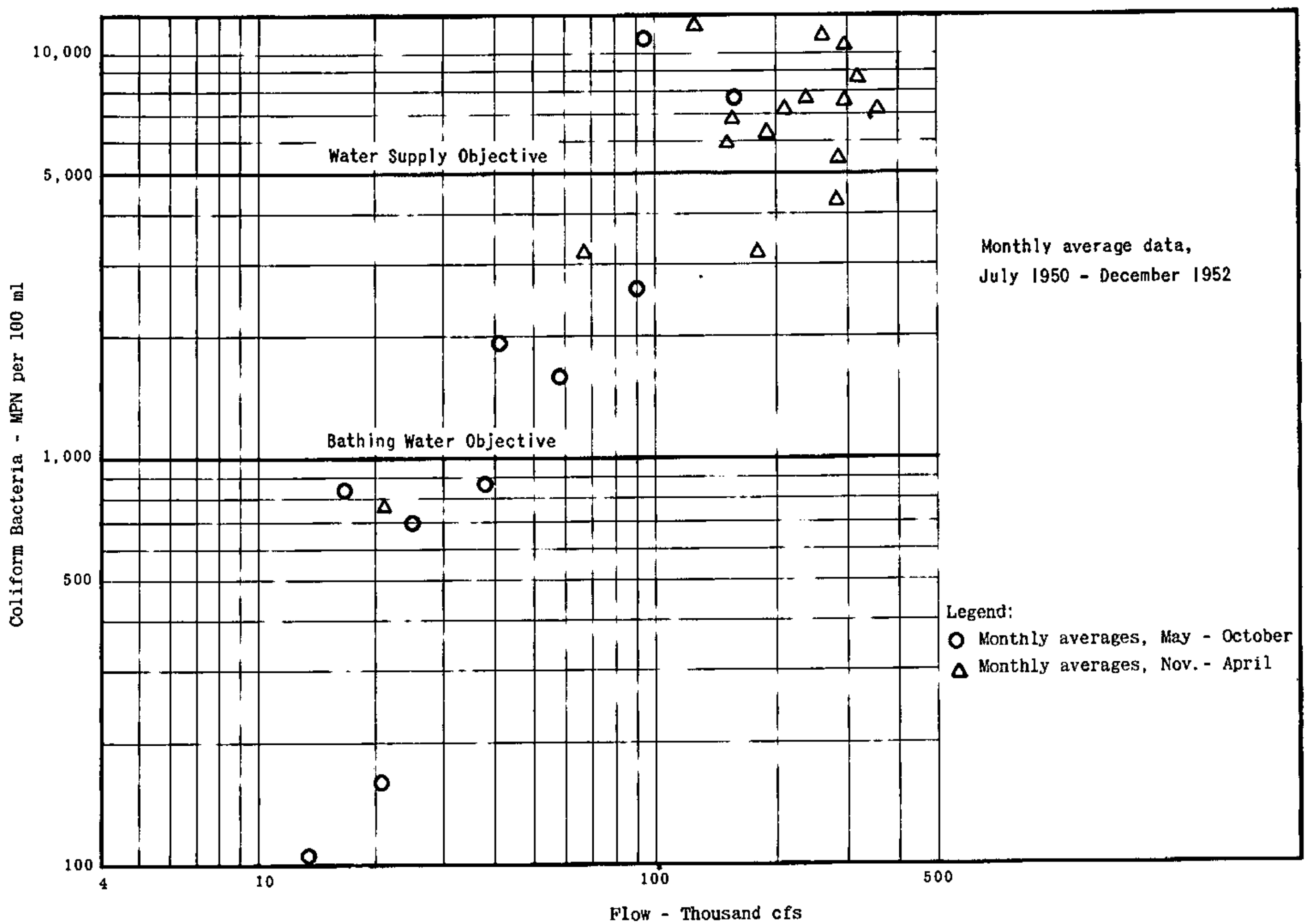

FIG. 2 - RELATION BETWEEN COLIFORM DENSITIES AND FLOW at Louisville water works intake

September 1953

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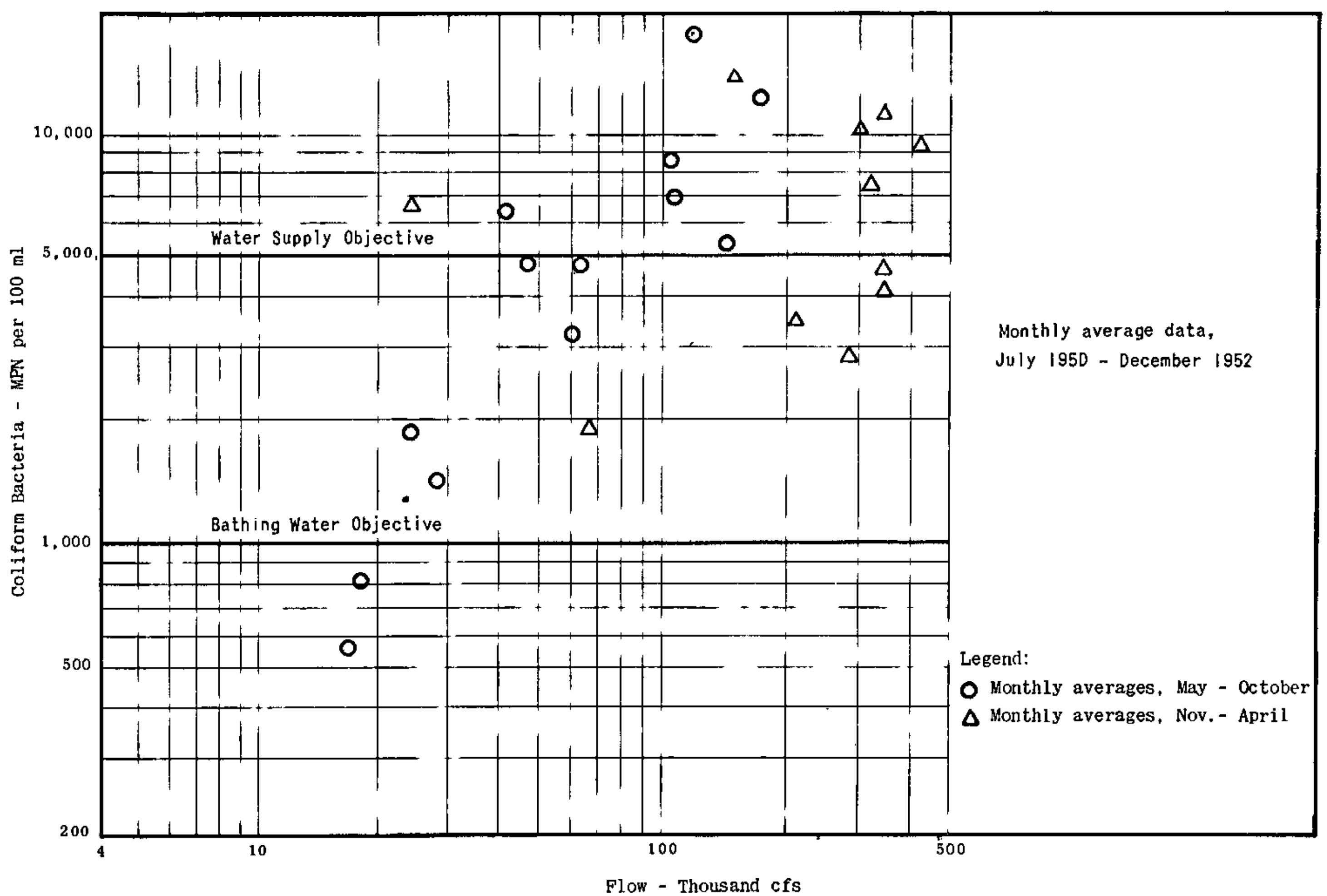

FIG. 3 - RELATION BETWEEN COLIFORM DENSITIES AND FLOW at Evansville water works intake

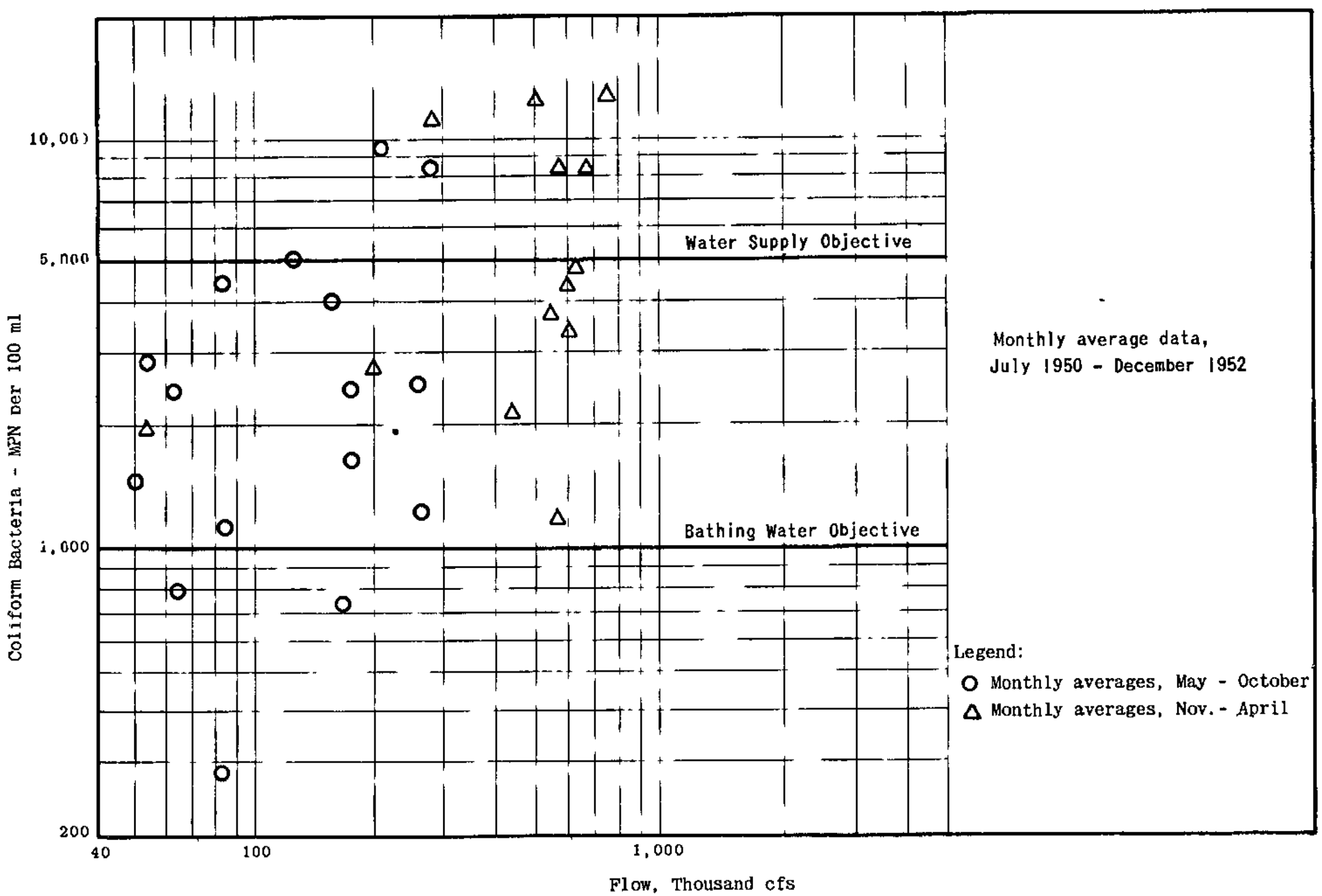

FIG. 4 - RELATION BETWEEN COLIFORM DENSITIES AND FLOW at Cairo water works intake

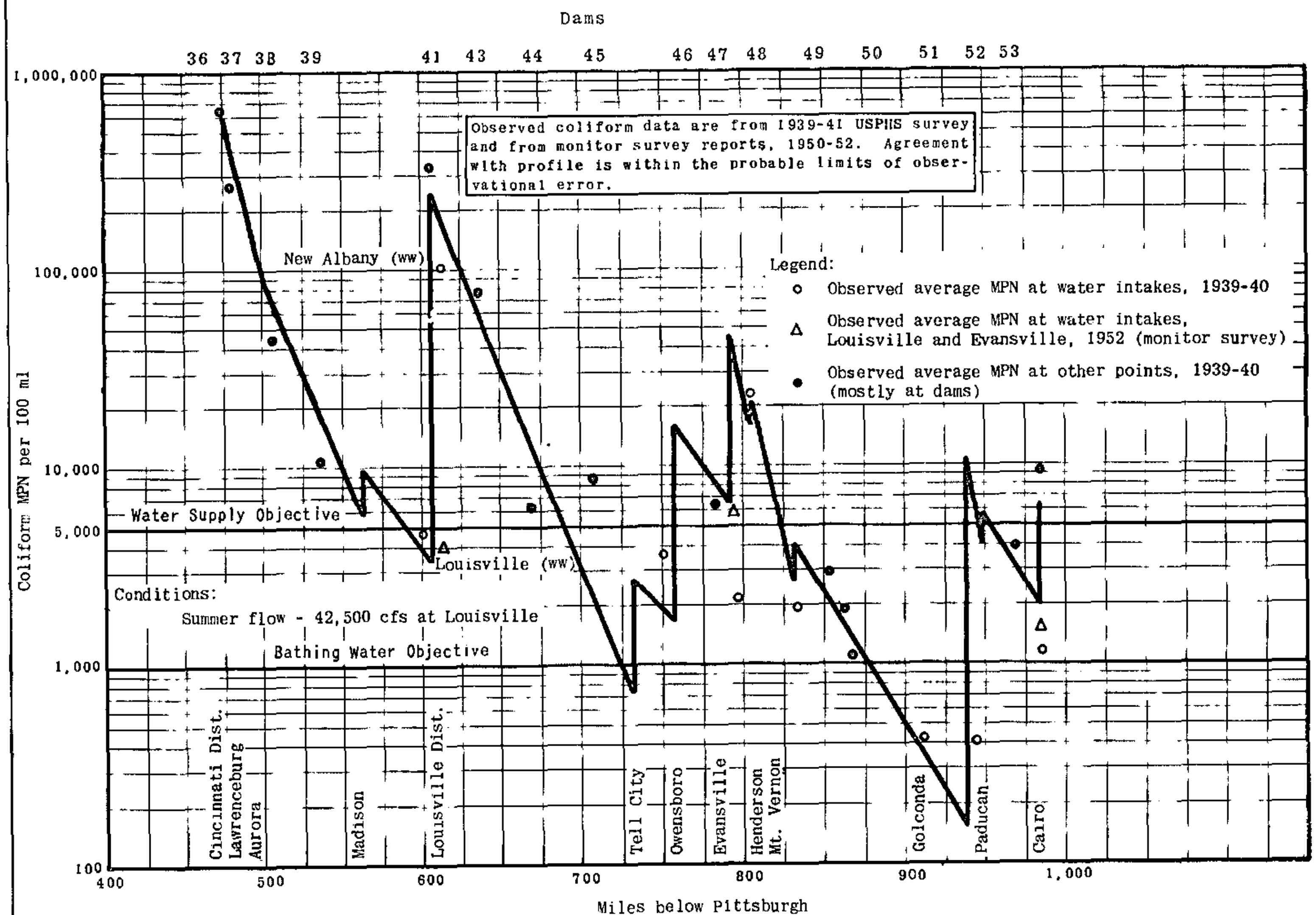

FIG. 5 - COMPUTED AND OBSERVED COLIFORM PROFILES under summer flow conditions; Ohio River between Cincinnati and Cairo

September 1953

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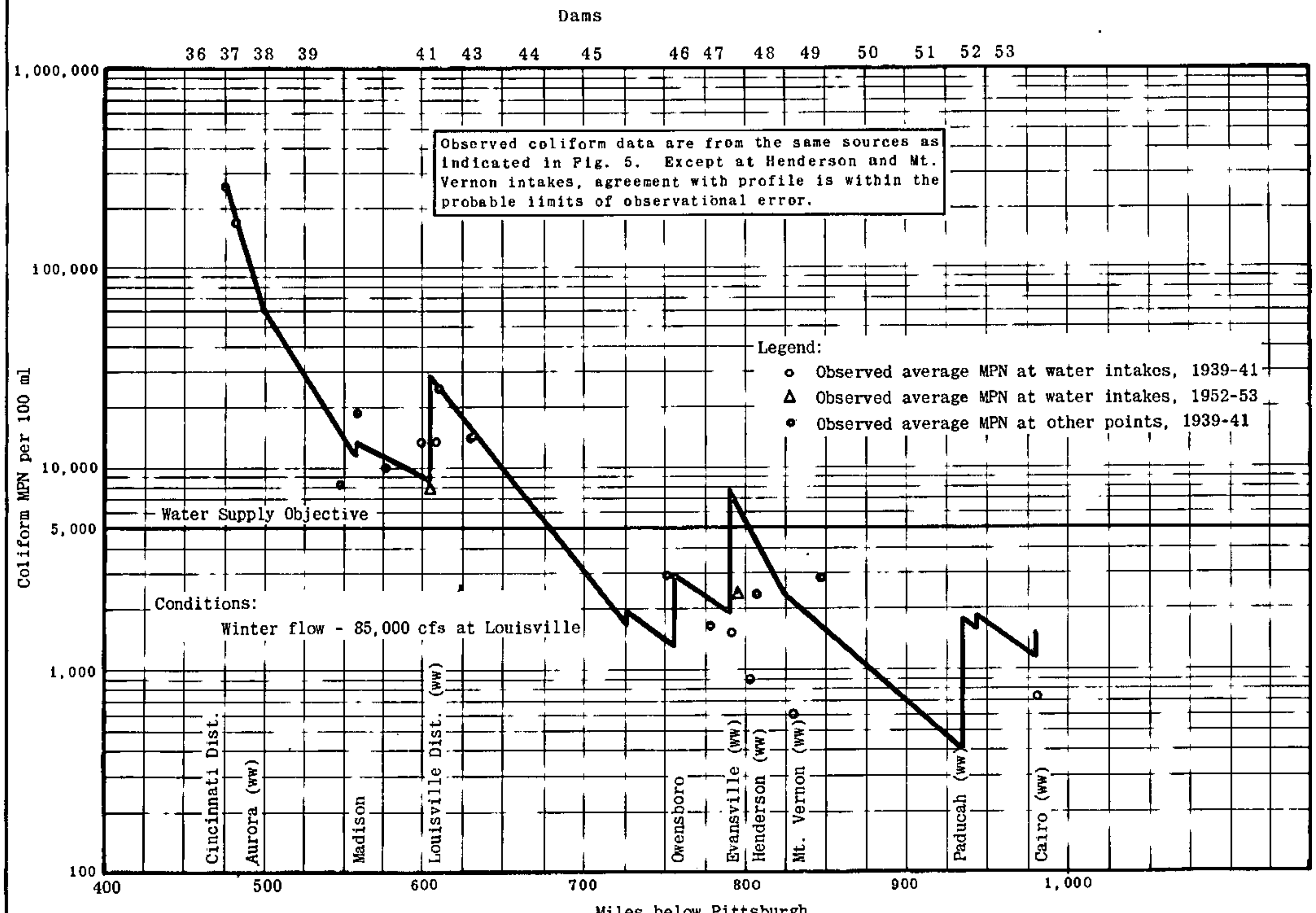

FIG. 6 - COMPUTED AND OBSERVED COLIFORM PROFILES under winter flow conditions; Ohio River between Cincinnati and Cairo

September 1953

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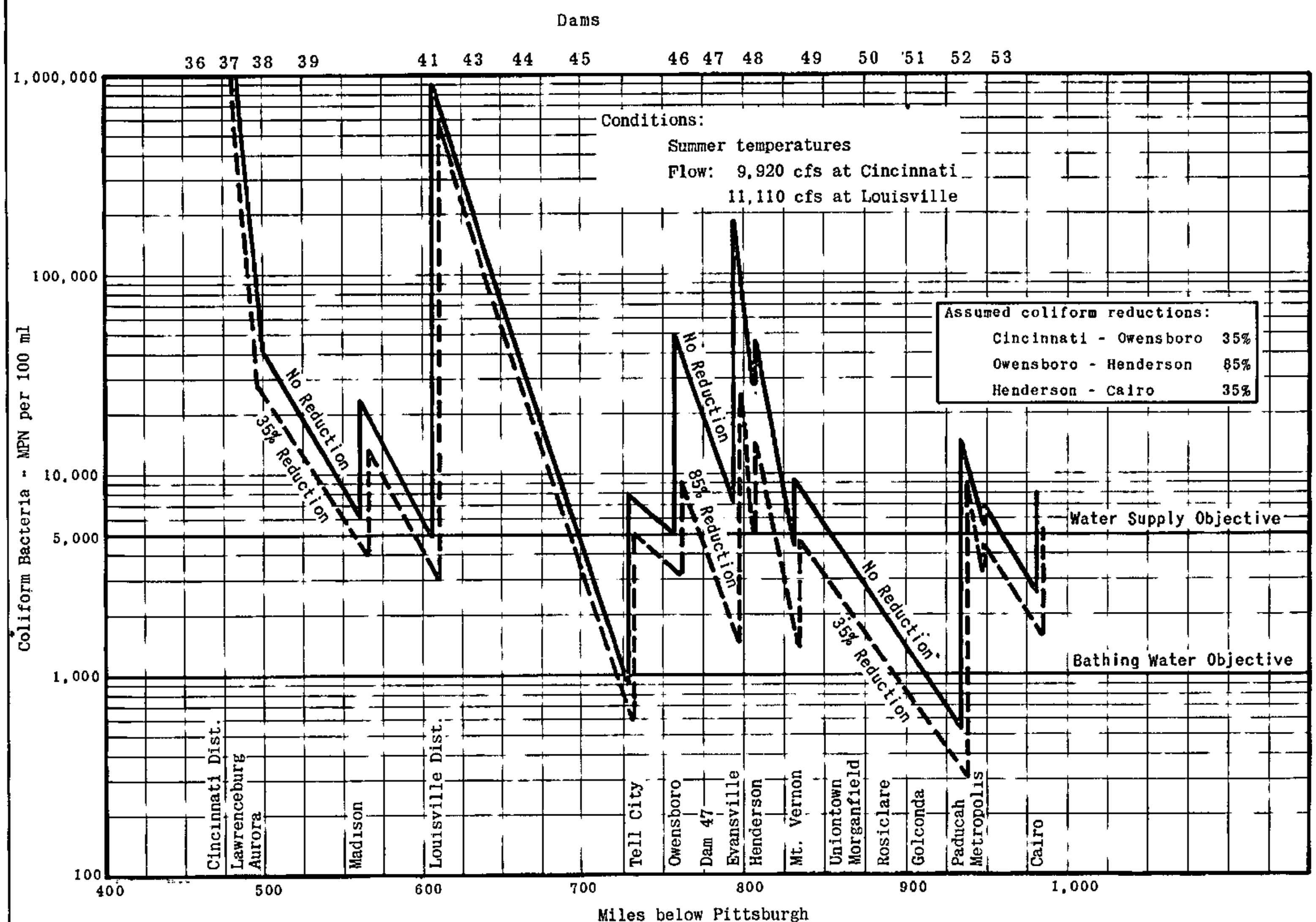

FIG. 7 - EFFECT OF BACTERIAL REDUCTION TREATMENT AT 10-YEAR MINIMUM MONTHLY FLOW; Ohio River between Cincinnati and Cairo

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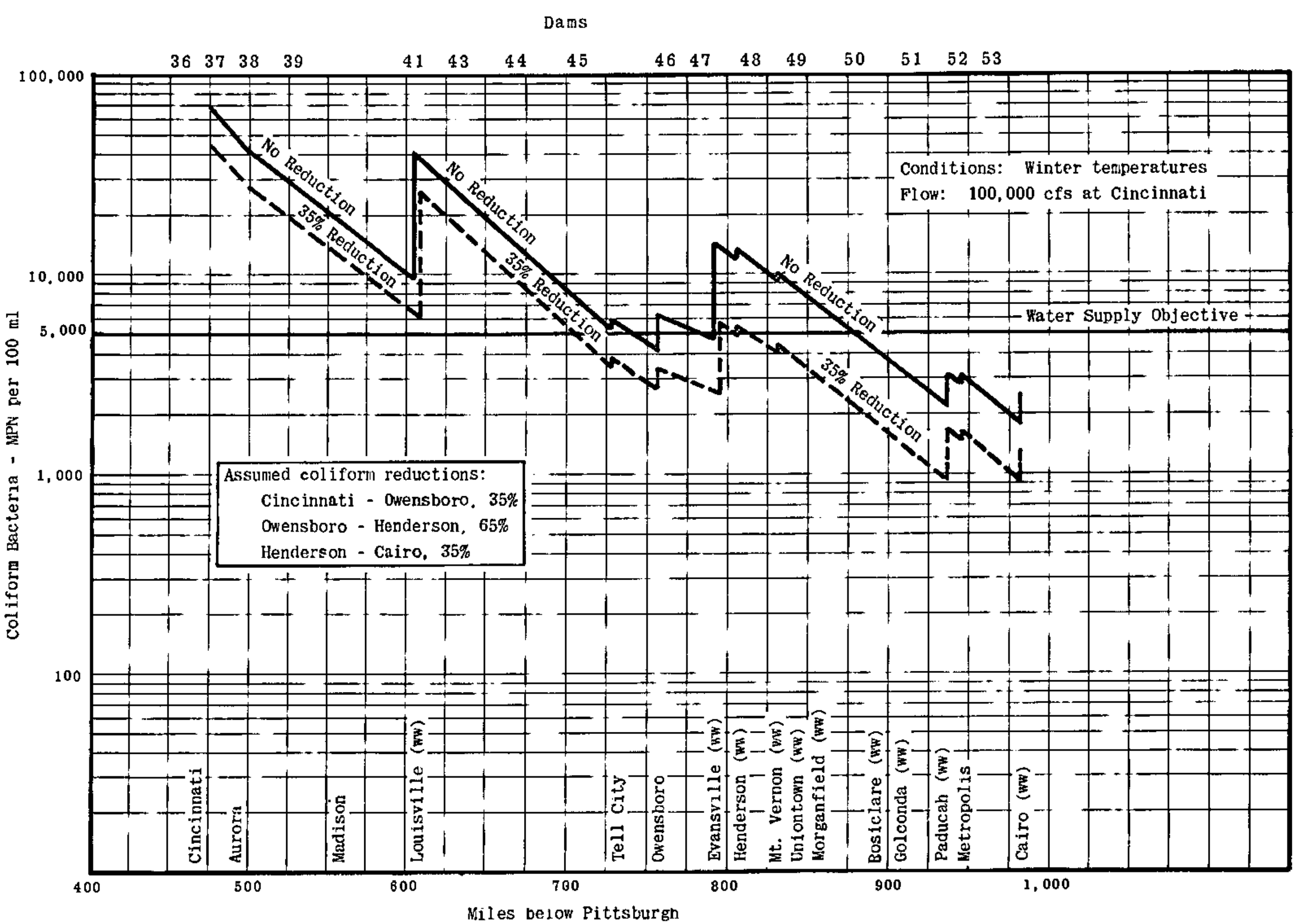

FIG. 8 EFFECT OF BACTERIAL-REDUCTION TREATMENT AT WINTER FLOW; Ohio River between Cincinnati and Cairo

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