PRELIMINARY REPORT

OF AN

INVESTIGATION OF RIVERS

— AND —

DEEP GROUND WATERS OF OHIO

AS SOURCES OF PUBLIC WATER SUPPLIES

BY THE STATE BOARD OF HEALTH.

1897-1898.

CLEVELAND
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CONTENTS.

INTRODUCTION.

An act of Legislature, passed March 14, 1893, provides that " * * no city, village, corporation or person shall introduce a public water supply or system of sewerage, or change or extend any public water supply or outlet of any system of sewerage now in use, unless the proposed source of such water supply or outlet for such sewerage system shall have been submitted to and received the approval of the State Board of Health."

The introduction of works of this character has been very largely entrusted to municipal officers, who usually have had little opportunity for making any special study of the subject. It has too often been the case with private water companies that quantity rather than quality of supply has been the first consideration. The enactment of this law grew out of the general recognition of the fact that the pollution of streams and lakes by sewage had already reached a point where it had become a menace to public health, and that some intelligent supervision and control of sources of public water supplies is necessary.

Under the provisions of this act, during the five years following its passage, plans for the introduction, change or extension of water supplies or sewerage in 126 towns have been acted upon. The Board has labored under great disadvantage from the lack of definite and sufficient information to enable it to pass judgment upon the fitness or unfitness of a proposed source of a public water supply. In nearly all cases a committee has visited the place proposing to introduce water works; samples of the water to be used have been submitted to chemical, and at times bacteriological, examination, and such information concerning the supply as could be obtained on the ground has been reported to the Board before action has been taken. The Board has realized that often some more extended examination than this is required in settling questions of such vital importance. To examine one or two samples of water taken from a stream may give little indication of its fitness for domestic use. It may be known that the stream at some point above is receiving sewage; and it was at one time held that this is sufficient cause to condemn it for such purposes. But we should not ignore Nature's process whereby streams are intended to be kept in a state of purity; and at the same time we must be very sure that the water has been sufficiently purified before approving it for general use.

Among the questions that should be fully answered in passing judgment upon a proposed water supply to be taken from some river, are: its general character; the volume of the stream at all seasons of the year; the area and character of its water-shed, with the number of people living upon it; the kind and amount of polluting matters which get into it, where they enter relative to the point at which the supply is to be taken, and the probabilities of increasing pollution in the near future. In addition, by the aid of chemistry and bacteriology, we should seek to learn the actual condition of the river at various points and at different times of the year, that we may know how far natural agencies may be depended upon for the removal, or change to harmless forms, of the pollutions which have entered it.

Knowledge of this kind cannot be gained in a day, but requires long and careful investigation. When this has been obtained, and fully worked out in all its details for all streams which may furnish public water supplies, the State Board of Health will be in a position to exercise good judgment and act with wisdom in approving or disapproving the plans for water works which are from time to time brought before it. Another useful purpose will be served by such knowledge: A basis will be established for such legislation as will tend to reclaim those streams already polluted beyond the limit of safety, while it may be possible to set aside others which may be used as carriers of sewage within well defined limits.

Since the investigations were begun which form the subject of this report, still further duties in this direction have been given to the Board. An act passed April 25th, 1898, provides that " * * * said Board shall examine and report annually the condition of all public water supplies." To further this work the Board was authorized to establish a laboratory for chemical and bacteriological examinations, and this has now been done. This additional responsibility adds greatly to the necessity of studying in a thorough manner the conditions of our streams and lakes which are or may be sources of public water supplies.

With the objects above stated in view, the Board has begun an investigation which it hopes to continue until the condition and liability to pollution of all important sources of public water supplies in Ohio shall have been satisfactorily examined. As the expenses of this work are being paid out of the regular appropriations of the Board (never a large one) it will be necessary to limit the investigation of streams to one, or at most two, each year.

Under the direction of Mr. Allen Hazen, well known as a writer and sanitary engineer, the Board has had made a drainage map of the State, prepared from the best existing data, which will afford a basis for future work. Upon it are shown the areas of all water-sheds; the number of urban and rural inhabitants living upon each; the location of all cities and villages of 1000 inhabitants or over, and of those having a system of water works or sewerage; the population of cities, showing in diagramatic form their population in 1880, 1890, and estimated population in 1900. Other data of a general character are furnished in the report of Mr. Hazen accompanying the map, which will prove of value to all persons interested in the introduction of public water supplies.

Special work was limited to the Scioto, Olentangy and Mahoning rivers. Commencing on June, 1897, and continuing till December of that year, monthly examinations of the waters of these rivers were made. The chemical work was conducted by Mr. N. W. Lord, Professor of Metallurgy and Mineralogy, Ohio State University; the bacteriological examinatons were made by Dr. A. M. Bleile, Professor of Physiology, Ohio State University, and the stream measurements by Mr. C. N. Brown, Professor of Civil Engineering of the same institution.

These rivers were regularly examined at various points along their course, special attention being given to their condition above and below all cities contributing sewage to, or obtaining water supplies from them. The plates for the bacteriological counts in all instances were made at the time and place of collecting the samples. A sample of water for chemical examination was collected at the same time and place, and forwarded by first train to Columbus. A full account of the methods employed and of the results obtained by these examinations will be found further on under appropriate headings.

As bearing upon the sources of pollution of the water supply of Columbus, which has for years, at times, taken a part of its supply directly from the Scioto river, and of the water supplies of Alliance, Warren and Youngstown, which use water at all times from the Mahoning river, special attention is called to the report of Professor Brown. A careful inspection of the water-sheds of these rivers for some distance above the points where water is taken from them for water works purposes, was made, and practically all the sources of contamination to be found have been noted.

In addition to these investigations of streams, Professor Edward Orton, State Geologist, was engaged to report upon the deep underground waters of Ohio, and the results of his investigations are included in this report.

The quality and quantity of our ground-water supplies is of much importance. A considerable part of the rainfall, the source of all water supplies, is received and held by the ground. In reaching deep levels the water is usually subjected to a slow process of filtration which removes most thoroughly all disease producing organisms; and when such waters are not too highly mineralized they form an ideal public supply. While not sufficient in quantity for our largest cities, they have been largely drawn upon by smaller towns; and nearly one-half the places in Ohio having public supplies obtain water wholly from the ground. The report of Professor Orton gives a substantial foundation for further studies in this direction.

The results of the examinations of the Scioto, Olentangy and Mahoning rivers bring forward many questions of much practical interest to cities and villages along their banks.

On the Scioto we have first the thriving city of Kenton. At present it obtains sufficient water for public purposes from the ground, but may in the future be obliged to resort to the river. While there is no direct sewage contamination of this stream above Kenton, the examinations indicate other sources of pollution which may render its water unfit for domestic use without some adequate purification. Kenton is but partially sewered, having no regular sewerage system. Sewerage will undoubtedly have to be provided in the near future. The river, during dry months, flows at a rate of less than a million and a half gallons in twenty-four hours. The sewage already contributed by Kenton is fully as much as the river can care for without the creation of a serious nuisance, so that it seems probable that sewage purification works must here go hand in hand with the introduction of additional sewerage.

There are no other cities on the Scioto to be considered until we reach Columbus. The condition of this city as regards water supply and sewerage has already become serious. The examination shows that the pollution of the Scioto river above the city is now such as to render it an unsafe source of water supply. The Olentangy river, which joins the Scioto at Columbus, is still less fit for that purpose. Columbus, during a part of the year, obtains all of its water supply from the ground, but during times of drought makes up the shortage from the Scioto river. Realizing the undesirable character of this supply, the city has recently begun extensions of its ground water supply which it is hoped will make up the deficiency for a time. Provision has been made, however, for a large storage dam in the Scioto river, to be constructed in the near future, which will furnish a sufficient supply for many years to come. The State Board of Health, in approving plans for this dam, and having in mind the results of its investigations of the Scioto river, has provided that the city shall purify the stored water in a satisfactory manner.

The pollution of the Scioto river by the sewage of Columbus has for several years been the cause of a serious nuisance. The chemical and bacteriological examinations indicate how great this pollution has now become. The city is preparing to meet this question, plans having been made for purifying the sewage.

It will be seen that the sewage of Columbus has almost disappeared by the time it reaches Circleville, except during a very low stage of the river. Circleville and Chillicothe, the only cities on the Scioto river below Columbus, obtain water supplies from the ground, and for the present are uninjured by any sewage pollution of the river.

Near the headwaters of the Olentangy river is the city of Galion. Its water supply is from wells. Sewerage is provided for a part of the city, which is discharged into the Olentangy river. During the months of August, September and October, 1897, the river practically ceased to flow, and a marked nuisance was created by the sewage of Galion. Sewerage facilities are badly needed in this city, but plans for discharging additional sewage into the Olentangy river were recently disapproved by the State Board of Health. The present condition of the river will undoubtedly soon force upon the authorities some measure for removing the nuisance already existing, and at such time the privilege of completing their sewerage system can be granted.

Delaware, on the Olentangy, formerly made use of this river in times of great necessity for a part of its water supply. This practice was condemned by the State Board of Health, and an excellent supply of ground water, sufficient for present needs, has now been secured. Delaware has no sewerage system, although some public, and possibly a few private, buildings contribute some sewage to the river. This has already been the cause of complaint; and it is evident that the river in summer is too small to receive all the sewage of the city without being first purified.

On, or rather near, the Little Scioto river, we have the rapidly growing city of Marion. Its water supply comes from the ground, but its sewage (about one-half of the city is sewered) goes to the river. The condition of the river below the sewer, as shown by the examinations, and as may be judged by the nose, is bad. The city authorities have expressed an intention of completing their sewerage system, but it is evident that purification works will have to be provided.

On the Mahoning river we have Alliance, Warren, Niles and Youngstown to consider.

Alliance obtains its water supply from the Mahoning river. No sewage enters the river above Alliance, but objectionable surface filth is contributed by several small villages upon its water-shed. The Fairmount Children's Home, near Alliance, until recently discharged its sewage into a run which empties into the Mahoning river above the source of the city's water supply. This matter received the attention of the State Board of Health, and acting on its suggestion arrangements were made for disposing of the sewage by sub-surface irrigation. In case of a stoppage, sewage would again be turned into this run. There is also some sewage from the city of Alliance which gains access to the river above the water works intake. These sources of pollution are a constant menace to the water supply of Alliance.

Alliance has a sewerage system with an average daily flow of about 300,000 gallons. As the river at Alliance reaches a minimum flow of 1,500,000 gallons per day, it is evident that purification of the sewage is necessary to prevent the creation of a nuisance. The city introduced chemical precipitation works a few years ago. Under "special examinations" in the reports of the chemist and bacteriologist will be found the results of examinations of the sewage and purified effluent at Alliance. During June, July and August no record was kept of the amount of lime used. For these months the samples were collected at different hours of the day to show the changes in character of the sewage during twenty-four hours' flow. In September and October a composite sample, representing a mixture of samples collected hourly for twenty-four hours, was taken. The amount of sewage flowing and quantity of chemicals used were accurately measured for these months. While the results of these examinations show that the treated sewage at Alliance has had a considerable proportion of the organic, putrefactive, matters removed, and the stream has been undoubtedly greatly improved by reason of the disposal plant, the very large number of bacteria in the effluent would make it an unsafe addition to a stream of small volume used for a public water supply.

The city of Warren, with a population of about 8,500 inhabitants, obtains a water supply from the Mahoning river. A few years ago the water works company installed a Warren filter and has since been filtering the entire public supply. Reference to Professor Brown's report upon the sources of pollution of the Mahoning river near Warren will show the importance of effectually purifying the water. The drainage from the County Infirmary is especially dangerous. The State Board of Health has called the County Commissioners' attention to this, and they are having plans prepared to purify the sewage in a satisfactory manner.

It will be noted in the table on page 124 that when the samples of filtered water were taken in June, October and November, no alum was being used. The river was then comparatively clear, and the engineer at the filter station said that alum was only used at times when the river was muddy. This will serve to call attention to a serious objection to the system of "mechanical filtration." Used without alum or other coagulant in sufficient quantities, the mechanical filters obtain only a low bacterial efficiency. It will be seen, however, that during the months of July and August, when alum was being used, the filter was only removing about one-third of the bacteria in the applied water It is reported that the filter is now being operated in a more efficient manner, but no later examinations have been made by us to verify this. Warren is discharging a considerable amount of sewage into the Mahoning river. The State Board of Health a few years ago refused to allow the city to put in additional sewerage without provisions for purification.

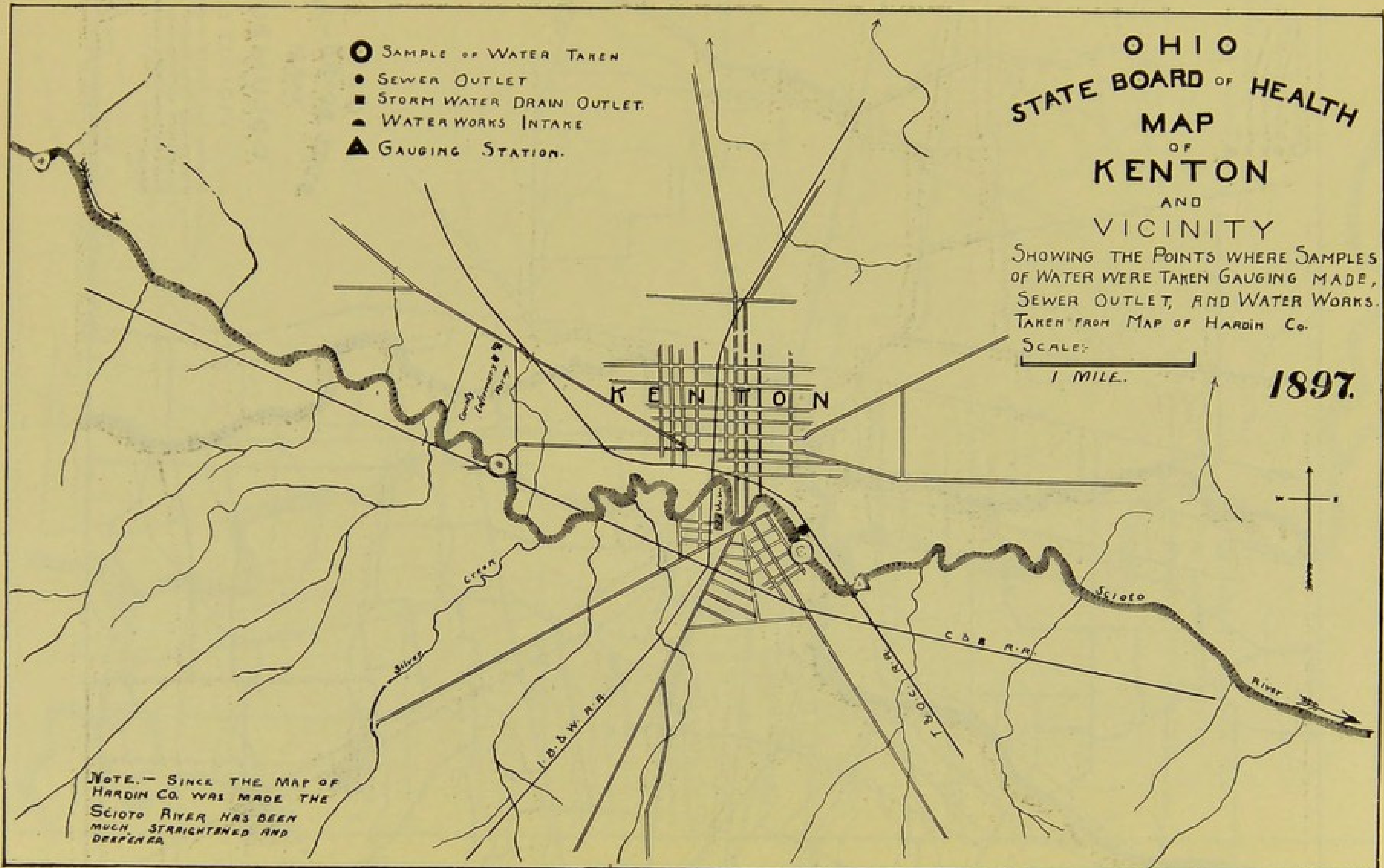
Niles, on the Mahoning river, about midway between Warren and Youngstown, has a ground water supply. It contributes a small amount of sewage to the Mahoning river. The city is growing, and is in urgent need of sewerage. Plans for improvements of this character were recently submitted to the State Board of Health but were disapproved, no provision having been made for purification of the sewage.

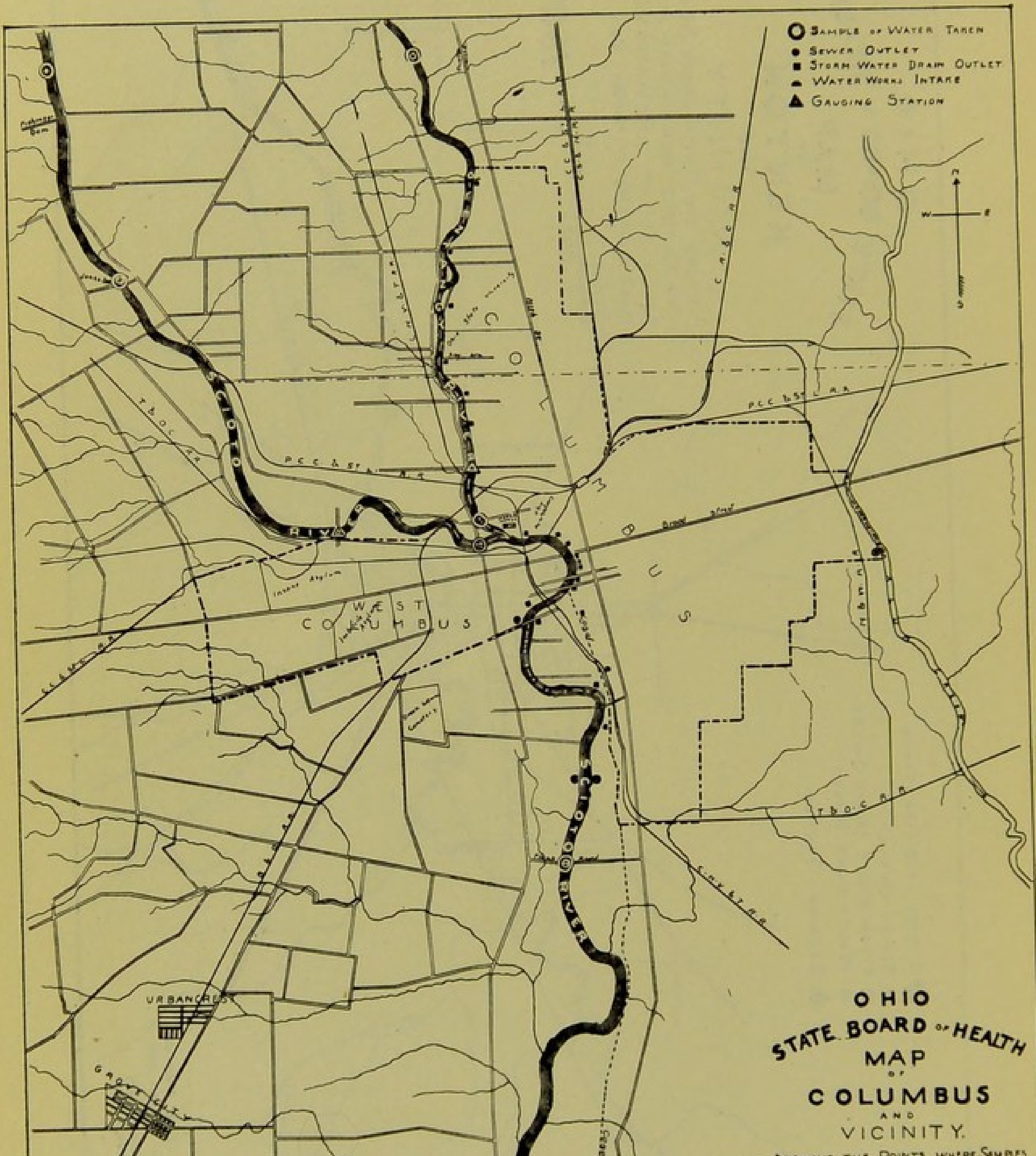
The city of Youngstown, with about 40,000 inhabitants, obtains a water supply from the Mahoning River, which is used without purification. In addition to the sewage from Warren and Niles, the river above the water works intake receives all the surface filth of a population belonging to the city of fully 10,000 people. There are also factory wastes entering the river, more or less injuriously affecting the water supply. Purification of the supply by some method which will maintain a constant high bacterial efficiency, would seem to be demanded in the immediate future.

The sewage of Youngstown all reaches the Mahoning river, but has not yet polluted it to an extent to cause serious complaint. No towns in Ohio derive a water supply from the Mahoning river below Youngstown.

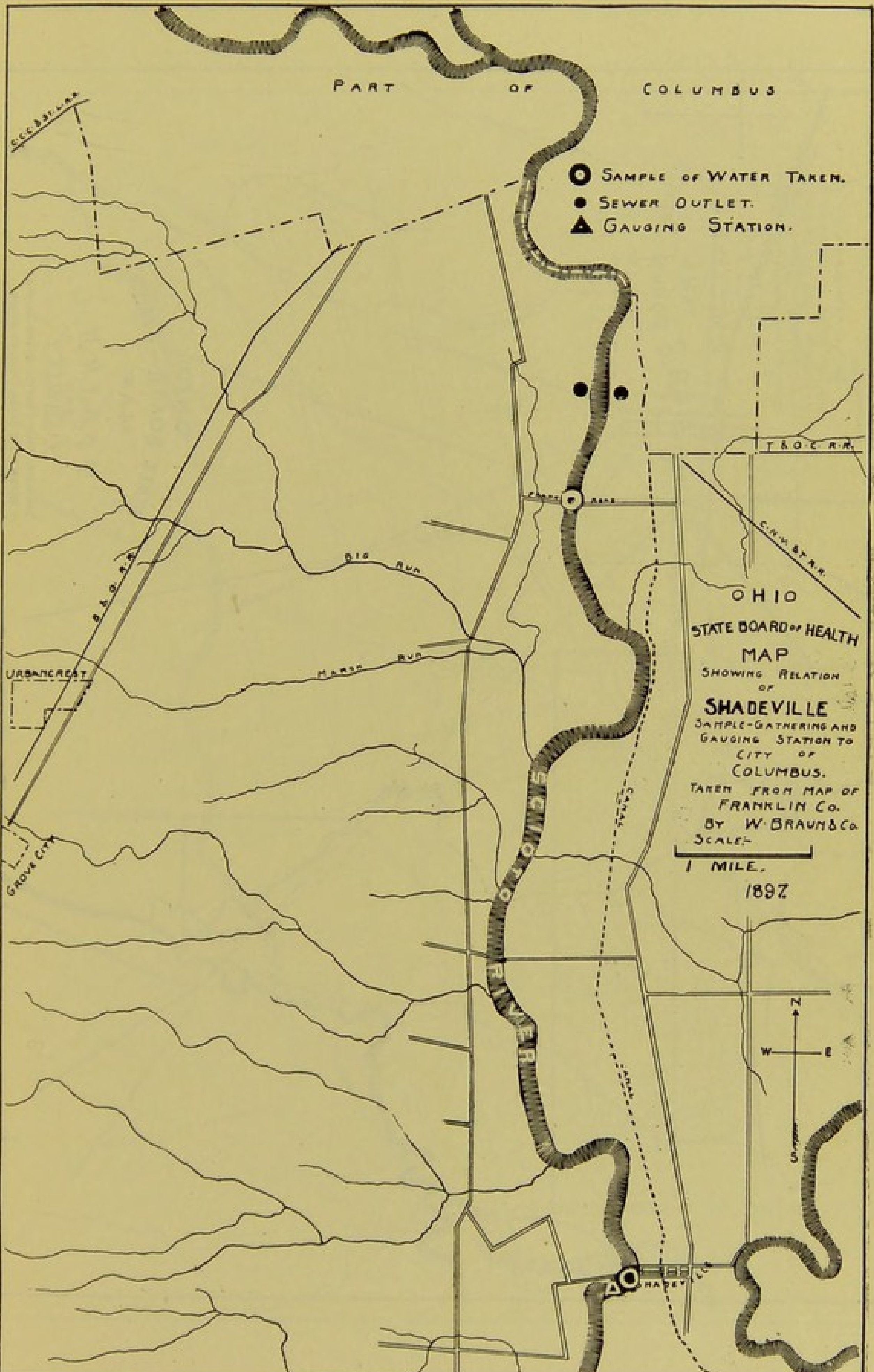
The Board wishes to express its sincere appreciation of the truly scientific interest shown by the contributors to the work which has thus been inaugurated, and to gratefully acknowledge their constant assistance in obtaining the greatest results possible with the limited means at its disposal.

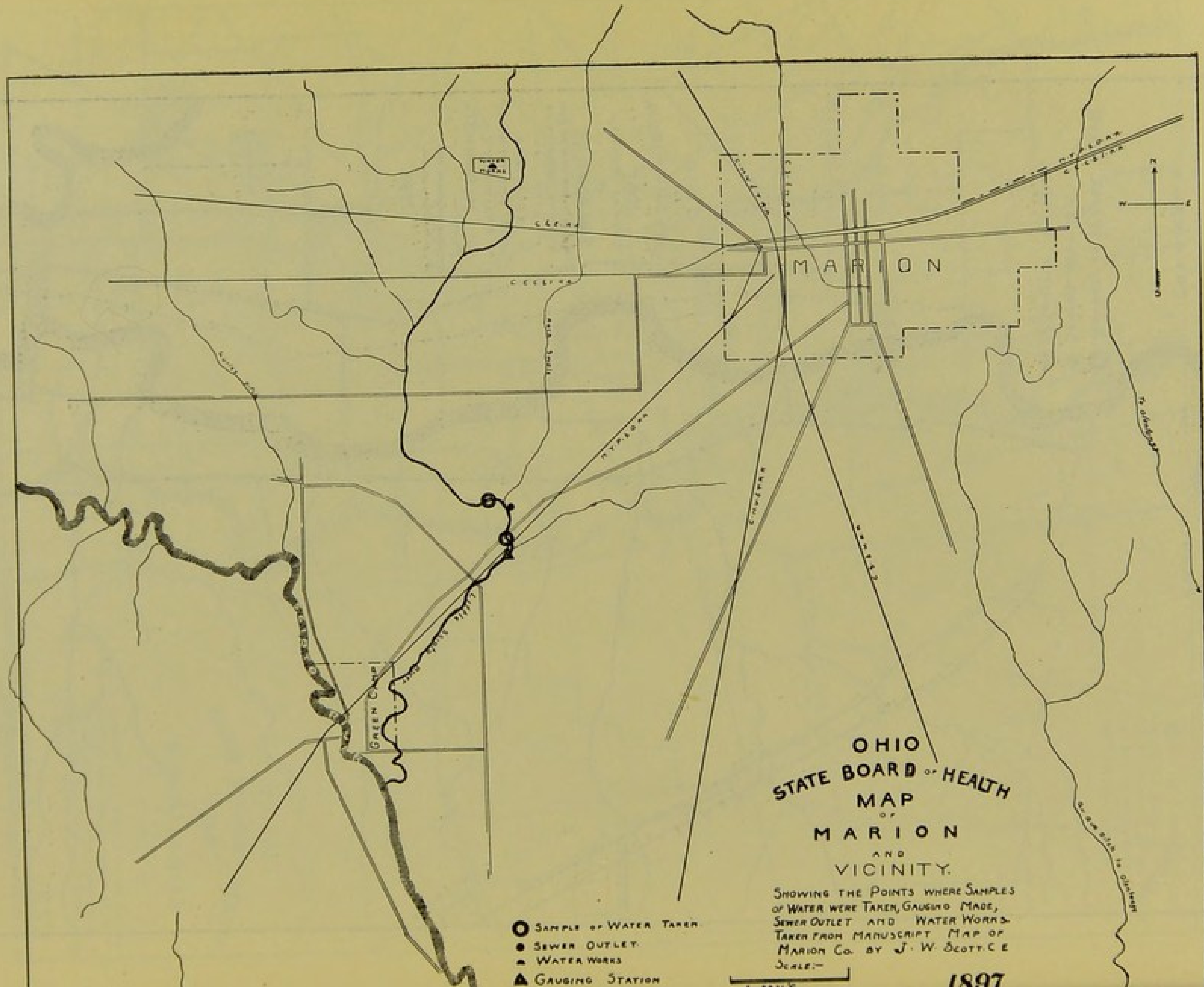
Columbus, Ohio. June 20, 1898.

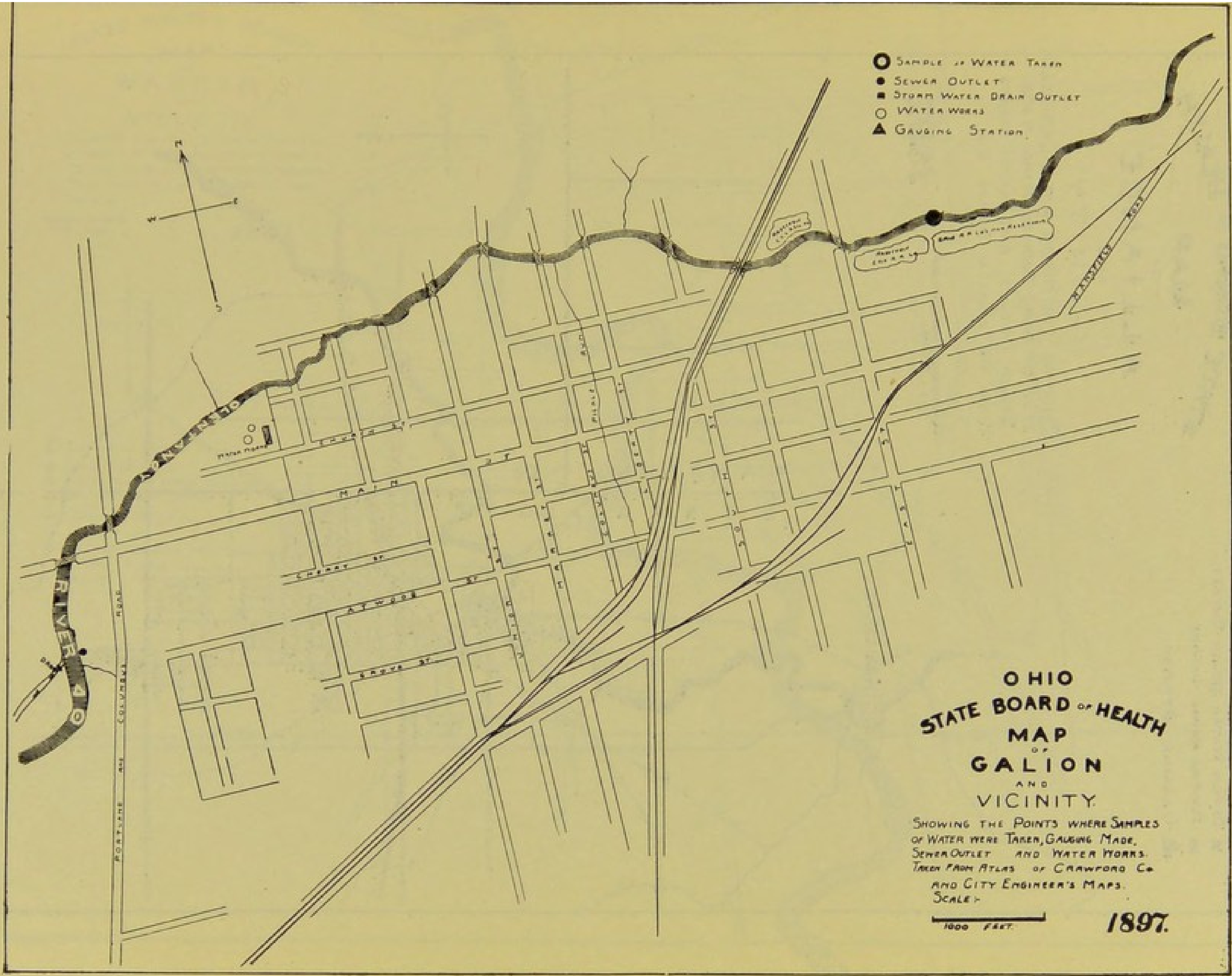

OHIO
STATE BOARD OF HEALTH
MAP
OF
KENTON
AND
VICINITY
SHOWING THE POINTS WHERE SAMPLES OF WATER WERE TAKEN GAUGING MADE, SEWER OUTLET, AND WATER WORKS.
TAKEN FROM MAP OF HARDIN CO.
SCALE:
1 MILE.
1897.
SAMPLE OF WATER TAKEN
SEWER OUTLET
STORM WATER DRAIN OUTLET.
WATER WORKS INTAKE
GAUGING STATION.
KENTON
Scioto
River
Silver
Creek
C. S. & R. R.
T. & O. C. R. R.
I. B. & W. R. R.
NOTE.— SINCE THE MAP OF HARDIN CO. WAS MADE THE SCIOTO RIVER HAS BEEN MUCH STRAIGHTENED AND DEEPENED.



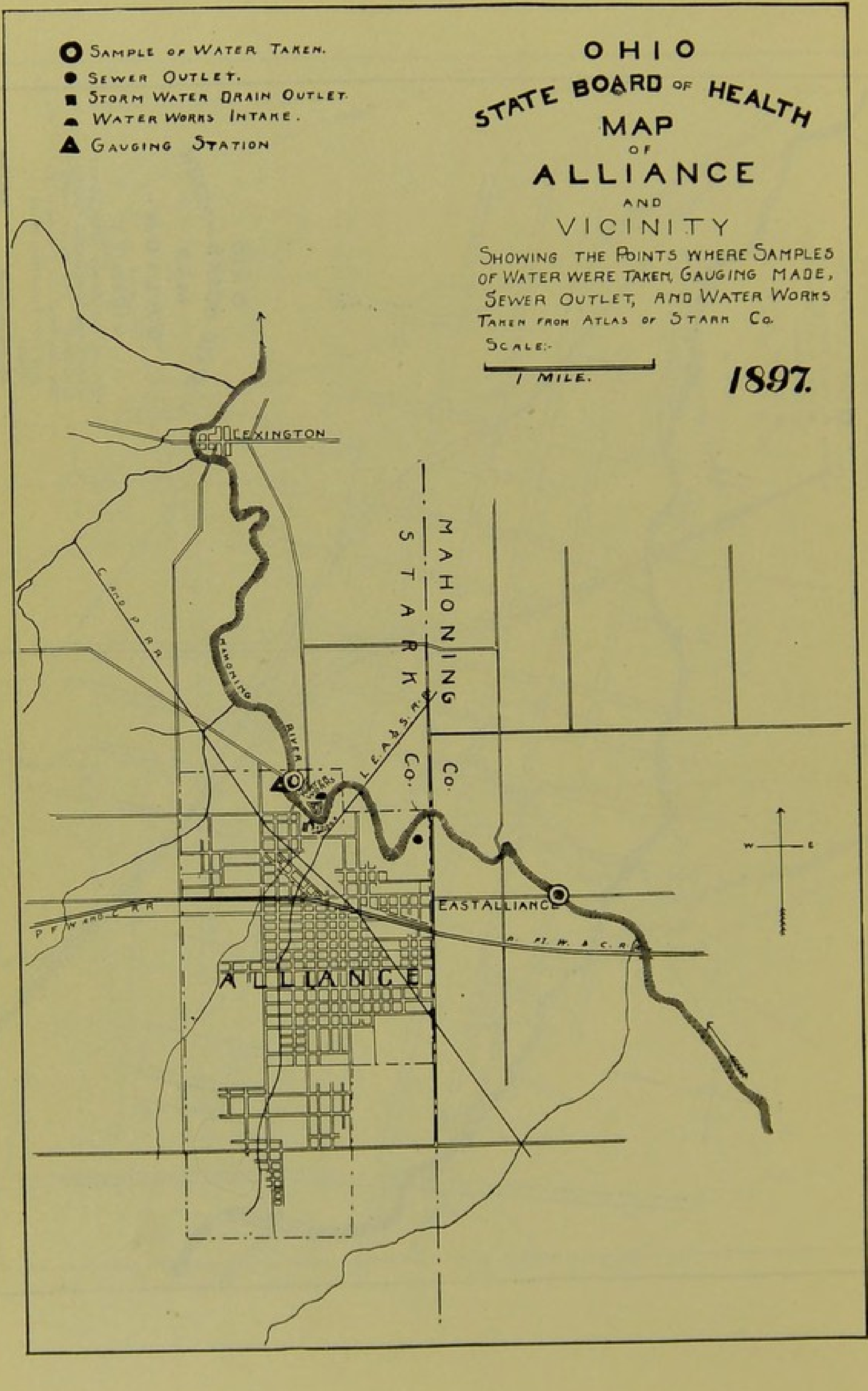
Sample of Water Taken
Sewer Outlet
Storm Water Drain Outlet
Water Works Intake
Gauging Station
SCIOTO RIVER
OLENTANGY RIVER
COLUMBUS
WEST COLUMBUS
Insane Asylum
Broad Street
P. C. C. & St. L. R.R.
T. & O. C. R.R.
URBANCREST
GROVE CITY
OHIO
STATE BOARD OF HEALTH
MAP
OF
COLUMBUS
AND
VICINITY.
SHOWING THE POINTS WHERE SAMPLES OF WATER WERE TAKEN, GAUGINGS MADE, SEWER OUTLETS AND WATER WORKS INTAKE.
TAKEN FROM MAP OF FRANKLIN CO. BY A.W. BRAUN & CO.
SCALE:-
1897.


PART OF COLUMBUS
Sample of Water Taken.
Sewer Outlet.
Gauging Station.
OHIO
STATE BOARD OF HEALTH
MAP
SHOWING RELATION
OF
SHADEVILLE
SAMPLE-GATHERING AND
GAUGING STATION TO
CITY OF
COLUMBUS.
TAKEN FROM MAP OF
FRANKLIN CO.
BY W. BRAUN & Co.
SCALE:-
1 MILE.
1897.
T. & O. C. R.R.
C. H. V. & T. R.R.
B. & O. R.R.
BIG RUN
MARSH RUN
URBANCREST
GROVE CITY
SCIOTO RIVER
CANAL
SHADEVILLE
N
S
W
E

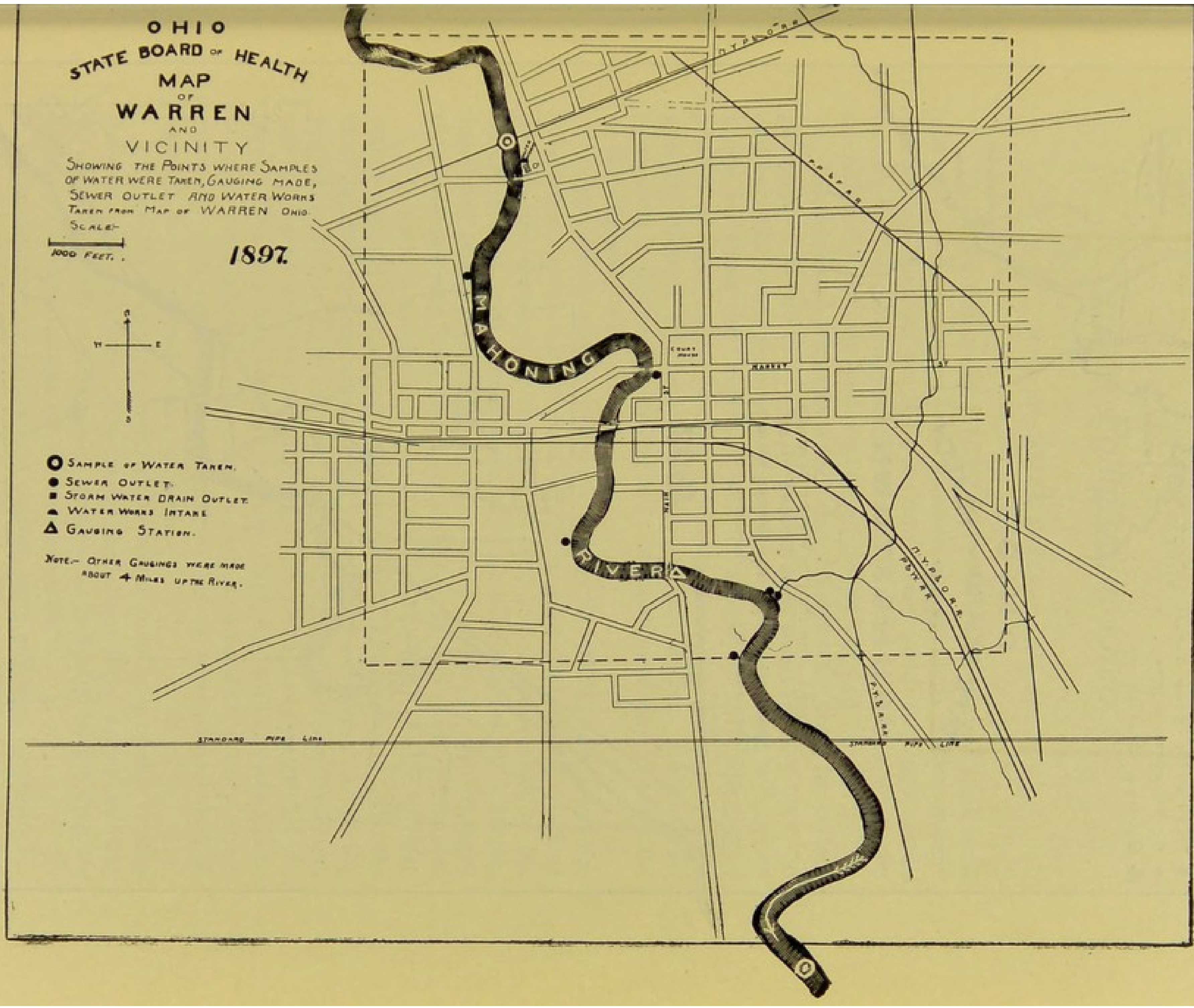

OHIO
STATE BOARD OF HEALTH
MAP
OF
MARION
AND
VICINITY.
SHOWING THE POINTS WHERE SAMPLES OF WATER WERE TAKEN, GAUGING MADE, SEWER OUTLET AND WATER WORKS.
TAKEN FROM MANUSCRIPT MAP OF MARION CO. BY J. W. SCOTT. C E
SCALE:-
1897
SAMPLE OF WATER TAKEN
SEWER OUTLET
WATER WORKS
GAUGING STATION
MARION
GREEN CAMP
N
S
E
W

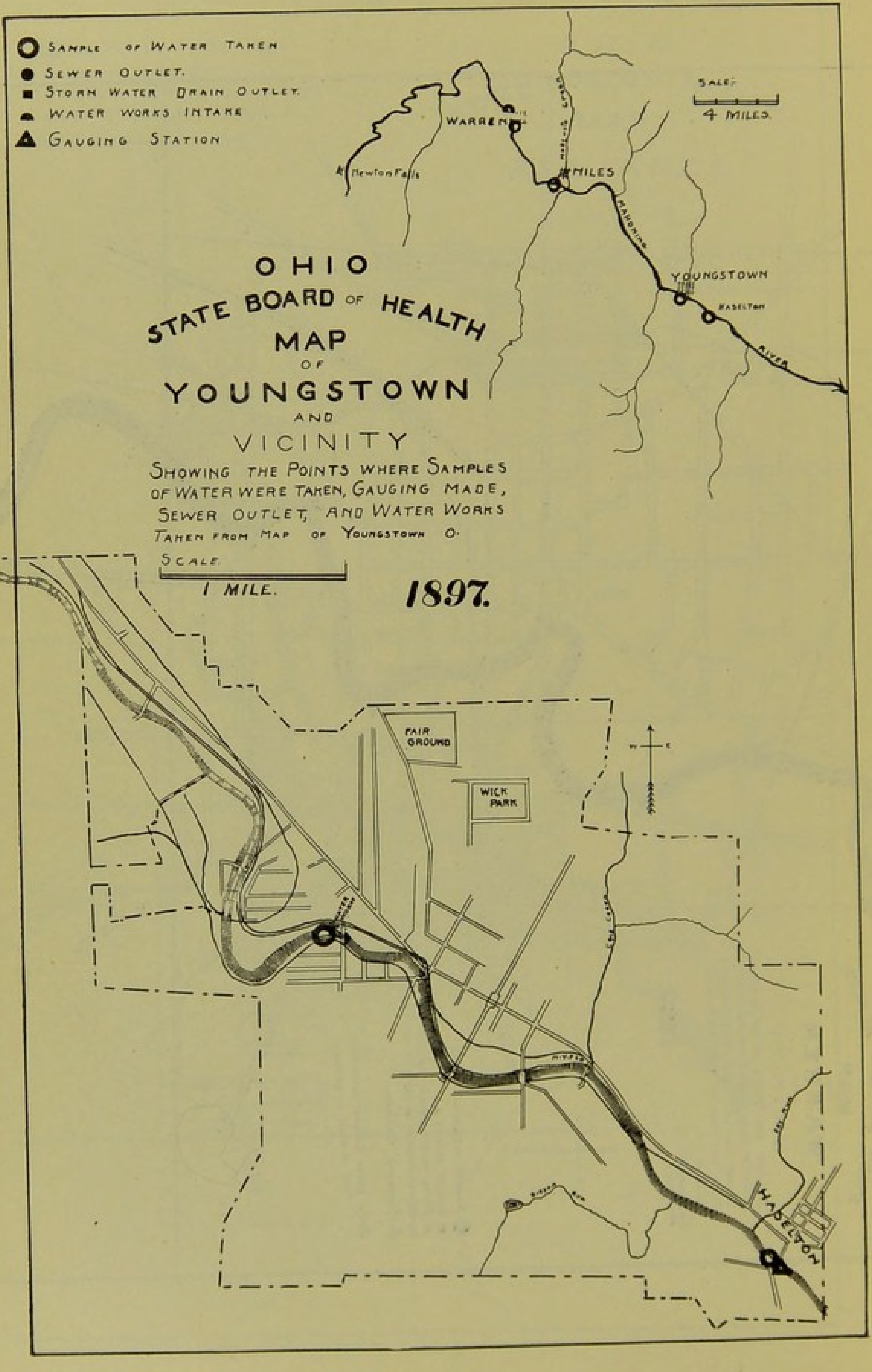


Sample of Water Taken
Sewer Outlet
Storm Water Drain Outlet
Water Works
Gauging Station
N
S
E
W
Main St
Cherry St
Atwood St
Grove St
Union St
Market St
South St
East St
Water Works
Mansfield Road
Portland and Columbus Road
River
OHIO
STATE BOARD OF HEALTH
MAP
OF
GALION
AND
VICINITY.
Showing the Points where Samples of Water were Taken, Gauging Made, Sewer Outlet and Water Works.
Taken from Atlas of Crawford Co. and City Engineer's Maps.
Scale:-
1000 Feet.
1897.



Sample of Water Taken.
Sewer Outlet.
Storm Water Drain Outlet.
Water Works Intake.
Gauging Station
OHIO
STATE BOARD of HEALTH
MAP
OF
ALLIANCE
AND
VICINITY
Showing the Points where Samples of Water were Taken, Gauging Made, Sewer Outlet, and Water Works
Taken from Atlas of Stark Co.
Scale:-
1 Mile.
1897.
LEXINGTON
MAHONING CO.
STARK CO.
MAHONING RIVER
EASTALLIANCE
ALLIANCE
W
E


OHIO
STATE BOARD of HEALTH
MAP
of
WARREN
AND
VICINITY
SHOWING THE POINTS WHERE SAMPLES OF WATER WERE TAKEN, GAUGING MADE, SEWER OUTLET AND WATER WORKS
TAKEN FROM MAP OF WARREN OHIO
SCALE-
1000 FEET.
1897.
N
E
W
S
SAMPLE OF WATER TAKEN.
SEWER OUTLET.
STORM WATER DRAIN OUTLET.
WATER WORKS INTAKE
GAUGING STATION.
NOTE.- OTHER GAUGINGS WERE MADE ABOUT 4 MILES UP THE RIVER.
MAHONING
RIVER
COURT HOUSE
MARKET
ST
MAIN
N.Y.P.&O.R.R.
P.&W.R.R.
P.Y.&A.R.R.
STANDARD PIPE LINE
STANDARD PIPE LINE



Sample of Water Taken
Sewer Outlet.
Storm Water Drain Outlet.
Water Works Intake
Gauging Station
OHIO
STATE BOARD OF HEALTH
MAP
OF
YOUNGSTOWN
AND
VICINITY
Showing the Points where Samples of Water were Taken, Gauging Made, Sewer Outlet, and Water Works
Taken from Map of Youngstown O.
Scale.
1 Mile.
1897.
Scale.
4 Miles.
Warren
Newton Falls
Miles
Mahoning
Youngstown
Haselton
River
Fair Ground
Wick Park
Hazelton

REPORT UPON

Stream Pollution in Ohio.

By ALLEN HAZEN.

This work was undertaken in April, 1897, and has taken the form of a study to determine as far as possible what methods of water supply and sewage disposal are likely to ultimately yield the most satisfactory results, especially with reference to deciding present questions in conformity with the policy to be ultimately adopted.

In connection with this work arrangements were made for certain gaugings of stream flows and other geographical studies, for chemical and bacterial examinations respectively, of the Mahoning and Scioto rivers, including the Olentangy, and for a study of the underground sources of water supply in Ohio. These questions, all of them of the greatest moment, will be taken up in separate reports. I shall draw upon them in this report only for such information as may be pertinent to the subjects herein discussed.

Upon taking up the question of river pollution in Ohio, I was unable to find a satisfactory map showing clearly the courses of the various streams, the towns upon their banks, etc., and it was decided at the outset to have such a map prepared. Mr. Christopher E. Sherman, Instructor of Engineering at the Ohio State University, was engaged to prepare this map, with the assistance of Mr. H. J. Shaw as draftsman.

We took as a basis a map published by Warner & Foote in 1883, with a nominal scale of four miles to an inch, which seemed to be the most satisfactory map available for our special purposes. A tracing was made of this map, showing all the streams thereupon indicated, and the county and township lines, and the locations of cities and villages. The railroads, section lines and other data not pertinent to our purpose were omitted. This map was compared with county maps, especially with reference to streams, as far as such maps could be secured, and corrected where necessary.

Upon the map thus prepared the water-shed lines of the various streams were indicated. The water-shed lines were drawn midway between the heads of the various streams, as indicated by the map, no other data being available for their determination.

The distances on the various streams were indicated by marks for every mile. For the Ohio water-sheds these marks were numbered consecutively from the junction of the Ohio and Great Miami rivers up the Ohio river as far as Pittsburgh (the last part of the way being on another map), and up the various tributaries as far as they enter into this discussion. The miles on the various tributaries were numbered, using as starting points the distances indicated on the Ohio river at the mouths of the respective streams. The distances on the rivers falling into Lake Erie were calculated from their mouths. The distance by water between any two cities upon the same stream can thus be taken directly from the map by taking the difference between the mileage numbers for the two places. The distances by water along some of the rivers, and the drainage areas of many of the streams were given by Professor Dwight Porter in the U. S. Census of 1880, Special Report upon Water Power, Vol. II, and similar figures have been published from time to time for certain streams, but no comprehensive statement for all the streams of the State has been heretofore published. The figures here given have been compared with those previously published, as far as available, and rarely differ materially from them. The figures here given are in every case our own measurements.

A list was made of all the towns and villages with populations of one thousand and over by the U. S. Census for 1890, with their populations as given by the censuses of 1880 and 1890. As the year 1890 is already long passed, and as many of the cities in Ohio have grown very much since that date, it was considered advisable to make an estimate of the present population, or rather of the population for the year 1900, and to use this estimated population in this discussion.

The population of each city or town was calculated for 1900 upon the supposition that the percentage rate of increase from 1890 to 1900 would be the same as it was from 1880 to 1890. The figures thus obtained were submitted to Dr. Probst, Secretary of the Board, and, in accordance with his suggestions, the estimates were revised in many instances in accordance with various sources of information. In only a few cases were the estimates increased, those being cases where new industries had come to towns since 1890, of such natures as to cause unusually rapid growths. A larger number of the estimates were reduced, and in many cases were due to some new industry which had come to town between 1880 and 1890, increasing its population very largely, but where no corresponding increase of population can be expected in the present decade.

It is probable that, on the whole, the populations are rather over than under-estimated, but if so, we are simply anticipating by at most a few years an increase of population which is certain to come and which will be very much exceeded at no remote date.

For the purpose of computation, the populations of several cities and towns very near to each other are grouped. Thus, Uhrichsville and Dennison are taken together, also Bridgeport and Martins Ferry, and Reading, Lockland and Hartwell. Certain suburbs of Cleveland

and Cincinnati are taken as being included in the populations estimated for those cities and are not otherwise mentioned.

The smaller villages are in reality rural as far as public water supply and sewerage are concerned; and for the purpose of discussion attention is limited to those towns which had populations of 3,000 or more in 1890, or estimated populations of 4,000 or more in 1900; but all towns half as populous as the above are included in case they have public water supplies. One hundred and twenty cities and towns, or groups of towns, are found in the State of Ohio having populations as above, and for the purpose of discussion these cities and towns are taken as constituting the urban population. All the rest of the population is considered as rural.

The urban population as given includes all towns having public water supplies, with a few exceptions noted below, and all towns having sewerage systems. It includes a few towns not having water supplies, and a much larger number of towns not having sewerage systems. It includes all the places which secure their public water supplies from the streams of the State, or are likely to wish to so secure them, and all the centers of population which contribute or are likely to contribute in considerable measure to the pollution of the streams of the State.

The urban populations are indicated upon the map by striking circles about the cities and towns. The sizes of these circles are such that their areas are proportional to the populations. Three concentric circles show the populations for 1880, 1890 and the estimated population for 1900. In a few cases the growth has been so slow as not to be capable of being shown in this manner, and in these cases a single circle shows the approximately constant population. The map thus prepared is presented herewith without the township boundaries, and with certain other changes made necessary or desirable by the reduction in scale incidental to publication.

Stream pollution is closely connected with the density of population. Streams flowing through densely populated areas, other things being equal, are more polluted than those flowing through sparsely settled areas. A study was made of the density of population upon the various water-sheds of the State. For this purpose the water-sheds of the larger rivers were subdivided into a considerable number of sections, these sections being, in general, so selected as to represent the rivers at points where they are taken for public water supplies or are polluted by the addition of sewage. The State was thus subdivided into 125 water-sheds, the area of each of which was determined by planimeter measurements and corrected for shrinkage in the map, which was determined by measuring the lengths of degrees of latitude and longitude. The areas of the sections so determined added up for the whole State 40,921 square miles. The area of the State, including water areas, is commonly reported at 41,060 square miles.

The rural population upon the various water-sheds was first determined. The population of each township was written on a black print copy of the map, deduction being made for urban population where it existed. The rural population is seldom increasing, and very often decreasing. The census report for 1890 was taken throughout for rural population as being sufficiently accurate for our purposes. Where a township was in two or more water-shed sections, the population was divided among them approximately in proportion to the area in each. A few townships were found upon the map for which no populations were reported in the census, and a few townships were reported in the census not shown on the map, these latter being apparently due to recent subdivisions of townships. These matters were straightened out as well as possible, and the rural population upon each water-shed section was then obtained by adding up all the population figures shown upon it. After obtaining the areas of, and the populations upon, the various sections, the sections were added together to give the totals for the larger sheds. The urban population was also calculated on each water-shed, the population, both by the census of 1890 and as estimated for the year 1900, being given. The urban populations of cities at the mouths of rivers are taken as being upon the water-sheds of those rivers.

The water-shed areas, rural and urban populations, are as follows:

SUMMARY OF WATER-SHEDS, AREAS AND POPULATION.

Water-Shed.	Total area, square miles	Populations			Population per Square Mile		
		Urban, 1890	Urban, 1900	Rural, 1890 and 1900	Rural	Urban 1900	Total 1900
Portage River	689	11,976	17,624	40,838	54	26	80
*Maumee "	4,704	149,572	221,953	248,730	53	47	100
Sandusky "	1,581	32,004	39,490	64,176	41	25	63
Huron "	510	10,247	13,371	26,170	51	26	77
Black "	479	14,850	27,325	21,968	46	57	103
Cuyahoga "	805	295,872	479,943	47,236	58	596	654
Grand "	670	7,558	9,000	27,257	40	13	53
Ashtabula "	129	8,338	15,642	6,327	49	121	170
*Beaver "	405	12,700	17,100	23.224	61	42	103
*Mahoning "	1,300	51,089	96,702	68,082	56	74	130
Hocking "	1,180	22,669	27,895	69,957	59	24	83
Raccoon Creek	648	4,377	8,000	26,872	47	12	59
Muskingum River	7,850	144,827	217,593	388,482	49	28	77
Scioto "	6,432	169,087	258,935	286,049	45	40	85
Little Miami "	1,742	15,644	18,331	100,541	58	10	68
Mill Creek	219	304,510	354,898	44,166	202	1620	1822
*Great Miami River	4,000	165,250	244,953	222,566	56	61	117
*Wabash "	317	2,702	5,424	17,742	54	17	71
Minor L. Erie Water-sheds	2,203	27,506	39,989	132,806	60	18	78
" Ohio River "	5,058	79,912	107,173	278,433	55	21	76
Totals	40,921	1,530,690	2,221,341	2,141,622	52	54	106

* Includes only that part of the water-shed which is in the State of Ohio.

The total rural population of the State computed in this way is 2,141,622, or 53 per square mile, and the urban population for 1890 is 1,530,630, the sum of these two being four less than the population for 1890 as given in the census.

The rural population is distributed over the State with remarkable regularity. On Mill creek alone, near Cincinnati, does the population exceed 61 per square mile, and this is a small shed, and a part of the population could perhaps be fairly classed as urban, although too much scattered to come within the definition. The rural population upon the Beaver river in the neighborhood of East Palestine, Lisbon and Salem amounts to 61 per square mile, and the minor water-sheds along the shore of Lake Erie have an average rural population of 60 per square mile. The water-shed of the Grand river, flowing into Lake Erie at Painesville, has a rural population of only 40 per square mile, while all the remaining water-sheds of the State are between 40 and 60. An examination of the sections of the larger water-sheds of the State by themselves also shows a very even distribution of population, the lowest single section examined being the water-shed of the Little Scioto river above Marion, with a rural population of only 22 per square mile.

The rural population is not very directly connected with the problem of stream pollution, but its presence upon a water-shed supplying water for a public supply is a source of more or less danger to that supply, although the danger is much less than from a corresponding urban population.

SIZE OF STREAMS.

The damage which a given amount of polluting material does in a stream is, in general, inversely proportional to the volume of water flowing in the stream, and it is thus important to know the relative sizes of the various streams of the state. The most obvious way to make this comparison is to determine the amount of water flowing in the various streams. Professor Brown has made some gaugings of several streams in this way, and it is to be hoped that his observations will be continued and extended to other streams.

The quantity of water flowing in any stream is subject to incessant fluctuation, and even when measurements can be secured of the requisite accuracy, it is very difficult to arrive at reliable comparisons of stream flows in this manner.

Another method of comparing stream sizes is to compare their drainage areas. The rainfall in different parts of Ohio is pretty nearly the same. Mr. H. W. Richardson of the U. S. Weather Bureau at Columbus, had kindly given me statements of the average precipitation at various points in the state for the thirteen years ending with 1895, the average of which are as follows by water-sheds.

Rivers	Number of Stations	Average Annual Precipitation
Great Miami	4	34.72
Maumee	3	34.81
Mahoning	5	35.07
Sandusky	2	35.18
Cuyahoga	3	37.27
Muskingum	8	38.32
Scioto	8	38.38
Little Miami	2	39.25
Hocking	2	40.22
All others	8	37.86

The rainfall upon the southern part of the state is somewhat greater than upon the northern part. This difference, however, is not very great, and generally speaking, the quantity of water which falls upon a given water-shed in the course of a year is pretty closely proportional to the area of the water-shed.

Of the water which falls upon a given water-shed, a certain proportion is either directly or ultimately evaporated into the air; the rest flows off in the water courses. The proportion which is evaporated is dependent to a limited extent upon the physical condition of the water-shed and is substantially independent of its size. The proportion evaporated is dependent in a measure on the mean annual temperature, being greater with higher temperature. The southern part of the state has both a greater precipitation and higher temperature, and these two factors thus tend to offset each other equalizing the run off for the streams of the state.

It can thus be said that the total quantity of water flowing from a given shed in the course of a year, and also the average daily discharge from the water-shed, are substantially proportional to the area of the water-shed. Now the areas of the water-sheds of the various rivers at different points in their courses can be determined from our map with comparative ease and accuracy, and we thus secure indirectly the relative average volumes of the stream flows.

This computation leaves out an important element, namely, the variation in stream flow. Streams draining large flat and sandy water-sheds are less subject to flood and their flows are better maintained in drought than streams coming from water-sheds with steep and impervious slopes. The average flows are nearly the same in the two cases, but the extremes are very different.

Looking at a raised map of the state of Ohio we see that the Sandusky and Maumee water-sheds are very flat. The Great Miami water-shed is rather flat, as is also the northern part of the Scioto water-shed, while the southern part of the Scioto and the water-sheds of the Muskingum, Hocking, Cuyahoga and Mahoning rivers have much steeper slopes, and the streams flow as a rule through relatively narrow and deep valleys. These differences require to be kept in mind, but the relative average flows, as indicated by the drainage areas, will be of substantial assistance to us.

To present this data in a readily understood form a plotting has been made of the principal rivers of the state. The horizontal distances are in miles as the water flows, while the width of line below represents at every point the drainage area and consequently the average volume of stream flow at that point, subject to the above mentioned corrections. This chart indicates at a glance and with substantial accuracy the relative lengths of the various rivers and their comparative volumes and their increases in volume from points near their head waters to their mouths. Above the distance line have been plotted the urban populations, as estimated for the year 1900, tributary to the rivers above the points shown.

If all the cities and towns rated as urban population were completely sewered this upper line would show the total amount of sewage discharged into each stream above each point, and the ratio of the urban population to the drainage area would indicate the total pollution of the various streams. The wider the line above in proportion to the line below, the greater the pollution. This is, however, far from being the case, as in even the larger cities a considerable proportion of the population is not connected with sewers, and in the smaller cities the proportion not connected is much larger, while many of the towns are not sewered at all. To complete this investigation it would be necessary to make an estimate of the proportion of population in each town connected with sewers entering the streams, and to make corrections accordingly on the diagram, and corrections should also be made for those cities and towns which treat or purify their sewage before discharging it. This investigation, however, has not been feasible within the limits of time available for this preliminary report.

Another element which must be taken into account in connection with this diagram is the use of water from certain streams in the state canals. Canals follow the Maumee, Auglaize, Great Miami, Scioto, Muskingum, Tuscarawas and Cuyahoga rivers, for parts or the whole of their lengths. These canals are fed near certain summits by reservoirs, otherwise they are fed from the streams near which they lie, and when required, all the water of the streams is taken for canal feeding. Of course a large part of this water ultimately finds its way back into the streams by seepage or otherwise, so that the loss is not by any means as great as might at first appear, but at points immediately below where the streams are so taken there may be but little water in the stream beds at times of drought, and the streams are thus reduced much below their natural sizes. On the other hand a certain quantity of water is diverted from the head waters of the Great Miami to the Auglaize, and from the head waters of the Tuscarawas to the Cuyahoga river, but these diversions are probably not sufficient to very largely affect the questions of stream pollution. The most important points where streams are used for canal feeders are indicated by the word "Canal" on the diagram, and the points where they are taken for the public water supplies of cities or towns are similarly indicated by the letters "W. S."

The relative pollutions as indicated on this diagram are such as would result if there were no self-purification of rivers. That is to say, all of the polluting population is carried forward and shows as an aggregate regardless of its distance. That is, of course, far from being the case, and while self-purification is often exaggerated, the pollution from a population at a remote point is much less than from a corresponding population near by.

The following tabular statement has been prepared of the watershed areas of the streams at each city or town in the state in comparison with their populations. The ratios thus secured indicate the pollutions which would result if the whole population at each place were connected with the sewers and discharging into equally pure water. That is to say, in this comparison the pollutions above each town are entirely ignored, and only the pollutions arising from the town itself are considered. This comparison, is, of course, far from the truth, especially where a series of towns of considerable size occur on the smaller rivers within a limited distance.

A true comparison would lie between the figures thus obtained and those which are plotted in the diagram, sometimes nearer one, sometimes nearer the other, depending upon the water stage and a whole series of conditions far too complex to allow of successful analysis with the data at our disposal.

TABLE OF URBAN POPULATIONS IN RELATION TO WATER-SHED AREAS.

PLACE.	Serial number order of size 1890.	Population in 1900.	NAME OF STREAM.	Area of water-shed — Square miles.	Square miles of water-shed per 1000 population	Water & sewers.
Salem	48	8,267	No streams having measurable areas shown on the map.			W S
Bowling Green	77	7,810				W S
Van Wert	52	7,448				W
Bellefontaine	69	4,507				W
Bellevue	87	4,295				W
Ashland	74	4,233				W
Barnesville	83	4,224				
Hillsboro	71	4,052				W
Ravenna	78	3,587				W S
Bryan	86	3,189				W S
East Palestine	112	3,150				W
Leetonia	94	3,129				W
Corning	118	2,500				W S
Clyde	104	2,275				W S
Orrville	113	2,162				W
Wadsworth	117	2,032				W S
Cadiz	114	1,923				W
Madisonville	106	3,848	Creek	5	1.3	W S
Akron	8	46,132	Creek	66	1.43	W S
			(*Cuyahoga, 3 miles below*)	*409*	*8.85*	
Xenia	36	7,587	Creek	12	1.6	W S
			(*Little Miami, 3 mi. bel.*)	*251*	*33.0*	
Hicksville	107	3,782	Creek	7	1.85	W
Oberlin	65	5,907	Plumb Creek	12	2.03	W S
Canton	9	55,952	Nimishillen Creek	115	2.05	W S
Mansfield	16	18,410	Mansfield Creek	39	2.12	W S
Shawnee	80	3,850	Monday Creek	12	3.1	
Fostoria	39	10,000	E. Br. Portage River	32	3.2	W S
Springfield	7	49,073	Buck Creek	158	3.22	W S
			(*Mad River, 3 mi. bel.*)	*456*	*9.3*	
Galion	43	7,102	Olentangy River	29	4.1	W S
Lima	14	25,000	Ottawa River	114	4.6	W S
London	79	3,578	Creek	18	5.0	W S
Eaton	91	4,017	Seven Mile Creek	22	5.5	W
Wellston	64	8,000	Little Raccoon Creek	47	5.87	W S partial 2 outl'ts
Marion	27	17,783	Little Scioto, 5 mi. bel.	109	6.15	W S
			(*Scioto, 7 miles below*).	*536*	*30.0*	
Lebanon	88	3,442	Creek	22	6.4	W
Lancaster	35	8,390	Hocking River	54	6.45	W S
Alliance	33	12,483	Mahoning River	82	6.60	W S
Crestline	92	3,500	Sandusky Riv., 2 mi. bel.	23	6.6	W
Jackson	67	6,177	Salt Creek	43	7.0	
Wilmington	85	3,454	Todds Fork, 4 mi. below	25	7.3	
Carey	116	2,244	Creek	21	9.5	W
Delphos	60	5,347	Jennings Creek	52	9.8	W S
Norwalk	37	9,076	Huron River	94	10.4	W S
Bucyrus	45	9,306	Sandusky River	98	10.5	W S
Salineville	103	2,438	Yellow Creek	26	10.7	W
Columbus	3	150,452	Scioto Riv. and Alum Ck.	1,784	11.9	W S
Reading, Lockland and Hartwell	34	9,387	Mill Creek	120	12.8	W S

TABLE OF URBAN POPULATIONS—CONTINUED.

PLACE.	Serial number order of size 1890.	Population in 1900.	NAME OF STREAM.	Area of water-shed — Square miles.	Square miles of water-shed per 1000 population.	Water & sewers.
North Baltimore	93	5,000	Middle Branch Portage	67	13	W S
Youngstown	6	71,420	Mahoning River	967	13	W S
Washington Court House	49	8,681	Paint Creek	120	13	W S
Greenville	53	8,474	Green Creek	119	14	W
Findlay	11	20,000	Blanchard River	322	16	W S
Shelby	109	2,089	Black Fork	37	17	W S
Marysville	95	3,831	Mill Creek	70	18	W S
St. Marys	89	5,158	St. Marys River	99	19	W
Kenton	51	7,838	Scioto River	153	19	W S
Minerva	120	2,296	Sandy Creek	47	21	W
Celina	98	5,424	Beaver Creek	130	24	W
Urbana	42	6,779	Spring Creek, 2 mi. away	166	25	W
Newark	15	21,210	Licking River	525	25	W S
Wapakoneta	72	4,728	Auglaize River	128	27	W
Dayton	5	96,899	Great Miami River	2,606	27	W S
Wooster	47	5,963	Killbuck Creek, 2 mi. bel.	172	29	W
Massillon	23	14,899	Tuscarawas River	471	32	W S
Mt. Vernon	44	6,920	Owl Creek	250	36	W S
Lisbon	105	2,554	Middle Fork Beaver Ck.	98	38	W S
Delaware	30	9,810	Olentangy River	422	43	W&Pr.S
Oxford	111	2,119	Four Mile Creek	96	45	W
Toledo	4	132,260	Maumee River	6,615	50	W S
Elyria	50	6,591	Black River	405	61	W S
Piqua	25	13,699	Great Miami River	878	64	W S
Uhrichsville & Dennison	40	10,927	Stillwater River	738	68	W S
Cambridge	66	6,597	Wills Creek	455	69	W
Tiffin	22	14,807	Sandusky River	1,042	70	W S
Warren	46	8,057	Mahoning River	596	74	W S
Painesville and suburbs	57	9,000	Grand River	670	74	W S
Upper Sandusky	73	3,604	Sandusky River	290	80	W S
Kent	75	3,704	Cuyahoga River	315	85	W
Nelsonville	59	6,712	Hocking River	572	85	W S
Greenfield	102	2,876	Paint Creek	247	86	W
Sidney	56	6,153	Great Miami River	561	91	W
Logan	84	3,649	Hocking River	520	143	W S
Hamilton	13	25,458	Great Miami River	3,652	144	W S
Niles	68	4,742	Mahoning River	815	172	W S
Troy	63	5,311	Great Miami River	931	175	W
Millersburg	110	2,038	Killbuck Creek	391	193	W
Montpelier	119	2,500	St. Joseph's River	530	212	W S
Fremont	38	6,029	Sandusky River	1,283	213	W S
Cincinnati	1	345,511	Ohio River	75,700	219	W S
New Philadelphia	61	6,468	Tuscarawas River	1,446	223	W S
Middletown	32	13,009	Great Miami River	3,164	244	W S
Zanesville	10	24,367	Muskingum River	6,639	272	W S
Chillicothe	19	11,646	Scioto River	3,755	322	W S
Athens	99	2,794	Hocking River	919	330	W S
Canal Dover	76	3,453	Tuscarawas River	1,401	405	W
Circleville	41	7,109	Scioto River	3,160	445	W S
Defiance	31	10,021	Maumee River	5,680	566	W S
Miamisburg	90	4,501	Great Miami River	2,735	607	
Harrison	115	1,831	White Water River	1,350	740	W
Franklin	97	3,123	Great Miami River	2,753	880	W S
Coshocton	70	4,430	Muskingum River	4,370	1,070	W
East Liverpool	20	21,558	Ohio River	23,330	1,080	W S

TABLE OF URBAN POPULATIONS—CONCLUDED.

PLACE.	Serial number order of size 1890.	Population in 1900.	NAME OF STREAM.	Area of water-shed—Square miles.	Square miles of water-shed per 1000 population.	Water & sewers.
Steubenville	17	14,833	Ohio River	23,710	1,600	W S
Bridgeport and Martins Ferry	28	14,968	Ohio River	24,400	1,630	W S
Bellaire	24	12,297	Ohio River	24,800	2,020	W S
Marietta	29	15,000	Ohio River	26,730	2,300	W S
Napoleon	96	2,520	Maumee River	5,820	2,309	W S
Wellsville	54	8,153	Ohio Oiver	23,350	2,880	W
Portsmouth	18	18,000	Ohio River	61,166	3,750	W S
Ironton	21	13,511	Ohio River	60,000	4,450	W S
Toronto	100	5,000	Ohio River	23,680	4,700	W S
Pomeroy	58	3,963	Ohio River	28,900	9,800	W
Gallipolis	62	4,598	Ohio River	51,500	11,200	W
Middleport	82	3,432	Ohio River	38,900	11,400	
Ripley	101	2,422	Ohio River	68,700	28,500	W S
Cleveland	2	426,517	Lake Erie	....	....	W S
Sandusky	12	21,541	Lake Erie	....	....	W S
Ashtabula	26	15,642	Lake Erie	....	....	W S
Lorain	55	14,827	Lake Erie	....	....	W S
Conneaut	81	8,363	Lake Erie	....	....	W S
Port Clinton	108	2,624	Lake Erie	....	....	W S

W indicates a public water supply. *S* that sewers more or less extensive are in use.

SEWAGE DISPOSAL.

The question of sewage disposal must be regarded from two entirely different standpoints, namely, from the standpoint of water-supply and from that of local nuisance. I shall take up first the question of local nuisance, and afterwards the bearing upon water supply.

LOCAL NUISANCE.

When sewage is discharged into a stream it may cause local nuisance in either or all of several ways. (1) It may deposit its suspended matters, forming banks of sewage mud which putrefy and give rise to offensive odors, are unsightly in appearance when exposed, and may obstruct the channel; or (2) the whole body of water into which sewage is drained may be rendered foul and of objectionable odor; or (3) floating particles of grease and other matters may be deposited on various shores and thereby cause offense.

The formation of sewage mud takes place principally in sluggish streams or in mill ponds, and will take place without much reference to the relative volumes of sewage and stream flow. If, however, the quantity of sewage is not large, and especially if the stream is subject to considerable floods, the deposits may not sufficiently accumulate to cause serious nuisance between the periods when the bed is reasonably well scoured out by flood flows.

Some streams are so sluggish that their beds are never scoured out, or only at intervals of some years, and such streams are specially liable to become offensive when sewage is discharged into them. The nuisance caused by floating particles is also largely dependent upon the character of the stream, and is usually less serious than the formation of deposits.

The putrefaction of the water of a stream as a whole results from the discharge into it of more polluting matters than can be oxidized by the dissolved oxygen in the water of the stream, and that which is absorbed before the water becomes objectionable. Sewage can be discharged into a stream up to the point where the greater part of the dissolved oxygen is removed without creating serious nuisance in this way. As long as the oxygen is everywhere in excess the organic matters in the sewage are more or less rapidly oxidized and destroyed without the formation of injurious products. When the quantity of sewage becomes so great that there is no longer oxygen enough to take care of all the matters requiring it, a part of the matters decomposes in the absence of oxygen and with the formation of sulphuretted hydrogen, carburetted hydrogens and other gases of powerful and disagreeable odors.

The amount of sewage which a given stream can receive without being overtaxed depends somewhat upon the amount of polluting material in the water before sewage is added. A pure mountain stream will carry more sewage without showing it than will a stream already considerably polluted, although as yet unobjectionable. It also depends somewhat upon the rapidity of flow, a stream having a rapid flow and fall having better opportunities for the absorption of oxygen than a sluggish stream.

The quantity of water required to dilute the sewage from a given population so that no nuisance will be created is commonly stated at from one and a half to four cubic feet of water per second per thousand of population. In the case of sluggish streams, or of streams the waters of which are already somewhat polluted, the quantity required for proper dilution may be increased to six, eight or even ten cubic feet per second per thousand of population.

The flow of water from streams like those in Ohio in times of drought is frequently as low as one-tenth of a cubic foot per second per square mile of drainage area, and may occasionally be much less. With this quantity of run off, and with the smallest suitable amount of dilution a stream would be required, having a drainage area of from 15 to 40 square miles for every thousand inhabitants, to properly dilute the sewage without creating a local nuisance. An inspection of the tables of areas and populations given above makes it apparent that very many streams are so small that cities and towns upon them will find it necessary to seek other methods of disposal than the simple discharge of crude sewage, in order to prevent the creation of local nuisances in the streams below. The following is a tabular statement of the cities and towns having sewage disposal works, or where such works seem likely to be required either at once or ultimately or when sewers shall be constructed.

SEWAGE DISPOSAL.

SEWERED.			NOT SEWERED.	
Having Disposal Works.	Works required now or in near future.	Works may be required.	Works will be required when sewers are built.	Works may be required when sewers are built.
(1)	(2)	(3)	(4)	(5)
‡Oberlin.	‡Salem.	Findlay.	Bellefontaine.	St. Marys.
Canton.	Bowl'g Green.	Shelby.	Bellevue.	Minerva.
‡Alliance.	Clyde.	‡Marysville.	Ashland.	Celina.
Fostoria. (in construction.)	Ravenna.	Kenton.	Barnesville.	Urbana.
	‡Bryan.	Newark.	Hillsboro.	Wapakoneta.
	Corning.	Dayton.	East Palestine.	
	Wadsworth.	Massillon.	Leetonia.	Wooster.
	Madisonville.	Mt. Vernon.	Orrville.	‡Delaware.
	Akron.	Lisbon.	Cadiz.	Oxford.
	Xenia.	Toledo.		Cambridge.
	Mansfield.	Elyria.	Hicksville.	
	Springfield.	Piqua.	Shawnee	
	Galion.	Uhrichsville and Dennison.	Eaton.	
	Lima.	‡Tiffin.	Lebanon.	
	London.		Crestline.	
	Wellston.		Jackson.	
	‡Marion.		Wilmington.	
	Lancaster.		Carey.	
	Delphos.		Salineville.	
	Norwalk.		Greenville.	
			Van Wert.	
	Bucyrus.			
	Columbus.			
	Reading, Lockland and Hartwell.			
	North Baltimore.			
	Youngstown.			
	‡Washington Court H'se.			

NOTE—Glenville has disposal works in course of construction. Glenville is a suburb of Cleveland, and its population is included in that estimated for Cleveland.

‡ Stream used for public water supply at a point or points in the state not more than fifty miles below. Warren, Upper Sandusky, Niles, Defiance and Napoleon also discharge sewage into streams used for water supply within fifty miles below.

In the above table those cities and towns having less than 15 square miles of drainage area per thousand of population are grouped together, and those having from 15 to 70 square miles are grouped together, 15 miles being taken as the smallest possible drainage area per thousand to give sufficient dilution to prevent local nuisance, with the climatic and geological conditions of the State of Ohio.

This limit was reached as much by an inspection of the table in connection with the known conditions of certain streams of the state as from theoretical considerations, and the same is true of the limit of 70 miles. It must, of course, be borne in mind that in preparing this table no account is taken of the different physical conditions of the beds of the streams below the points of discharge, nor of the different conditions with respect to maintaining large minimum stream flows. These conditions have not been considered because of inadequate data. Such data can be secured by more extended and minute examinations.

The question as to the necessity or advisability of establishing sewage disposal works is also dependent upon the population living in the immediate neighborhood of the stream below the point of sewage discharge and the damage which they suffer by reason of it. The extent of the damage resulting from stream pollution must be considered in connection with the cost of purifying sewage, and the question must be settled as to whether or not the inconveniences suffered are sufficient to justify the expenditures required for sewage purification.

The odors arising from a sewage polluted stream may be, in a broad sense, unhealthy, but as far as known, under ordinary conditions they do not directly cause serious disease, but are principally objectionable because of their disagreeable qualities. It is a serious question whether the purification of the sewage of a city, involving large expenditures of money, is warranted, if the most serious damage which can be shown to result from its discharge untreated is the occasional production of slight or moderate odors at points where they can affect only a scattered population below the outfall.

Without attempting to draw any general conclusions it will be readily seen that the damage caused by a given amount of pollution and the resulting fermentation and evolution of offensive smelling gas depends very largely upon the character of the country through which the stream flows below the point of sewage discharge. In view of these and other conditions the table given must not be taken as a final statement of the necessity of sewage disposal in Ohio, but rather as a provisional classification for aid in further study.

Taking up the columns of the table in order, the first column contains four cities and towns having sewage disposal works in operation or construction. Two of these towns, Oberlin and Fostoria, dispose of their sewage by irrigation or intermittent filtration; and two, Canton and Alliance, by chemical precipitation.

The second column contains twenty-six cities and towns having sewers but not having sewage disposal, and having drainage areas of less than 15 square miles per thousand of population. It would be expected that more or less local nuisance would be caused at times in the streams below the points of discharge of sewage from these cities and towns. Such nuisances are caused in many cases. In other cases the sewerage systems are very incomplete as yet, and the population actually discharging into the streams is much smaller than the total population, so that the conditions of stream pollution are not yet as critical as they will be when the sewerage systems are more completely developed. Others perhaps have unusually favorable conditions for the discharge of sewage, or the populations of the streams below may not warrant at present the expense of sewage purification.

The third column contains fourteen cities and towns upon streams having water-shed areas of from 15 to 70 square miles per thousand of population. In some of these cases local nuisances have already been caused and suggest the necessity of sewage purification, and it is probable that sewage works will be required sooner or later in a number, if not all, of these cities and towns.

Columns 4 and 5 contain the names of twenty-nine towns which are not as yet sewered, but which have been divided into two classes, according to the relative sizes of their water-sheds, corresponding to columns 2 and 3. When sewers are built in these towns the question of sewage disposal will require to be considered, and sewage disposal will probably be required by most of the towns in column 4 and some of the towns in column 5.

The remaining forty-seven cities and towns of the state classed as urban population and not included in this table are upon streams with more than 70 miles of drainage area per thousand of population, or upon Lake Erie. The local conditions in some of these cases may be unfavorable for the discharge of crude sewage, and it may be found desirable to treat the sewage in such cases, but in general the pollutions are less pressing than in the places enumerated above.

SEWAGE DISPOSAL WITH REFERENCE TO WATER SUPPLY.

One of the most serious questions presented is the discharge of sewage into streams above points where those streams are used for public water supplies. At the present time in the State of Ohio, with very few exceptions, river waters are used by cities and towns only in their raw state. The use of water taken from such rivers mixed with sewage is an unhealthy and highly objectionable habit.

Two ways suggest themselves for correcting this condition; to purify the sewage before it is discharged into the streams, or to purify the water before supplying it to the cities. From the standpoint of any particular city, the latter is the more efficient method, but the other is worth considering, especially if other objects are accomplished at the same time. With some European rivers the purification of both sewage and of river water is insisted upon, thus giving a double line of protection, which is certainly advisable in cases of very dense populations upon water-sheds.

This problem must be considered, not only with reference to water supplies now taken from streams, but also with reference to those cities which may ultimately find themselves compelled to use river waters, although not at present so supplied.

The problems presented will be best understood by a brief consideration of the present sources of public water supply, their possibilities, and the lines of development most likely to be followed to meet the needs of the increasing populations of the various cities.

PUBLIC WATER SUPPLIES.*

About two-thirds of the public water supplies now in use are taken from wells or other underground sources, but the average populations of the towns and cities so supplied are much less than of those municipalities using surface supplies. For the smaller towns underground sources will continue to be used, and are usually the best available sources of supply; and for the larger cities also as far as sufficient water can be obtained in this way.

The difficulties in securing water from underground sources increase much more rapidly than the volume of supply required. A gravel deposit which yields half a million gallons of water daily with ease may completely fail to yield a million gallons, even though the number of wells and other collecting appliances is very greatly increased.

The underground waters are among the most valuable resources of the state, and deserve to be most carefully studied, developed and improved. By the use of better and more systematic methods larger volumes of water can be secured in this way, and by the use of meters, and with other precautions against waste, the present quantities can be made to supply much larger populations. The excessive hardness and iron which at present render some of them unpleasant can be removed by suitable treatments and at not excessive expense, yielding waters of the greatest purity, and absolutely free from the germs of infectious disease.

There are probably localities where the geological conditions do not admit of obtaining sufficient underground supplies for the requirements of the present or of larger cities, which we may confidently expect will ultimately be found in the interior of the State of Ohio, and the problem of supplying these cities with water is indeed a very serious one.

The quantity of water which can be drawn from a stream is often limited. In connection with sewage disposal it was stated that stream flows often fall to as little as one-tenth of a cubic foot a second, or 64,000 gallons daily per square mile of water-shed area, and occasionally to much lower quantities. It is assumed that the average consumption of water is 100 gallons per capita daily. One thousand

* Many data used in the following paragraph have been taken from the American Water Works Manual, by M. N. Baker, edition of 1897.

people will thus require one hundred thousand gallons daily, requiring 1.6 square miles of drainage area to supply them. The run off is often less than a tenth of a foot per square mile, and in continued very dry weather may become much less. If it fall to two-hundredths of a cubic foot a second per square mile, eight square miles of drainage area will be required to supply water to each thousand of population.

An inspection of the table on page 29 shows that this area is not available at some of the cities of the state, even with the present populations. That is to say, some of the cities of Ohio are upon streams so small that at times of drought the entire streams may be pumped into the water supply pipes without meeting the legitimate requirements for water of even the present population.

The average stream flows for the whole year are, of course, many times greater. In the Atlantic States storage reservoirs are often built upon small streams, which collect the flood flows and hold them until they are required in times of drought.

Such reservoirs have not as yet been used to any considerable extent for water supply purposes in Ohio, nor indeed in any part of the Middle States. Some of the summit levels of the canals have been fed from storage reservoirs, and a reservoir is under consideration upon the Scioto river for the supply of the city of Columbus.

There are some good reasons why storage reservoirs have not been used for water supply purposes in Ohio. In topography the state is rather flat, particularly that part of it where water supplies are most required, there being no cities among the hills in the southeastern part of the state not situated so as to readily secure other sources of supply. A storage reservoir constructed by damming a stream in a flat country results in a large amount of shallow flowage. The land flowed is valuable and the damage heavy. The rich soil which forms the bottom affords abundant food supply for innumerable organisms which impart disagreeable tastes, odors and appearances to the water stored. If this condition is corrected by removing the soil from the flowed area, and by extensive cuts and fills to avoid excessively shallow flowage, the condition is much improved, but at very heavy expense, and even then it may be difficult or impossible to secure adequate depth in all parts of the reservoir.

In those places where valleys exist apparently more favorable for storage reservoirs, the formation is often limestone, containing cavities and fissures which may carry the water off in other directions than those intended, defeating the purpose for which the reservoirs were built.

The construction of storage reservoirs to allow relatively large water supplies to be taken from small streams is thus much more difficult than in the Atlantic States, but there may very likely be found places where such supplies can be used, and will ultimately have to be used, to furnish the quantities of water absolutely required.

The cities upon the Ohio river having public water supplies take them from that river, and without filtration, with the exception of one town taking it by means of wells on an island. The use of water from the Ohio river at all points is considered unhealthy and objectionable. The amount of sewage which it receives is very large. A large part of the pollution comes from cities outside of the state limits. It is estimated that of the urban population on the watershed of the Ohio river and its tributaries above Cincinnati forty per cent. is in the State of Ohio, and sixty per cent. in the States of New York, Pennsylvania, West Virginia and Kentucky. The question of sewage discharge in the Ohio river is thus an inter-state rather than a state question, and this use of the river is not likely to be given up in the near future. The water of the Ohio river can be sufficiently purified by adequate filtration; and thus purified, its water will probably be the best source of supply for the cities upon its banks.

The cities upon Lake Erie draw their water supplies from it. A large amount of sewage is discharged into the lake by the cities upon its shores, and into the tributaries of the lake all over the vast watershed feeding it. It is believed, however, that owing to the enormous dilution and the natural purifying agencies which have unusual opportunities for their operation in the Great Lakes, the water of the lake is suitable for the purpose of public water supply when taken well out in the lake and away from all points of local pollution. Unfortunately many of the present intakes are not so situated, and are subject to very serious local pollutions. It seems reasonably certain that Lake Erie will always continue to be used as a source of supply by all the cities upon its banks, and perhaps also by some of the cities not too far removed from it to make such a supply impracticable. The present methods of using the lake water will in many cases require to be improved either by changing the position of the intakes to points not subject to local pollutions, or by filtering the water before using it.

The smaller interior cities and towns, and the larger ones as far as they are favorably situated, will continue to use ground water. These ground waters are often hard and contain iron, and will be improved by softening, which can be so arranged as to also remove the iron. Some of the interior cities not able to secure ground water are situated upon the larger rivers of the state and will continue as at present to use those river waters, but with filtration.

There remain some cities that will not be able to secure sufficient water either from underground sources nor from the streams, and these cities will ultimately be forced to take radical measures for securing sufficient water.

In the following table are given all the cities and towns taking public water supplies from interior streams, as reported in the American Water Works Manual for 1897, together with the drainage areas of the streams, as nearly as can be determined from our map, at the points of intake, and the rural and urban populations per square mile, the rural populations being computed from the census of 1890 and the urban population being that estimated for the year 1900.

PUBLIC WATER SUPPLIES TAKEN FROM INTERIOR STREAMS.

Water supply of	Population.		Supply from what River.	Drainage Area: Square Miles.	Population per Square Mile on Drainage Area.	
	1890.	Estimated 1900.			Urban. 1900.	Rural. 1890.
Norwalk	7,195	9,076	Huron,	90	0	40
Wellston	4,377	8,000	Raccoon Creek		0	45
Findlay	18,553	20,000	Blanchard,	218	0	50
Alliance	7,607	12,483	Mahoning,	75	0	51
Fostoria	7,070	10,000	Creek,	30	0	55
Cambridge	4,361	6,597	Wills Creek,	300	0	55
Greenfield	2,460	2,876	Paint Creek,	245	4	41
Uhrichsville & Dennison	6,767	10,927	Big Stillwater,	372	11	49
Piqua	9,090	13,699	Canal	561*	(12)	49
Elyria	5,611	6,591	Black,	400	15	45
Tiffin	10,801	14,807	Sandusky,	1,040	18	40
Warren	5,973	8,057	Mahoning,	590	21	44
Toledo	81,434	132,260	Maumee,	6,600	21	(53)
Napoleon	2,764	2,520	Maumee,	5.820	24	(50)
Fremont	7,141	6,029	Sandusky,	1.280	26	40
Defiance	7,694	10,021	Maumee,	2,412	26	(45)
Harrison	1,690	1,831	White,	1,350	27	
Youngstown	33,220	71,420	Mahoning,	950	27	51
Zanesville	21,009	24,367	Muskingum,	5,875	27	51
Columbus	88,150	150,452	Scioto,	1,070	28	46
Bucyrus	5,974	9,306	Sandusky,	95	37	34
Lisbon	2,278	2,554	Creek,	90	126	70

*Great Miami river.

The urban populations upon the water-sheds furnishing water to the last 16 places given in the table are shown more in detail in the following table.

MOST IMPORTANT POINTS OF POLLUTION OF PUBLIC WATER SUPPLIES.

(INTERIOR STREAMS ONLY.)

Water supply of.	From what Stream.	Places Polluting River.	Estimated Populat'n in 1900.	Distance: above water works, Miles	Whether Sewered or not.
Greenfield........	Paint Creek,	Washington C. H.	8,681	15	Yes.
Uhrichsville & Dennison......	Big Stillwater River,	Barnesville,	4,224	44	No.
Piqua	Canal, fed from Great Miami River,	Part of Sidney,	6,153	12	Private Sewer.
		Bellefontaine,	4,507	40	No.
Elyria............	Black River,	Oberlin,	5,907	10	Yes. Sewage Farm.
Tiffin............	Sandusky River,	Carey,	2,244	28	No.
		Upper Sandusky,	3,604	34	Yes.
		Bucyrus,	9,306	58	Yes.
		Crestline,	3,500	74	No.
Warren.....	Mahoning River,	Alliance,	12,483	38	Yes. Chemical Precipitation.
Toledo	Maumee River,	Napoleon,	2,520	40	Yes.
		Defiance,	10,021	57	Yes.
		Lima,	25,000	115	Yes.
		Findlay,	20,000	124	Yes.
		Ft. Wayne,	46,389	109	Yes.
		and others.			
Napoleon.........	Maumee River,	Defiance,	10,021	17	Yes.
		Lima,	25,000	75	Yes.
		Findlay,	20,000	84	Yes.
		Ft. Wayne,	46,389	69	Yes.
		and others.			
Fremont..........	Sandusky River,	Tiffin,	14,807	22	Yes.
		Bucyrus,	9,306	80	Yes.
		and others.			

MOST IMPORTANT POINTS OF POLLUTION OF PUBLIC WATER SUPPLIES.

(INTERIOR STREAMS ONLY.)

[CONCLUDED.]

Water supply of.	From what Stream.	Places Polluting River.	Estimated Populat'n in 1900.	Distance: above water works, Miles	Whether Sewered or not.
Harrison..........	White River,	Richmond, Ind.,	21,546	......	Yes.
		Connersville, Ind.,	6,424	.....	Yes.
Defiance..........	Maumee River,	Hicksville,	3,782	25	No.
		Ft. Wayne, Ind.	46,389	47	Yes.
		Decatur, Ind.,	5,183	72	Yes.
		Montpelier,	2,500	108	Yes.
		St. Marys,	5,158	128	No.
Youngstown.....	Mahoning River,	Niles,	4,742	9	Yes.
		Warren,	8,057	14	Yes.
		Alliance,	12,483	52	Yes. Chemical Precipitation.
Zanesville........	Muskingum River,	Coshocton,	4,430	30	No.
		Millersburg,	2,038	59	No.
		Cambridge,	6,597	67	Plans.
		Mt. Vernon,	6,920	68	Yes.
		Uhrichsville & Dennison.	10,927	70	Yes.
		Mansfield,	18,410	93	Yes.
		Massillon,	14,899	103	Yes.
		Canton, and others.	55,952	107	Yes. Chemical Precipitation.
Columbus...	Scioto River,	Marysville,	3,831	38	Yes.
		Marion,	17,783	46	Yes.
		Kenton,	7,838	65	Yes.
Bucyrus	Sandusky River,	Crestline,	3,500	16	No.
			3,129	10	
Lisbon	Creek,	Leetonia,	8,267	11	No.
		Salem,			Yes.

The following cities and towns have mixed supplies, or supplies from small water-sheds, the data in regard to which are inadequate. As far as surface waters are used, there is no urban population upon the water-sheds.

PLACE.	Population 1890	Estimated Population in 1900.	Source of Supply.
Canton	26,189	55,952	Artesian wells and creek.
Akron	27,601	46,135	Wells and lakes.
Lima	15,981	25,000	Wells and surface water.
Greenville	5,473	8,474	Driven wells and creek.
Oberlin	4,376	5,907	East branch Vermillion River.
Bellevue	3,052	4,295	Surface water.

The following are the largest cities reported as being supplied entirely with ground water:

PLACE.	Population 1890.	Estimated Population in 1900.
Dayton	61,220	96,899
Springfield	31,895	49,073
Hamilton	17,565	25,458
Newark	14,270	21,210
Mansfield	13,473	18,410
Marion	8,327	17,783
Massillon	10,092	14,899
Middletown	7,681	13,009
Chillicothe	11,288	11,646
Delaware	8,224	9,810

All cities and towns having public water supplies, not on Lake Erie or on the Ohio river and not mentioned above, are reported as being supplied with ground waters, usually from wells.

Seven towns classed as urban have as yet no public water supplies and are the largest places in the state not supplied. These towns are as follows:

PLACE.	COUNTY.	Population in 1890.	Estimated Population in 1900.
Pomeroy	Meigs	4,726	3,963
Jackson	Jackson	4,320	6,177
Shawnee	Perry	3,266	3,850
Middleport	Meigs	3,211	3,432
Barnesville	Belmont	3,207	4,222
Wilmington	Clinton	3,079	3,454
Miamisburg	Montgomery	2,952	4,501

The following is a list of villages not classed as urban, but having public water supplies. The list does not include, however, some small suburbs of Cincinnati having separate water supplies. Supplies are taken in every instance from wells or underground sources.

VILLAGES HAVING PUBLIC WATER SUPPLIES NOT CLASSED AS URBAN.

Place.	County.	Population in 1890.	Estimated Population in 1900.
Wauseon	Fulton	2,060	3,970
Tippecanoe City	Miami	1,465	1,533
Glendale	Hamilton	1,444	1,489
Granville	Licking	1,366	1,655
Louisville	Stark	1,323	1,667
Bluffton	Allen	1,290	1,290
Plain City	Madison	1,245	1,707
Chagrin Falls	Cuyahoga	1,243	1,276
Carrollton	Carroll	1,228	1,328
Willoughby	Lake	1,219	1,384
Blanchester	Clinton	1,196	1,843
Columbiana	Columbiana	1,112	1,201
Shreve	Wayne	1,012	1,128
Marice City	Putnam	896	......
Greenwich	Huron	881	1,200
Lynchburg	Highland	763	865
Mt. Sterling	Madison	752	1,179
Milford Center	Union	718	1,051
Osborn	Greene	713	772
Attica	Seneca	682	702
Milan	Erie	627	453
Dalton	Wayne	610	780
Perrysville	Ashland	522	569
West Carrollton	Montgomery	360	......
Barberton	Summit	......	......
Piedmont	Harrison	......	......
Rockford	Mercer	......	......

RECOMMENDATIONS AND CONCLUSIONS.

In the above report I have been able to little more than outline the problem of stream pollution as it presents itself in the state of Ohio. Most of the larger streams of the state are used for public water supplies. All of them are used as receptacles for sewage for at least a part of the cities and towns upon their banks. The water supplies taken from these streams below the points where they receive sewage are unhealthy, and measures are required for their improvement. In many cases also the quantities of sewage discharged are so great as to create serious local nuisances at the points of outfall.

Already something has been done to improve these conditions. Three municipalities in the state have works in operation for the treatment or purification of their sewage, and others are expected to follow, while several other cities are making more or less serious effort to purify their water supplies.

The larger cities of the state are all supplied with sewers serving at least considerable proportions of their populations. In the smaller cities and towns the proportions of people connected with the sewers are much smaller, while many considerable towns are not as yet sewered. These cities and towns are growing rapidly, and the proportions of the respective populations connected with the sewers will inevitably increase, so that the pollutions of the various streams will increase for a time much more rapidly than the increase in population.

The pollutions already existing in the rivers of Ohio may thus be expected to be greatly increased in the coming years. Your Board is vested with very great authority over matters of water supply and sewerage in those cases where new works are proposed. It is highly important that a comprehensive policy should be adopted with reference to the applications which are made for permission to discharge sewage into the various streams of the state. This policy should not be unnecessarily severe, putting burdens upon cities and towns which they are hardly able to meet, and which will delay the progress of sanitary improvements; but on the other hand it should be firm and should protect as far as possible riparian rights of municipalities and individuals in the waters of the streams below. To decide just where to draw the line will often be a delicate matter, requiring the best of judgment and the fullest consideration of all the facts involved.

Your Board should have all obtainable data in regard to all the streams of the state and the uses that are made of them, to assist it in arriving at wise and prudent decisions in the cases presented to it. Some of the data, the need of which has been made apparent in this preliminary investigation, are as follows:

(1.) Local conditions. The Board should be in possession of full information in regard to the water supply, sewerage and sewage disposal of each city and town of the state, having on file in its office maps showing the exact position of regular and emergency intakes from all streams used for water supply, and the points of discharge of all the sewers, and memoranda of the approximate population living upon the area drained by each sewer, and the population actually connected with it.

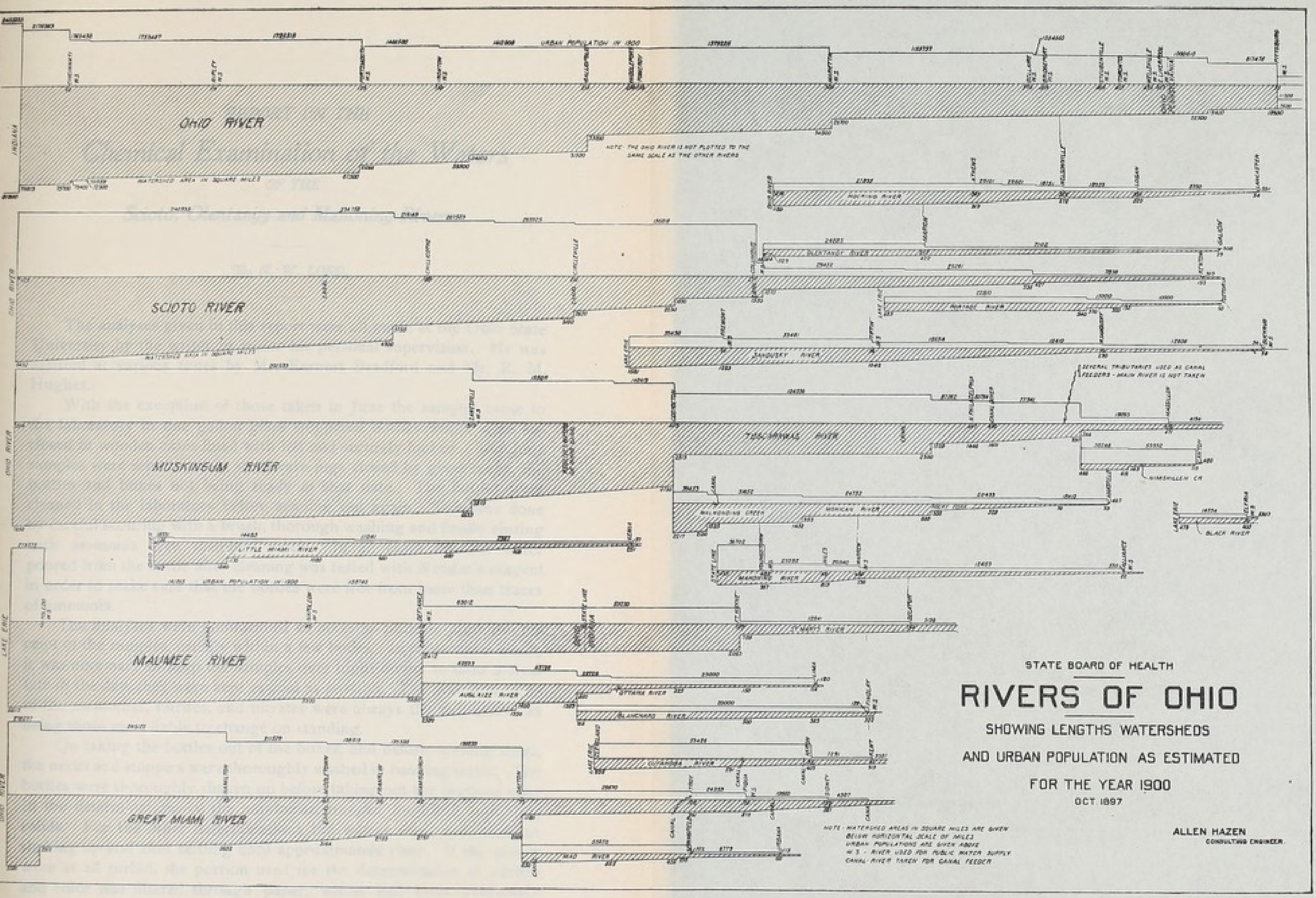
(2.) The Board should be in full possession of the fullest information in regard to the physical conditions of the beds of the various streams of the state, of the dams, pools, etc., and the rate of fall of the different parts of their courses, and of the water-shed areas at all points.

The water-shed areas given in this report have been secured from our own map measurements, and it is believed that all the figures for the larger water-sheds will be found sufficiently accurate for practical purposes. In the smaller water-sheds, however, which from a sanitary point of view, are often most important, there are probably larger relative errors, owing to lack of information as to the exact points of intakes and outfalls, and to difficulties in tracing with accuracy the water-shed limits upon a map with so small a scale as the one which we necessarily used. More precise information in regard to these points can be secured from examination of local maps, reconnaissance of the various towns, and in some cases from special measurements or surveys.

(3.) Information in regard to stream flow. The information at hand prior to the commencement of this work was almost nothing. The best estimates which could be had were based upon observations of stream flows in other parts of the country where climatic and topographical conditions were different. The gaugings made in 1897 are a step in the right direction; but to be of material service these gaugings must be continued for a long time so as to include periods of extreme minimum flows. It is highly desirable that continuous records should be kept of the discharges from representative streams throughout the year, and for a period of years, from which data sufficiently accurate conclusions can be made as to the probable discharges of other streams in the state.

(4.) Observations as to the effects of pollutions upon various streams, with reference both to their influence upon the public health of cities using the water for public water supplies below, and with reference to the creation of local nuisances. In regard to the latter it is desirable that the streams should be examined not only by chemical and biological analyses, but that all possible data should be collected as to the odors arising from such rivers, the extent of country affected by them, the number of people inconvenienced thereby and the seriousness of the inconveniences to which they are put.

This data taken in connection with the information as to the number of people directly contributing to the pollution of the streams, and of the stream flows at the particular times when odors were observed, will be of great value to the Board in enabling it to establish standards of stream pollution, which will be of the greatest service to it in deciding the questions presented, and in enabling it to anticipate and take measures to prevent stream pollutions detrimental to the public health and prosperity.



STATE BOARD OF HEALTH
RIVERS OF OHIO
SHOWING LENGTHS WATERSHEDS
AND URBAN POPULATION AS ESTIMATED
FOR THE YEAR 1900
OCT. 1897
ALLEN HAZEN
CONSULTING ENGINEER.
NOTE - WATERSHED AREAS IN SQUARE MILES ARE GIVEN BELOW HORIZONTAL SCALE OF MILES
URBAN POPULATIONS ARE GIVEN ABOVE
W. S. - RIVER USED FOR PUBLIC WATER SUPPLY
CANAL - RIVER TAKEN FOR CANAL FEEDER
OHIO RIVER
NOTE - THE OHIO RIVER IS NOT PLOTTED TO THE SAME SCALE AS THE OTHER RIVERS
SCIOTO RIVER
MUSKINGUM RIVER
MAUMEE RIVER
GREAT MIAMI RIVER
LITTLE MIAMI RIVER
HOCKING RIVER
OLENTANGY RIVER
SANDUSKY RIVER
TUSCARAWAS RIVER
WALHONDING CREEK
MOHICAN RIVER
MAHONING RIVER
ST MARYS RIVER
AUGLAIZE RIVER
OTTAWA RIVER
BLANCHARD RIVER
CUYAHOGA RIVER
MAD RIVER
BLACK RIVER
NIMISHILLEN CR.
SEVERAL TRIBUTARIES USED AS CANAL FEEDERS - MAIN RIVER IS NOT TAKEN
URBAN POPULATION IN 1900
WATERSHED AREA IN SQUARE MILES

REPORT ON THE

Chemical Examination of the Waters

OF THE

Scioto, Olentangy and Mahoning Rivers.

By N. W. LORD.

The analyses given in this report were all made at the Ohio State University by the writer or under his personal supervision. He was assisted at various times by Mr. Earnest Bradford and Mr. R. M. Hughes.

With the exception of those taken in June the samples came to the laboratory in one gallon glass stoppered bottles which were enclosed in wooden cases lined with felt and securely locked. The June samples were sent to me in stoneware jugs closed by good corks, the bottles and boxes not being ready at that date. The bottles were cleaned in the laboratory before sending out again. This was done by careful scouring with a brush, thorough washing and finally rinsing with ammonia free distilled water. In all cases the last water poured from the bottle after cleaning was tested with Nessler's reagent in order to make sure that the bottles were free from more than traces of ammonia.

The analyses were commenced as soon as possible after the receipt of the samples, usually within a few hours. In those cases where it was necessary to keep the samples over night owing to their arrival late in the day, they were kept as cool as possible. The determinations of the ammonias, nitrites, and nitrates were always the first made, as being those most liable to change on standing.

On taking the bottles out of the boxes, and before opening them, the necks and stoppers were thoroughly washed in running water. The bottles were thoroughly shaken up before taking out the portions used in the determinations of the ammonias, oxygen required and total solids. For the other determinations the waters were used without shaking up and after settling until approximately clear. If the waters were at all turbid, the portion used for the determination of nitrites and color was filtered through paper, which had been previously washed until the filtrate showed no reaction for nitrous acid. Turbid waters were clarified previous to the chlorine determination by shaking up some of the water with a little alumina hydrate. This was prepared by precipitating alumina sulphate with carbonate of soda and washing the precipitate by decantation until free from chlorine and alkalies. After mixing the water with the alumina hydrate it was filtered through washed filter paper.

METHODS OF ANALYSIS.

Color: This was graded by the method of Mr. Hazen as published in the American Chemical Journal, vol. 14, p. 302. The details were as follows: 0.623 grammes of bichloride of platinum and potassium were dissolved in water, 50 c. c. of hydrochloric acid and 0.5 grammes of chloride of cobalt were added, and the whole diluted to 500 c. c. This solution, of which the color would rate 5, was used for making a series of standards ranging in color from 0.1 to 1; 1 c.c. diluted to 50 c.c. representing 0.1, 2 c.c. diluted to 50 c.c. representing 0.2, and so on. It was found that the colors so produced match closely those of the waters we had to handle, so that comparisons could be easily made, and the standard colors once made up were permanent and could be easily reproduced. In comparing the waters two Nessler tubes of fifty cubic centimeters capacity were used, one filled to the mark with the water to be tested and the other with the standard required. The colors were observed by looking lengthwise of the tube against a white porcelain plate. The standards were made up in quantities of 100 c. c., and were kept in tightly closed bottles when not in use. The sediment and turbidity of the water were judged from the appearance of the water in the original bottles after standing. The odor was observed in the water at the temperature of the room after shaking up the water in a partly filled bottle and withdrawing the stopper momentarily.

The oxygen required was determined by Kubel's method, using 100 c. c. of water and boiling ten minutes. The waters were measured off into 200 c. c. Erlenmyer flasks. To each flask was added 5 c. c. of dilute sulphuric acid (1:3) previously freed from organic matter by heating with permanganate. To the acid water, standard permanganate was added until a faint pink color was produced which did not vanish immediately. The amount so used was not counted in the determination because it was considered to represent that required to color the liquid and oxidize ferous salts, and sulphureted hydrogen when present. Now to each flask ten cubic centimeters of permanganate solution was added with a pipette. The flask was set on a hot iron plate and boiled ten minutes; if the color grew perceptibly lighter, from 5 c. c. to 10 c. c. more permanganate was added. After removal from the plate, ten cubic centimeters of standard oxalic acid solution were added with a pipette; and, when the color was entirely discharged, the residual oxalic acid titrated with standard permanganate. The permanganate and oxalic acid solutions were adjusted so that 10 c. c. of one corresponded to 10 c. c. of the other, and the strength of permanganate was such that 10 c. c. represented 1 milligramme of oxygen absorbed.

The free and albuminoid ammonia were determined with slight modifications, by the method given by the Massachusetts State Board of Health in the Report on the Examination of Waters, 1890, page 523. The distillations were made in glass retorts provided with block tin condensers similar to, but larger than those described by Mason in his book on Water Supply, page 389. The necks of the retorts were drawn out and inserted into the tubes of the condensers and further connected by heavy soft rubber tubing. The retorts were charged with about 150 c. c. of distilled water and 4 or 5 c. c. of ammonia free sodium carbonate solution, then boiled till the distillates showed no reaction for ammonia. After this was found to be the case the water for analysis was added. In most cases 500 c. c. of the water was used for the determination. But in the case of impure waters and sewages, much smaller quantities were used. In such cases the retorts were charged with enough ammonia free water originally to make the actual volume in the retort during the distillation approximately the same in all cases. Three distillates of 50 c. c. each were collected for the determination of the free ammonia, then 50 c. c. of alkaline permanganate added to the residue in the retort, and five distillates collected for the determination of the albuminoid ammonia, no attempt being made to push the distillation until the albuminoid ammonia ceased to appear, as this was found impossible for most of the waters examined. The uniform proceeding adopted was considered as giving results that would be strictly comparable. The alkaline permanganate used was prepared by dissolving the potassium permanganate and potassium hydrate in the amount of distilled water called for by the customary formula, and boiling the solution for several hours in a large flask, replacing the water evaporated from time to time. A small condenser was arranged so that it could be fitted to the flask from time to time and the distillate tested. When this was found practically free from ammonia, the solution was cooled in the flask and kept for use. The solution so prepared was tested from time to time by running blank determinations on ammonia free water previously boiled with alkaline permanganate to destroy the small amount of organic nitrogen always found in the distilled water. When so tested the alkaline permanganate was found to remain ammonia free for an indefinite period.

The time of distillation was made as nearly as possible fifteen minutes for 50 c. c. To avoid errors from the accidental and unsuspected contamination of receiving tubes the simple precaution was always taken of washing out consecutively all the sets of tubes with the same portion of 50 c. c. of water just before they were used. This water was then tested for ammonia. All the distillates were Nesslerized at about the same time, and compared with standards made up with each set. Standards and distillates, however, were not compared until all had stood long enough to have come to a constant color. Where the distillates were too concentrated for a proper comparison they were diluted with distilled water before Nesslerizing.

The nitrogen as nitrites was determined by the modified Gries method as described by Leffman (Examination of Water, page 44). The determination was always made in 50 c. c. of the water. If the nitrites were very high the water was diluted to some definite amount before being tested, and the color thus reduced to a proper depth to admit of comparison. The standard solution of potassium nitrite was much more dilute than that given by Leffman, one cubic centimeter corresponding to 0.00025 milligrammes of nitrogen as nitrous acid.

The nitrogen as nitrates was determined by the Phenoldisulphonic acid method as described by Leffman (Loc. Cit., p. 41). The amount of water taken for the determination was from five to twenty-five cubic centimeters according to whether the nitrates were high or low.

The chlorine was determined in 100 c. c. of water by titration with silver nitrate. The end of the reaction was determined by comparison with an equal volume of water colored by potassium chromate and containing a small amount of sodium chloride and to which silver nitrate had been added to just short of completion of the reaction. The determinations were usually made by artificial light, or with the use of a potassium chromate light screen for observing the end of the reaction. As the chlorine was low in the majority of the samples a measured amount of standard sodium chloride solution was always added, and an equivalent amount deducted from the silver nitrate solution used. The correction for volume was made according to the method described by Mr. Hazen in the American Chemical Journal, vol. 11, p. 409, by running a blank with each set of chlorine titrations, using 100 c. c. of water and a known amount of standard salt solution. The amount of silver nitrate used to bring about the end reaction, in excess of that theoretically required for the salt solution added, was thus determined and deducted from the volumes taken in the titration of the water. The results obtained by this method were found so satisfactory that concentration of the liquid was considered unnecessary.

The temporary hardness was determined by titration with one-fiftieth normal sulphuric acid, according to the method of Hehner. Methyl orange was used as an indicator, and the titration made in the cold water. A sample of methyl orange of great sensitiveness was obtained from Merck & Co., and no trouble was found in reading the alkalinity to a tenth of a cubic centimeter. The titration was made in short wide Nessler tubes, using 50 c. c. of the water, and using a second tube containing water colored to the same depth with the indicator, for comparison in order to determine the first change of color, which marked the end of the reaction. By looking down the tubes the end of the reaction is shown with great sensitiveness.

Permanent hardness was determined by evaporating 50 c. c. to dryness after having added a measured volume of a fiftieth normal solution of sodium carbonate, and then washing the soluble salts from the residue through a filter with freshly boiled distilled water. The filtrate was then titrated as before; the difference between the titration of the carbonate of soda used and the titration of the final filtrate was taken as a measure of the calcium and magnesium sulphates present. (Hehner, Analyst, vol. 8, p. 77.) The waters were evaporated in small porcelain dishes, and with each set a blank of distilled water, to which the same amount of the soda solution was added, was evaporated in a similar dish. The titration of this blank was then taken as the value of the carbonate of soda solution added. This was done to eliminate the possible error due to the action of the porcelain. Platinum dishes were not used as they were not available in the number required. The blank determinations so made, on the carbonate of soda, ran uniformly a few tenths of a centimeter lower than the value of the unevaporated soda solution, thus demonstrating the importance of the precaution where porcelain was used. The soap test so generally used on eastern waters was tried carefully and found entirely unsatisfacory as applied to the waters with which we had to deal, which were not only high in lime but also in magnesia. Even where samples were much diluted it was found impossible to get results, comparing at all with the gravimetric analysis of the waters; while the results obtained by the Hehner test not only compared well with each other, but corresponded satisfactorily with the gravimetric analysis where the two were tested together. As an illustration of this the following analysis of the hydrant water at the State University made on May 19th, 1897, may be taken:

Carbonate of lime	18.53
Carbonate of magnesia	15.46
Sulphate of lime	19.92
Oxides of iron and alumina	0.20
Alkalies, etc., not determined	......
	54.11

Carbonates of lime and magnesia estimated as equivalent carbonate of lime equal 36.93.

Temporary hardness by titration 37.2.

The permanent hardness determined a day before the above sample was drawn was 11.3. The sulphate of lime in the sample would be equivalent to 14.6 of permanent hardness; but, as the hydrant water contains traces of alkalies, the permanent hardness determined by the soda method may be considered as corresponding fairly with the true hardness of the water, while the temporary hardness corresponds almost exactly. The soap test on this same water gave for the total hardness only 30 degrees. My experience with the soap test as applied to such waters as we were analysing confirms entirely that of Dr. Waller published in the Analyst in volume 14, p. 108. He finds it entirely unfitted for waters of this class. The total solids were determined by evaporating 100 c. c. in platinum and drying on the water bath to constant weight. The loss on ignition was determined by carefully igniting the residue from evaporation, avoiding a heat above the faintest visible redness. The ignition was continued for about three minutes, or until the carbonaceous matter appeared burned out. The results obtained are of course somewhat meaningless, representing largely water of hydration and carbonic acid, and cannot be taken at all as standing for organic matter. Every effort was made to keep the conditions of the ignition fairly constant by having the work done by the same person and always in the same way.

The dissolved oxygen was determined by Dr. Bleile, who made the determinations on the spot at the time of taking the samples. The method of L. A. Winkler, as described in the Massachusetts report for 1892, p. 172, was used. The necessary solutions were furnished from the laboratory. The theosulphate was made of such strength that one cubic centimeter corresponded to one milligramme of oxygen. It was checked against standard potassium bichromate after it had been brought back to the laboratory at the end of the sampling trip to see that no variation had occurred. It was found by using pure salts and pure ammonia free water in making the solution it could be relied upon for several days, even during hot weather, and after being carried to and fro on this trip. The process was conducted as follows: the solutions required being, first, a clear saturated solution of manganous sulphate; second, a solution of 20 grammes of potassium iodide in 80 c. c. of water, to which was added 160 c. c. of a clear saturated solution of sodium hydrate; third, dilute sulphuric acid, one of acid to three of water by volume; fourth, theosulphate solution containing 6.2 grammes of sodium theosulphate to one liter of water; fifth, starch paste. A bottle with a well ground glass stopper was carefully calibrated. The one we used held 288 grammes of water when filled and the stopper inserted so as to exclude all air. This was filled with the water to be tested, using a suction syringe and a rubber tube so as to pump a continuous stream from beneath the surface of the water, which was delivered into the bottle by a tube reaching nearly to its bottom. The water was kept flowing through the bottle till several times its capacity had overflowed. The tube was then withdrawn and the stopper inserted so as to include no air bubble. After again removing the stopper, one-half cubic centimeter of manganous sulphate solution was added by means of a long slender pipette so that the solution entered below the surface and sank to the bottom of the bottle; then one cubic centimeter of the alkaline iodide solution was added in the same way, the stopper again inserted, care being taken to avoid including any air, which was made easy by the increase of volume due to the added reagents. The bottle was now thoroughly shaken, and the precipitate allowed to settle for a few minutes, all the oxygen being absorbed by the manganous oxide liberated by the reactions. When the precipitate had settled sufficiently, the stopper was withdrawn and 5 c. c. of sulphuric acid added. The stopper was again inserted and the liquid again shaken, iodine being liberated in proportion to the amount of oxygen absorbed by the manganous hydrate. As the acid liquid no longer absorbs oxygen, it could be poured into a white dish and titrated with the theosulphate, using starch as an indicator. The process worked very nicely, and no trouble was found in duplicating results to a tenth of a cubic centimeter. The temperature of the water was observed at the time of taking the samples. The dissolved oxygen is given in percentages of that held by distilled water saturated with air at the observed temperature. In making these comparisons the following table was used, prepared from one furnished by Mr. Hazen:

QUANTITIES OF DISSOLVED OXYGEN IN PARTS PER MILLION—BY WEIGHT, IN WATER SATURATED WITH AIR AT THE TEMPERATURE GIVEN.

(MILLIGRAMMES PER LITRE.)

Temp. C.	Oxygen.	Temp. C.	Oxygen.
0	14.70	16	9.94
1	14.27	17	9.74
2	13.87	18	9.55
3	13.50	19	9.37
4	13.15	20	9.19
5	12.28	21	8.97
6	12.48	22	8.84
7	12.17	23	8.67
8	11.87	24	8.51
9	11.58	25	8.35
10	11.31	26	8.19
11	11.06	27	8.03
12	10.82	28	7.90
13	10.59	29	7.74
14	10.36	30	7.60
15	10.14		

It will be noticed that in several samples the amount of oxygen taken up is considerably in excess of saturation. These results were obtained with care and in duplicate. The explanation of such results demands work, time for which has not yet been available. It is possible that these results may be found to correspond with the presence of growing plants or easily reduceable salts in the water. It will be noticed that the occurrence of these super-saturated waters is confined to certain specific stations, and is not general in the waters examined.

The following list gives the samples analyzed, by serial number, where and when taken, and the date they were received in the laboratory:

No. 1. Delaware, above, Olentangy, June 12.
No. 2. Delaware, below, Olentangy, June 12.
No. 3. Marion, above, Little Scioto, June 12.
No. 4. Marion, below, Little Scioto, June 12.
No. 5. Kenton, above, Scioto, June 12.
No. 6. Kenton, below, Scioto, June 12.
No. 7. Columbus, below sewer outlet, Scioto, June 12.
No. 8. Circleville, above Darby Creek, Scioto, June 14.
No. 9. Circleville, below, Scioto, June 14.
No. 10. Columbus, Dublin bridge, Olentangy, June 14.
No. 11. Columbus, Sandusky St. bridge, Scioto, June 14.
No. 12. Columbus, Wyandotte Grove, Scioto, June 14.
No. 13. Columbus, Jones' Dam, Scioto, June 14.
No. 14. Chillicothe, above, Scioto, June 18.
No. 15. Warren, above, Mahoning, June 19.
No. 16. Warren, below, Mahoning, June 19.
No. 17. Warren, filtered water, June 20.
No. 18. Youngstown, below, Mahoning, June 20.
No. 19. Youngstown, above, Mahoning, June 20.
No. 20. Girard, above, Mahoning, June 20.
No. 21. Alliance, below, Mahoning, June 21.
No. 22. Alliance, above, Mahoning, June 21.
No. 23. Alliance, sewage, June 21.
No. 24. Alliance, sewage effluent, June 21.
No. 25. Delaware, above, Olentangy, July 15, 6:45 A. M., rec'd July 16, 3:00 P. M.
No. 26. Delaware, below, Olentangy, July 15, 8:00 A. M., rec'd July 16, 3:00 P. M.
No. 27. Galion, below, Olentangy, July 15, 11:45 A. M., rec'd July 16, 3:00 P. M.
No. 28. Galion, above, Olentangy, July 15, 12:00 M., rec'd July 16, 3:00 P. M.
No. 29. Marion, above, Little Scioto, July 15, 4:45 P. M., rec'd July 16, 3:00 P. M.
No. 30. Marion, below, Little Scioto, July 15, 6:00 P. M., rec'd July 16, 3:00 P. M.
No. 31. Columbus, 1½ miles above Olentangy Park, Olentangy, July 16, 4:00 P. M., rec'd July 16, 5:00 P. M.
No. 32. Kenton, below, Scioto, July 16, 9:00 A. M., rec'd July 17, noon.
No. 33. Kenton, above, Scioto, July 16, 10:15 A. M., rec'd July 17, noon.
No. 34. Columbus, Shadeville, Scioto, July 17, 8:30 A. M., rec'd July 19, A. M.
No. 35. Columbus, Frank Road bridge, Scioto, July 17, 10:45 A. M., rec'd July 19, A. M.
No. 36. Columbus, Dublin bridge, Olentangy, July 17, 12:45 P. M., rec'd July 17, 8:00 P. M.

No. 37. Columbus, Sandusky St. bridge, Scioto, July 17, 1:15 P. M., rec'd July 17, 8:00 P. M.
No. 38. Columbus, Wyandotte Grove, Scioto, July 17, 5:15 P. M., rec'd July 17, 8:00 P. M.
No. 39. Columbus, Jones' Dam, Scioto, July 17, 6:15 P. M., rec'd July 17, 8:00 P. M.
No. 40. Circleville, above, Scioto, July 22, rec'd July 23.
No. 41. Youngstown, below, Mahoning, July 23, 10:00 A. M., rec'd July 24, A. M.
No. 42. Youngstown, above, Mahoning, July 23, 11:15 A. M., rec'd July 24, A. M.
No. 43. Warren, filtered water, July 23, 2:30 P. M., rec'd July 24, 11:00 A. M.
No. 44. Warren, above, Mahoning, July 23, 3:00 P. M., rec'd July 24, 11:00 A. M.
No. 45. Warren, below, Mahoning, July 23, 4:00 P. M., rec'd July 24, 11:00 A. M.
No. 46. Niles, Mahoning, July 24, 7:15 A. M., rec'd July 26, noon.
No. 47. Alliance, above, Mahoning, July 24, 10:30 A. M., rec'd July 26, noon.
No. 48. Alliance, below, Mahoning, July 24, 11:30 A. M., rec'd July 26, noon.
No. 49. Alliance, sewage, July 24, 12:30 P. M., rec'd July 26, noon.
No. 50. Alliance, sewage effluent, July 24, 12:30 P. M., rec'd July 26, noon.
No. 51. Columbus, Olentangy Park, Olentangy, Aug. 23, 9:30 A. M., rec'd Aug. 24, A. M.
No. 52. Columbus, Wyandotte Grove, Scioto, Aug. 23, 10:15 A. M., rec'd Aug. 24, A. M.
No. 53. Columbus, Jones' Dam, Scioto, Aug. 23, 11:30 A. M., rec'd Aug. 24, A. M.
No. 54. Columbus, Sandusky St. bridge, Scioto, Aug. 23, 12:45 P. M., rec'd Aug. 24, A. M.
No. 55. Columbus, Dublin bridge, Olentangy, Aug. 23, 1:15 P. M., rec'd Aug. 24, A. M.
No. 56. Columbus, Frank Road bridge, Scioto, Aug. 23, 3:30 P. M., rec'd Aug. 24, A. M.
No. 57. Columbus, Shadeville, Scioto, Aug. 23, 5:30 P. M., rec'd Aug. 24, A. M.
No. 58. Delaware, below, Olentangy, Aug. 24, 6:45 A. M., rec'd Aug. 26, P. M.
No. 59. Delaware, above, Olentangy, Aug. 24, 7:30 A. M., rec'd Aug. 26, P. M.
No. 60. Galion, below, Olentangy, Aug. 24, 11:30 A. M., rec'd Aug. 26, P. M.
No. 61. Galion, above, Olentangy, Aug. 24, 12 M., rec'd Aug. 26, P. M.
No. 62. Marion, above, Little Scioto, Aug. 24, 4:40 P. M., rec'd Aug. 26, P. M.
No. 63. Marion, below, Little Scioto, Aug. 24, 5:15 P. M., rec'd Aug. 26, P. M.
No. 64. Kenton, above Scioto, Aug. 25, 9:15 A. M., rec'd Aug. 26, P. M.

No. 65. Kenton, below, Scioto, Aug. 25, 10:00 A. M., rec'd Aug. 26, P. M.

No. 66. Circleville, above, Scioto, Aug. 26, 9:30 A. M., rec'd Aug. 26.

No. 67. Niles, Mahoning, Aug. 28, 6:00 A. M., rec'd Aug. 29, A. M.

No. 68. Warren, filtered water, Aug. 28, 7:30 A. M., rec'd Aug. 29, A. M.

No. 69. Warren, above, Mahoning, Aug. 28, 8:00 A. M., rec'd Aug. 29, A. M.

No. 70. Warren, below, Mahoning, Aug. 28, 9:00 A. M., rec'd Aug. 29, A. M.

No. 71. Youngstown, below, Mahoning, Aug. 28, 12:30 P. M., rec'd Aug. 30, P. M.

No. 72. Youngstown, above, Mahoning, Aug. 28, 1:40 P. M., rec'd Aug. 30, P. M.

No. 73. Alliance, sewage, Sept. 2, 3:00 P. M., rec'd Sept. 3, A. M.

No. 74. Alliance, sewage effluent, Sept. 2, 3:00 P. M., rec'd Sept. 3, A. M.

No. 75. Alliance, above, Mahoning, Sept. 2, 3:30 P. M., rec'd Sept. 3, A. M.

No. 76. Alliance, below, Mahoning, Sept. 2, 4:30 A. M., rec'd Sept. 3, A. M.

No. 77. Columbus, Frank Road bridge, Scioto, Sept. 23, 2:30 P. M., rec'd Sept. 24, A. M.

No. 78. Columbus, Shadeville, Scioto, Sept. 23, 4:15 P. M., rec'd Sept. 24, A. M.

No. 79. Columbus, Olentangy Park, Olentangy, Sept. 23, 7:30 A. M., rec'd Sept. 24, A. M.

No. 80. Columbus, Dublin bridge, Olentangy, Sept. 23, 12 M., rec'd Sept. 25, A. M.

No. 81. Columbus, Wyandotte Grove, Scioto, Sept. 23, 9:15 A. M., rec'd Sept. 25, A. M.

No. 82. Columbus, Jones' Dam, Scioto, Sept. 23, 10:15 A. M., rec'd Sept. 25, A. M.

No. 83. Columbus, Sandusky St. bridge, Scioto, Sept. 23, 11:45 A. M., rec'd Sept. 25, A. M.

No. 84. Delaware, above, Olentangy, Sept. 24, 7:00 A. M., rec'd Sept. 25, A. M.

No. 85. Delaware, below, Olentangy, Sept. 24, 8:00 A. M., rec'd Sept. 25, A. M.

No. 86. Marion, above, Little Scioto, Sept. 24, 4:30 P. M., rec'd Sept. 25, P. M.

No. 87. Marion, below, Little Scioto, Sept. 24, 5:00 P. M., rec'd Sept. 25, P. M.

No. 88. Galion, above, Olentangy, Sept. 24, 11:00 A. M., rec'd Sept. 25, P. M.

No. 89. Galion, below, Olentangy, Sept. 24, 12 M., rec'd Sept. 25, P. M.

No. 90. Kenton, above, Scioto, Sept. 25, 9:30 A. M., rec'd Sept. 25,. P. M.

No. 91. Kenton, below, Scioto, Sept. 25, 10:30 A. M., rec'd Sept. 25, P. M.
No. 92. Circleville, above, Scioto, Sept. 27, 6:00 A. M., rec'd Sept. 27.
No. 93. Bucyrus, above, Sandusky, Sept. 29, 8:00 A. M., rec'd Sept. 30, 8 A. M.
No. 94. Bucyrus, below, Sandusky, Sept. 29, 9:00 A. M., rec'd Sept. 30, 8 A. M.
No. 95. Alliance, above, Mahoning, Sept. 29, 2:30 P. M., rec'd Oct. 1, noon.
No. 96. Alliance, below, Mahoning, Sept. 29, 4:15 P. M., rec'd Oct. 1, noon.
No. 97. Warren, above, Mahoning, Sept. 30, 7:45 A. M., rec'd Oct. 1, noon.
No. 98. Warren, below, Mahoning, Sept. 30, 8:30 A. M., rec'd Oct. 1, noon.
No. 99. Niles, Mahoning, Sept. 30, 6:00 A. M., rec'd Oct. 1, noon.
No. 100. Youngstown, above, Mahoning, Sept. 30, 2:45 P. M., rec'd Oct. 1, noon.
No. 101. Youngstown, below, Mahoning, Sept. 30, 1:30 P. M., rec'd Oct. 1, noon.
No. 102. Alliance, sewage, rec'd Oct. 2, A. M.
No. 103. Alliance, sewage effluent, rec'd Oct. 2, A. M.
No. 104. Girls' Ind. Home, above, Scioto, Oct. 7, rec'd Oct. 8.
No. 105. Girls' Ind. Home, below, Scioto, Oct. 7, rec'd Oct. 8.
No. 106. Alliance, sewage, rec'd Oct. 9, A. M.
No. 107. Alliance, sewage effluent, rec'd Oct. 9, A. M.
No. 108. Columbus, Wyandotte Grove, Scioto, Oct. 21, 9:15 A. M., rec'd Oct. 22, A. M.
No. 109. Columbus, Jones' Dam, Scioto, Oct. 21, 10:15 A. M., rec'd Oct. 22, A. M.
No. 110. Columbus, Sandusky St. bridge, Scioto, Oct. 21, 11:45 A. M., rec'd Oct. 22, A. M.
No. 111. Columbus, Frank Road bridge, Scioto, Oct. 21, 3:15 P. M., rec'd Oct. 22, A. M.
No. 112. Columbus, Olentangy Park, Olentangy, Oct. 21, 7:30 A. M., rec'd Oct. 22, A. M.
No. 113. Columbus, Dublin bridge, Olentangy, Oct. 21, 12:15 P. M., rec'd Oct. 22, A. M.
No. 114. Columbus, Shadeville, Scioto, Oct. 22, 4:30 P. M., rec'd Oct. 22, A. M.
No. 115. Galion, above, Olentangy, Oct. 22, 11:00 A. M., rec'd Oct. 23, P. M.
No. 116. Galion, below, Olentangy, Oct. 22, 11:45 A. M., rec'd Oct. 23, P. M.
No. 117. Circleville, above, Scioto, Oct. 25. 6:15 A. M., rec'd Oct. 25, P. M.
No. 118. Kenton, above, Scioto, Oct. 23, 1:15 P. M., rec'd Oct. 25, P. M.
No. 119. Kenton, below, Scioto, Oct. 23, 2:00 P. M., rec'd Oct. 25, P. M.
No. 120. Marion, above, Little Scioto, Oct. 23, 7:30 A. M., rec'd Oct. 25, P. M.

No. 121. Marion, below, Little Scioto, Oct. 23, 8:30 A. M., rec'd Oct. 25, P. M.

No. 122. Girls' Ind. Home, above, Scioto, Oct. 26, 12 M., rec'd Oct. 27, P. M.

No. 123. Girls' Ind. Home, below, Scioto, Oct. 26, 1:30 P. M., rec'd Oct. 27, P. M.

No. 124. Girls' Ind. Home, below, Scioto, Oct. 26, 2:00 P. M., rec'd Oct. 27, P. M.

No. 125. Delaware, above, Olentangy, Oct. 26, 8:15 A. M., rec'd Oct. 27, P. M.

No. 126. Delaware, below, Olentangy, Oct. 26, 9:30 A. M., rec'd Oct. 27, P. M.

No. 127. Alliance, above, Mahoning, Oct. 27, 2:30 P. M., rec'd Oct. 28, P. M.

No. 128. Alliance, below, Mahoning, Oct. 27, 4:00 P. M., rec'd Oct. 28, P. M.

No. 129. Warren, above, Mahoning, Oct. 28, 8:15 A. M., rec'd Oct. 29, noon.

No. 130. Warren, below, Mahoning, Oct. 28, 9:15 A. M., rec'd Oct. 29, noon.

No. 131. Warren, filtered water, no alum, Oct. 28, 7:45 A. M., rec'd Oct. 29, noon.

No. 132. Niles, Mahoning, Oct. 28, A. M., rec'd Oct. 29, noon.

No. 133. Youngstown, above, Mahoning, Oct. 28, 2:30 P. M., rec'd Oct. 29, noon.

No. 134. Youngstown, below, Mahoning, Oct. 28, 1:30 P. M., rec'd Oct. 29, noon.

No. 135. Alliance, above, Mahoning, Nov. 26, 2:45 P. M., rec'd Nov. 29, noon.

No. 136. Alliance, below, Mahoning, Nov. 26, 3:45 P. M., rec'd Nov. 29, noon.

No. 137. Warren, above, Mahoning, Nov. 27, 8:30 A. M., rec'd Nov. 29, noon.

No. 138. Warren, below, Mahoning, Nov. 27, 9:30 A. M., rec'd Nov. 29, noon.

No. 139. Warren, filtered water, Nov. 27, 8:00 A. M., rec'd Nov. 29, noon.

No. 140. Niles, Mahoning, Nov. 27, 6:30 A. M., rec'd Nov. 29, noon.

No. 141. Youngstown, above, Mahoning, Nov. 27, 1:15 P. M., rec'd Nov. 29, noon.

No. 142. Youngstown, below, Mahoning, Nov. 27, 2:15 P. M., rec'd Nov. 29, noon.

No. 143. Kenton, above, Scioto, Dec. 1, 1:30 P. M., rec'd Dec. 2, noon.

No. 144. Kenton, below, Scioto, Dec. 1, 2:30 P. M., rec'd Dec. 2, noon.

No. 145. Galion, above, Olentangy, Nov. 30, 11 A. M., rec'd Dec. 2, noon.

No. 146. Galion, below, Olentangy, Nov. 30, 12 M., rec'd Dec. 2, noon.

No. 147. Marion, above, Little Scioto, Dec. 1, 7:45 A. M., rec'd Dec. 2, noon.

No. 148. Marion, below, Little Scioto, Dec. 1, 8:30 A. M., rec'd Dec. 2, noon.
No. 149. Delaware, above, Olentangy, Dec. 2, 8:30 A. M., rec'd Dec. 3, A. M.
No. 150. Delaware, below, Olentangy, Dec. 2, 9:30 A. M., rec'd Dec. 3, A. M.
No. 151. Girls' Ind. Home, above, Scioto, Dec. 2, 12:30 P. M., rec'd Dec. 3, A. M.
No. 152. Girls' Ind. Home, below, Scioto, Dec. 2, 2:30 P. M., rec'd Dec. 3, A. M.
No. 153. Girls' Ind. Home, below, Scioto, Dec. 2, 2:05 P. M., rec'd Dec. 3, A. M.
No. 154. Columbus, Olentangy Park, Olentangy, Dec. 3, 8:45 A. M., rec'd Dec. 4, A. M.
No. 155. Columbus, Dublin bridge, Olentangy, Dec. 3, 3:00 P. M., rec'd Dec. 4, A. M.
No. 156. Columbus, Wyandotte Grove, Scioto, Dec. 3, 10:00 A. M., rec'd Dec. 4, A. M.
No. 157. Columbus, Jones' Dam, Scioto, Dec. 3, 11:30 A. M., rec'd Dec. 4, A. M.,
No. 158. Columbus, Sandusky St. bridge, Scioto, Dec. 3, 2:30 P. M., rec'd Dec. 4, A. M.
No. 159. Columbus, Frank Road bridge, Scioto, Dec. 4, 9:15 A. M., rec'd Dec. 4, P. M.
No. 160. Columbus, Shadeville, Scioto, Dec. 4, 11:00 A. M., rec'd Dec. 4, P. M.
No. 161. Circleville, above, Scioto, Dec. 4, 2:00 P. M., rec'd Dec. 6, A. M.

RESULTS OF THE ANALYSIS.

The table which follows gives the analytical result for all the samples examined. The analyses are grouped according to the river and by stations. The first column gives the serial number attached to the sample when it came to the laboratory; the second the station number for the point of sampling as shown on the large map accompanying Mr. Hazen's report. This represents the distance in miles measured along the stream from the zero station which is located at the mouth of the big Miami on the Ohio River. The third column gives the distance of each sampling point from the first point on the stream at which samples were taken. The distances are given to the nearest mile, and show the length of flow from the starting point measured on the stream. The next column gives the names of the places at which samples were taken; the next the date on which the samples were drawn. It will be seen from the table that the work covered about six months of the drier portion of the year, extending from June to December, and that samples were drawn at all stations at intervals of about a month. The averages of all the determinations made at each station are given and are printed in different type so as to be readily recognized. The rest of the table is self-explanatory.

With the exception of the dissolved oxygen, all results are given in parts per 100,000 by weight. The dissolved oxygen is given in percentages of saturation, as previously explained.

Station.	Sample Number.	Approximate Distances.	Locality of Samples.	Date of Sample. Month.	Day.	Color.	Turbidity.	Sediment.	Odor.	Oxygen required.	Ammonia: Free.	Ammonia: Albuminoid.	Nitrogen: As Nitrates.	Nitrogen: As Nitrites.	Chlorine.	Hardness: Temporary.	Hardness: Permanent.	Total solids.	Vol. solids.	Dissolved oxygen. % of Saturation.	Temperature, °C.	Bacteria, per cubic centimeter.
304.	5	0	Kenton, above town	June	12	0.4	Very slight	Marked.	None.	1.14	.0062	.0514	.150	.0024	0.20	21.0	22.6	73.0	10.0	....	....	1308
	33		" "	July	16	0.4	Distinct.	"	Earthy.	1.02	.0098	.0462	.042	.0003	0.10	23.2	x	80.5	11.0	91.	25.5	476
	64		" "	August	25	0.2	Marked.	Distinct.	None.	0.61	.0084	.0292	None	None	0.25	23.4	13.0	62.5	7.5	85.	21.	433
	90		" "	Sept.	25	0.4	Distinct.	Slight.	Slight earthy.	0.62	.0028	.0238	"	"	0.38	22.6	12.2	67.0	9.0	84.	16.	268
	118		" "	Oct.	23	0.3	"	"	Sour musty.	0.54	.0030	.0240	"	"	0.33	25.2	11.2	60.5	9.5	114.	15.	393
	143		" "	Dec.	1	0.5	Marked.	"	Musty.	1.14	.0571	.0638	.938	.0030	0.15	10.4	51.0	107.5	19.5	84.	4.	1859
			Average							**0.85**	**.0145**	**.0397**	**.190**	**.0010**	**0.23**	**21.0**	**18.3**	**75.2**	**11.1**			
302.	6	2	Kenton, below town	June	12	0.45	Very slight	Slight.	Slight.	1.06	.0142	.0430	.160	.0026	0.40	21.4	22.8	71.0	10.0	....	....	x
	32		" "	July	16	0.3	Distinct.	Marked.	Offensive.	1.53	.0476	.1720	None	None	0.45	3.2	x	72.0	12.5	114.	25.	5774
	65		" "	August	25	0.2	"	"	"	0.87	.0384	.1328	"	.0010	0.65	23.2	11.8	60.5	9.5	169.	23.5	2436
	91		" "	Sept.	25	0.35	Slight.	Distinct.	Oily.	0.70	.0764	.0360	"	.0003	1.25	23.8	11.4	64.5	11.0	72.	18.5	4200
	119		" "	Oct.	23	0.3	Clear.	Marked.	Slight offensive	0.75	.2160	.0588	"	.0005	1.80	25.8	11.4	65.0	12.0	159.	16.5	17220
	144		" "	Dec.	1	0.5	Distinct.	Slight.	Marked musty.	1.13	.0584	.0624	.944	.0030	0.20	11.8	46.6	97.5	16.0	90.	3.75	13900
			Average							**1.01**	**.0751**	**.0841**	**.184**	**.0012**	**0.79**	**18.2**	**17.3**	**71.8**	**11.8**			
	104	49	Girls' Industrial Home, above	Oct.	7	0.15	Clear.	Slight.	Very faint musty.	0.50	.0078	.0308	None	Trace	0.87	17.0	11.2	48.5	10.0	106.	17.5	628
	122		" " "	Oct.	26	0.25	Slight.	"	Slight musty.	0.46	.0054	.0276	"	None	0.95	21.0	10.8	53.0	10.5	99.	15.5	1265
	151		" " "	Dec.	2	0.5	Marked.	"	Earthy.	0.83	.0128	.0418	.530	.0025	0.20	14.4	14.8	51.2	11.5	94.	2.5	2781
			Average							**0.60**	**.0086**	**.0334**	**.0176**	**.0008**	**0.66**	**17.5**	**12.3**	**50.9**	**10.7**			
	105	50	Girls' Industrial Home, below	Oct.	7	0.15	Clear.	Slight.	Faint musty.	0.51	.0114	.0274	Tr'ce	.0003	1.03	17.0	12.2	50.0	10.0	113.	17.	658
	123		" " "	Oct.	26	0.25	"	Very slight	Slight musty.	0.48	.0070	.0272	None	Trace	1.00	21.0	11.0	52.5	9.0	116.	17.	484
	124		" " "	Oct.	26	0.20	"	"	Slight musty sour.	0.47	.0068	.0278	"	.0002	1.10	21.0	11.3	52.5	10.0	118.	17.	1980
	152		" " "	Dec.	2	0.5	Marked.	Slight.	Earthy.	0.85	.0124	.0416	.640	.0025	0.15	13.8	14.8	49.2	11.0	....	3.	2446
	153		" " "	Dec.	2	0.40	"	"	Slight musty.	0.83	.0126	.0412	.598	.0025	0.17	14.0	14.2	50.1	11.0	91-93	3.	2449
			Average							**0.61**	**.0103**	**.0320**	**.206**	**.0009**	**0.75**	**17.3**	**12.6**	**50.7**	**10.2**			
246.	12	58	Wyandotte Grove	June	13	0.2	Slight.	Marked.	Trace sweet.	0.54	.0040	.0260	.029	.0002	0.40	19.4	5.2	44.5	9.0	....	....	731
	38		"	July	17	0.3	Marked.	"	Very faint.	0.55	.0028	.0378	.017	.0002	0.55	18.2	9.4	50.0	7.5	103.	27.	914
	52		"	August	23	0.2	Slight.	Slight.	None.	0.59	.0096	.0344	.003	.0003	0.38	17.2	8.8	44.0	8.0	88.	23.	289
	81		"	Sept.	23	0.15	Very slight	Distinct.	Slight earthy.	0.51	.0098	.0316	.003	.0002	0.78	17.6	12.6	55.0	9.0	89.	17.	302
	108		"	Oct.	21	0.2	Distinct.	Slight.	Earthy.	0.45	.0048	.0268	.005	.0002	0.77	20.0	14.0	58.5	9.0	79.	16.	199
	156		"	Dec.	3	0.5	Marked.	Distinct.	Slight earthy.	0.81	.0100	.0366	.630	.0020	0.15	14.6	13.2	46.7	10.0	85.	2.5	2015
			Average							**0.58**	**.0068**	**.0322**	**.115**	**.0005**	**0.50**	**17.8**	**10.5**	**49.8**	**8.8**			

NOTE—In averaging the results at the Girls' Industrial Home two samples taken at the same date were counted as one and the average result taken.

243.5	13	61	Jones' Dam	June	13	0.2	Slight.	Marked.	None.	0.58	.0037	.0276	.034	.0002	0.45	19.4	4.8	45.5	10.0	....	....	816
	39		"	July	17	0.3	Marked.	"	Trace.	0.59	.0028	.0398	.020	.0003	0.38	18.4	10.4	51.0	9.0	93.	25.5	394
	53		"	August	23	0.2	Slight.	Distinct.	Slight sour.	0.65	.0092	.0380	.008	.0003	0.41	17.8	8.0	45.0	7.5	101.	23.	588
	82		"	Sept.	23	0.2	Very slight	Slight.	Slight earthy.	0.50	.0088	.0306	None	.0003	0.73	17.6	11.6	51.0	9.5	86.	19.	354
	109		"	Oct.	21	0.2	Distinct.	"	Earthy.	0.46	.0082	.0296	.005	.0006	0.74	19.2	12.4	54.5	9.0	73.	16.	705
	157		"	Dec.	3	0.5	Marked.	Distinct.	Slight earthy.	0.84	.0102	.0354	.650	.0025	0.17	14.0	13.6	46.4	10.0	86.	2.5	2223
			Average							**0.60**	**.0071**	**.0335**	**.120**	**.0007**	**0.48**	**17.7**	**10.1**	**48.9**	**9.2**			
238.	11	66	Columbus, Sandusky St. Bridge	June	13	0.2	Distinct.	Distinct.	None.	0.52	.0110	.0342	.032	.0007	0.70	19.0	6.2	48.0	10.0	....	....	1472
	37		" " "	July	17	0.3	Marked.	Marked.	Faint musty.	0.62	.0048	.0376	.026	.0002	0.40	18.4	9.2	48.0	9.5	118.	27.5	1028
	54		" " "	August	23	0.2	Very slight	Slight.	Sour musty.	0.61	.0200	.0394	.007	.0015	1.01	18.0	7.8	44.5	8.5	42.	22.5	4541
	83		" " "	Sept.	23	0.2	"	Distinct.	Slight musty.	0.58	.0280	.0420	None	.0005	1.15	15.2	10.6	46.0	10.0	91.	20.	10800
	110		" " "	Oct.	21	0.15		Slight.	Slight offensive.	0.58	.0086	.0392	.004	.0004	0.87	15.8	9.8	52.5	10.0	96.	16.	1150
	158		" " "	Dec.	3	0.6	Marked.	Distinct,	Slight earthy.	0.91	.0110	.0418	.582	.0025	0.23	14.4	13.6	47.4	10.5	89.	3.	10170
			Average							**0.64**	**.0139**	**.0390**	**.109**	**.0010**	**0.72**	**16.8**	**9.5**	**47.7**	**9.8**			
234.	7	70	Columbus, Frank Rd. Bridge	June	11	0.2	Slight.	Slight.	Offensive.	1.17	.2322	.1130	.003	Tr'ce	1.60	23.8	8.6	49.5	8.0	....	....	8856
	35		" " "	July	17	0.4	Distinct.	Very m'ked	Offensive oily.	1.11	.1644	.0896	None	.0188	1.30	18.2	8.4	44.0	8.5	9.	23.5	63650
	56		" " "	August	23	0.4	Very slight	Distinct.	Offensive.	1.26	.3824	.1136	"	None	2.11	25.6	9.4	52.0	13.5	21.	23.	195100
	77		" " "	Sept.	23	0.3	Distinct.	Marked.	Offensive musty	1.36	.7600	.0876	"	Tr'ce	3.90	33.0	11.2	68.0	11.0	None	19.5	246100
	111		" " "	Oct.	21	0.5	Very m'ked	"	Very offensive.	2.39	1.0170	.2340	"	None	4.15	34.6	9.2	76.5	14.0	"	17.	183400
	159		" " "	Dec.	4	0.4	Marked.	"	Oily.	1.05	.0880	.0780	.442	.0070	0.60	16.0	13.4	47.2	9.0	78.	5.	135000
			Average							**1.39**	**.4406**	**.1193**	**.074**	**.0043**	**2.27**	**25.2**	**10.0**	**56.2**	**10.7**			
227.	34	77	Shadeville Bridge	July	17	0.25	Very slight	Marked.	Slight earthy.	0.61	.1352	.0360	.020	.0395	1.45	22.6	6.6	47.0	8.0	46.	23.	708
	57		" "	August	23	0.3	"	Slight.	Slight sour.	0.85	.0176	.0756	.049	.0150	1.68	24.2	7.0	47.5	9.0	100.	22.5	885
	78		" "	Sept.	23	0.3	Clear.	Marked.	Slight offensive.	0.91	.6630	.0760	None	.0022	2.85	31.4	6.8	56.0	9.5	58.	19.	8234
	114		" "	Oct.	22	0.5	Marked.	Distinct.	Offensive.	1.49	.7960	.1620	"	.0002	3.15	35.6	5.2	60.5	8.5	None	17.	13160
	160		" "	Dec.	4	0.4	"	"	Musty.	0.91	.0508	.0536	.536	.0037	0.53	15.2	11.6	43.8	7.6	81.	4.5	18140
			Average							**0.95**	**.3352**	**.0806**	**.121**	**.0121**	**1.93**	**25.8**	**7.4**	**51.0**	**8.5**			
212.5	8	91	Circleville, above Darby Creek	June	14	0.15	Clear.	Decided.	None.	0.50	.0112	.0326	.043	.0026	0.65	24.4	0.8	39.5	7.5	....	....	118
210.5	40	94	Circleville, Main St. Bridge	July	22	1.0	Very turbid	Heavy.	Slight earthy.	1.58	.0118	.0660	.113	.0030	0.17	11.4	5.4	28.5	6.0	57.	26.	14428
	66		" " "	August	26	0.2	Slight.	Distinct.	x x	0.52	.0352	.0378	.016	.0023	0.55	22.8	2.0	39.5	7.0	67.	22.5	610
	92		" " "	Sept.	27	0.15	"	Slight.	Slight earthy.	0.52	.0210	.0320	Tre'e	.0007	1.17	24.2	2.8	40.0	2.5	71.	18.	503
	117		" " "	Oct.	25	0.25	Distinct.	"	Slight musty.	0.41	.0534	.0314	.013	.0045	1.12	28.2	2.8	43.5	8.5	32.	14.	756
	161		" " "	Dec.	4	0.5	Marked.	"	Musty.	0.96	.0314	.0424	.268	.0050	0.25	14.4	7.6	39.3	5.2	59.	6.	3451
			Average							**0.80**	**.0312**	**.0419**	**.082**	**.0031**	**0.65**	**20.2**	**4.1**	**38.2**	**5.8**			
209.5	9	95	Circleville, below town	June	14	0.15	Clear.	Decided.	Slight sweet.	0.51	.0136	.0394	.041	.0022	0.65	24.0	3.0	40.5	7.0	....	....	....
188.5	14	113	Chillicothe, above	June	18	0.15	None.	Marked.	Musty.	0.49	.0152	.0258	.046	.0015	0.45	24.6	2.4	39.0	7.0	....	....	....

LITTLE SCIOTO RIVER.

Station.	Sample Number.	Approximate Distances.	Locality of Sample.	Date of Sample. Month.	Day.	Color.	Turbidity.	Sediment.	Odor.	Oxygen required.	Ammonia. Free.	Ammonia. Albuminoid.	Nitrogen. As Nitrates.	Nitrogen. As Nitrites.	Chlorine.	Hardness. Temporary.	Hardness. Permanent.	Total solids.	Vol. solids.	Dissolved oxygen. % of saturation.	Temperature, °C.	Bacteria, per cubic centimeter.
281.	3	0	Marion, above town	June	11	0.3	Marked.	Distinct.	Faint musty.	0.83	.0142	.0370	.030	.0015	0.23	20.2	5.6	43.0	5.0	......	......	868
	29		" "	July	15	0.4	"	Marked.	Slight.	0.83	.0144	.0778	.036	.0030	0.10	18.0	4.4	43.0	5.5	116.	26.	866
	62		" "	August	24	0.3	Distinct.	Distinct.	Slight musty.	0.97	.0210	.0756	None	None	0.23	20.4	5.8	47.0	6.5	114.	23.	1375
	86		" "	Sept.	24	0.2	Very slight	Slight.	Slight sour.	0.62	.0058	.0430	"	.0001	1.65	25.8	10.6	57.0	8.5	50.	20.	1169
	120		" "	Oct	23	0.15	Slight.	Distinct.	Musty.	0.45	.1646	.0290	"	.0015	0.87	28.4	6.8	54.5	6.0	50.	11.	430
	147		" "	Dec.	1	0.5	Marked.	Slight.	"	0.66	.0068	.0310	.683	.0015	0.10	9.4	11.8	36.7	9.0	82.	1.	2755
			Average	......		......	......	......	......	**0.73**	**.0378**	**.0489**	**.125**	**.0013**	**0.53**	**20.4**	**7.5**	**46.9**	**6.8**	......	......	......
280.	4	1	Marion, below town	June	11	0.3	Distinct.	Marked.	Faint musty.	0.70	.0512	.0526	.043	.0084	0.65	20.8	4.6	48.5	10.0	......	......	1156
	30		" "	July	15	0.3	Marked.	"	Sour musty.	0.72	.0762	.0632	.035	.0060	1.03	19.8	5.4	48.5	10.0	1 125.	26.	4306
	63		" "	August	24	0.15	Clear.	"	Sour.	0.57	.1732	.0476	.003	.0034	2.55	27.6	8.8	64.5	10.0	46.	23.	16783
	87		" "	Sept.	24	0.2	Slight.	Slight.	Sour musty	0.60	.1690	.0422	None	.0020	3.50	28.0	12.2	67.5	9.0	61.	21.	12520
	121		" "	Oct.	23	0.15	Clear.	Marked.	Offensive.	0.44	.6090	.0370	"	.0006	1.95	30.8	9.4	64.0	7.5	72.	11.2	7100
	147		" "	Dec,	1	0.5	Marked.	Slight.	Musty.	0.63	.0176	.0356	.703	.0015	0.23	11.8	10.8	39.2	9.0	27.	2.	15320
			Average	......		......	......	......	......	**0.61**	**.1827**	**.0464**	**.131**	**.0037**	**1.65**	**23.1**	**8.5**	**55.3**	**9.3**	......	......	......
278.	......	3	Junction with Scioto	......		......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......

OLENTANGY RIVER.

Station.	Sample Number.	Approximate Distances.	Locality of Sample.	Month.	Day.	Color.	Turbidity.	Sediment.	Odor.	Oxygen required.	Ammonia. Free.	Ammonia. Albuminoid.	Nitrogen. As Nitrates.	Nitrogen. As Nitrites.	Chlorine.	Hardness. Temporary.	Hardness. Permanent.	Total solids.	Vol. solids.	Dissolved oxygen. % of saturation.	Temperature, °C.	Bacteria, per cubic centimeter.
307.	28	0	Galion, above town	July	15	0.4	Marked.	Marked.	Musty.	0.85	.0124	.0446	.007	.0011	0.40	17.0	2.6	35.5	6.5	147.	22.5	318
	61		" "	August	24	0.3	None.	Distinct.	"	0.91	.0150	.0632	None	Trace	0.95	23.0	5.0	44.0	7.5	123.	25.5	247
	88		" "	Sept.	24	0.3	Clear.	"	"	1.11	.0112	.0464	"	None	1.38	27.8	4.2	52.5	10.0	107.	21.	131
	115		" "	Oct.	22	0.3	"	"	"	1.09	.0182	.0564	.003	.0003	1.15	24.8	11.2	62.5	10.5	74.	12.	563
	145		" "	Nov.	30	0.5	Distinct.	Slight.	"	0.55	.0090	.0274	.308	.0020	0.27	10.2	11.5	37.2	7.5	90.	3.	982
			Average	......		......	......	......	......	**0.90**	**.0132**	**.0476**	**.064**	**.0007**	**0.83**	**20.6**	**6.9**	**46.3**	**8.4**	......	......	......
305.	27	2	Galion, below town	July	15	0.4	Distinct.	Distinct.	Sour musty.	0.88	.3216	.0640	.068	.0315	5.05	22.2	x	80.5	14.0	51.	24.	2702
	60		" "	August	24	0.2	None.	Slight.	" "	0.73	.4664	.0636	.003	.0125	4.35	32.0	x	108.0	15.5	36.	20.	18446
	89		" "	Sept.	24	0.35	"	"	" "	1.07	.4720	.0804	None	.0100	6.75	27.2	x	95.0	14.5	77.	18.	31600
	116		" "	Oct.	22	0.5	Marked.	Marked.	Offensive.	1.85	.9350	.2110	.003	None	5.80	33.6	12.6	82.5	17.0	none	13.	111900
	146		" "	Nov.	30	0.4	Distinct.	Distinct.	Mouldy.	0.94	.1500	.0780	.248	.0015	3.40	15.8	25.5	70.3	11.5	72.	4.	81100
			Average	......		......	......	......	......	**1.09**	**.4696**	**.0994**	**.064**	**.0111**	**5.07**	**26.2**	**19.0**	**87.3**	**14.5**			

264.	1	43	Delaware, above town..........	June	10	0.2	Slight.	Slight.	Faint musty.	0.64	.0070	.0264	.013	Trace	0.35	20.4	1.6	35.5	9.0	....	....	608
	25		" "	July	15	0.5	Strong.	Marked.	Musty.	0.85	.0086	.0422	.013	.0010	0.20	16.4	2.2	35.0	8.0	87.	22.	1352
	59		" "	August	24	0.2	Slight.	Distinct.	None.	0.59	.0112	.0326	.003	.0001	0.20	20.2	4.4	38.5	5.0	76.	21.	866
	84		" "	Sept.	24	0.2	"	Slight.	Slight musty.	0.54	.0068	.0290	None	Trace	0.20	20.2	6.6	43.5	5.5	84.	15.	261
	125		" "	Oct.	26	0.2	Clear.	Very slight	Very slight earthy	0.49	.0040	.0282	Trace	"	0.30	22.6	12.0	55.0	6.5	87.	14.	883
	149		" "	Dec.	2	0.8	Marked.	Slight.	Musty.	0.72	.0060	.0348	.489	.0015	0.23	12.0	9.6	37.6	8.0	82.	1.	2210
			Average	....		....	....	....	....	**0.64**	**.0073**	**.0322**	**.086**	**.0004**	**0.25**	**18.6**	**6.1**	**40.8**	**7.0**	....	....	....
261.	2	46	Delaware, below town..........	June	10	0.25	Very slight	Very slight	Faint musty.	0.68	.0090	.0296	.020	.0011	0.47	20.2	2.8	35.5	6.5	....	....	890
	26		" "	July	15	0.5	Strong.	Marked.	Musty.	0.85	.0184	.0512	.064	.0034	0.40	15.2	3.0	33.0	7.5	91.	24.	1038
	58		" "	August	24	0.25	Slight.	Distinct.	Very slight musty	0.63	.0154	.0372	.018	.0012	0.77	20.6	6.2	40.5	6.5	71.	19.	519
	85		" "	Sept.	24	0.2	Very slight	Slight.	Musty.	0.57	.0108	.0284	.012	.0015	1.57	23.6	8.0	51.5	8.5	79.	13.	420
	126		" "	Oct.	26	0.25	"	Very slight	"	0.60	.0084	.0328	.010	.0010	5.15	26.0	14.2	71.0	12.5	99.	14.	1622
	150		" "	Dec.	2	0.6	Marked.	Slight.	"	0.68	.0090	.0352	.362	.0020	0.33	12.2	10.2	37.4	8.0	89.	2.5	2373
			Average	....		....	....	....	....	**0.67**	**.0118**	**.0357**	**.081**	**.0017**	**1.45**	**19.6**	**7.4**	**44.8**	**8.3**	....	....	....
243.	31	64	Olentangy Park, above..........	July	16	0.3	Distinct.	Marked.	Slightly earthy.	0.84	.0062	.0426	.024	.0003	0.30	17.8	5.0	39.0	6.5	85.	24.5	680
	51		" "	August	24	0.25	Slight.	Slight.	None.	0.57	.0094	.0334	.005	.0003	0.58	20.6	7.4	45.0	7.0	80.	22.5	701
	79		" "	Sept.	23	0.3	Distinct.	Marked.	Faint earthy.	0.55	.0076	.0354	None	.0002	1.02	20.4	13.4	55.5	10.5	74.	17.	394
	112		" "	Oct.	21	0.2	"	Distinct.	Slight earthy.	0.58	.0072	.0286	.012	.0005	0.77	22.6	12.2	62.0	8.5	61.	15.5	275
	154		" "	Dec.	3	0.5	Very m'ked	"	"	0.69	.0066	.0362	.495	.0020	0.30	12.6	9.8	40.4	9.0	83.	3.	1797
			Average	....		....	....	....	....	**0.64**	**.0074**	**.0353**	**.107**	**.0007**	**0.59**	**18.8**	**9.6**	**48.4**	**8.3**	....	....	....
238.	10	69	Columbus, Dublin Bridge..........	June	13	0.2	Slight.	Decided.	Slight earthy.	0.55	.0066	.0294	.021	.0011	0.55	20.2	4.8	41.5	6.5	....	....	1152
	36		" "	July	17	0.3	Marked.	Marked.	Very faint.	0.66	.0058	.0388	.032	.0004	0.32	16.6	4.4	36.0	7.5	109.	27.	1636
	55		" "	August	23	0.2	None.	Slight.	Sour musty.	0.58	.0096	.0302	.002	.0002	0.54	19.4	7.2	44.0	9.5	97.	23.	2073
	80		" "	Sept.	23	0.2	"	Distinct.	Slight musty.	0.57	.0126	.0352	None	.0001	0.85	19.2	11.0	52.5	9.5	129.	21.	773
	113		" "	Oct.	21	0.15	Slight.	Slight.	Sour musty.	0.48	.0036	.0294	"	.0002	0.87	21.8	11.2	58.5	9.5	93.	16.2	520
	155		" "	Dec.	3	1.0	Marked.	Distinct.	Slight earthy.	0.75	.0074	.0372	0.480	.0020	0.30	13.2	9.6	38.7	9.5	89.	3.	4017
			Average	....		....	....	....	....	**0.60**	**.0076**	**.0334**	**0.089**	**.0007**	**0.57**	**18.4**	**8.0**	**45.2**	**8.7**	....	....	......

MAHONING RIVER.

Station.	Sample Number.	Approximate Distance.	Locality of Sample.	Date of Sample. Month.	Day.	Color.	Turbidity.	Sediment.	Odor.	Oxygen required.	Ammonia. Free.	Ammonia. Albuminoid.	Nitrogen. As Nitrates.	Nitrogen. As Nitrites.	Chlorine.	Hardness. Temporary.	Hardness. Permanent.	Total solids.	Vol. solids.	Dissolved oxygen. % of Saturation.	Temperature °C.	Bacteria, per cubic centimeter.
536.	22	0	Alliance, above—Pat. St. Br.....	June	19	0.45	None.	Marked.	Slight earthy.	1.01	.0136	.0528	.023	.0012	0.15	11.0	3.6	24.0	6.5	....	....	1623
	37		" "	July	24	0.7	Slight.	"	Faint earthy.	1.11	.0126	.0478	.028	.0010	0.02	7.0	3.8	17.5	4.5	66.	23.	1768
	75		" "	Sept.	2	0.4	Distinct.	"	Slight musty.	0.71	.0094	.0390	.007	.0005	0.23	13.6	5.4	40.0	7.0	94.	23.	263
	95		" "	Sept.	29	0.15	None.	Slight.	Slight earthy.	0.35	.0059	.0136	None	.0003	0.30	18.2	5.8	41.5	5.5	97.	19.	410
	127		" "	Oct.	27	0.2	Very slight	Distinct.	" "	0.38	.0060	.0150	Trace	Trace	0.32	20.4	5.4	41.0	4.5	80.	14.	742
	135		" "	Nov.	26	1.0	Turbid.	Marked.	None.	1.02	.0114	.0592	0.65	.0007	0.23	7.8	6.4	47.0	7.0	81.	11.	20215
			Average							**0.76**	**.0100**	**.0379**	**0.021**	**.0006**	**0.21**	**13.0**	**5.1**	**35.0**	**5.8**	....	....	....
534.	21	2	Alliance, below	June	19	0.3	None.	Distinct.	Slight earthy.	0.66	.0200	.0422	.007	.0022	0.30	12.8	5.6	30.0	6.5	....	....	1914
	48		" "	July	24	0.8	Slight.	Marked.	Earthy.	1.18	.0196	.0520	.033	.0020	0.02	5.6	3.4	16.5	4.0	75.	25.	7032
	76		" "	Sept.	2	0.3	"	"	Slight musty.	0.73	.0122	.0422	.012	.0015	0.48	13.8	6.8	41.0	6.0	81.	25.	5594
	96		" "	Sept.	29	0.2	None.	Slight.	Sour musty	0.61	.0473	.0366	Trace	.0035	0.90	17.0	6.8	41.5	6.0	70.	19.	9910
	128		" "	Oct.	27	0.4	"	Marked.	Slightoffensive.	0.49	.2100	.0356	.003	.0055	1.55	21.6	9.8	48.0	6.0	35.	16.	20370
	136		" "	Nov.	26	0.5	V'ry m'rk'd	Distinct.	Faint musty.	0.63	.0176	.0390	.054	.0022	0.45	10.2	9.8	38.0	6.5	90.	8.	57250
			Average							**0.72**	**.0544**	**.0412**	**.018**	**.0028**	**0.62**	**13.5**	**7.0**	**35.8**	**5.8**	....	....	....
497.	15	39	Warren, above	June	18	0.3	None.	Marked.	Faint musty.	0.62	.0062	.0370	.009	.0002	0.20	9.2	1.6	19.0	2.5	....	....	816
	44		" "	July	23	1.2	V'ry m'rk'd	V'ry m'rk'd	" "	1.47	.0156	.0606	.023	.0010	0.03	3.6	2.2	13.0	6.0	68.	23.	5974
	69		" "	Aug.	28	0.3	Very slight	Slight.	Slight earthy.	0.69	.0062	.0336	Trace	None	0.35	10.0	2.8	24.5	4.5	99.	23.5	155
	97		" "	Sept.	30	0.15	Trace.	"	" "	0.44	.0036	.0180	None	.0005	0.42	12.4	3.2	27.5	6.0	90.	16.	163
	129		" "	Oct.	28	0.3	Slight.	"	Earthy.	0.38	.0018	.0158	"	None	0.37	14.0	1.4	23.5	3.5	82.	13.	540
	137		" "	Nov.	27	0.7	V'ry m'rk'd	Distinct.	None.	0.98	.0074	.0440	.085	.0009	0.33	5.4	4.6	20.5	4.0	83.	7.	5720
			Average							**0.76**	**.0068**	**.0348**	**.020**	**.0004**	**0.28**	**9.1**	**2.6**	**21.3**	**4.4**	....	....	....
494.	16	42	Warren, below	June	18	0.35	None.	Distinct.	Faint musty.	0.64	.0126	.0392	.005	.0007	0.40	10.2	2.4	20.0	3.5	....	....	1455
	45		" "	July	23	1.2	V'ry m'rk'd	V'ry m'rk'd	" "	1.54	.0144	.0620	.025	.0010	0.03	3.4	1.8	13.5	5.0	76.	23.	14820
	70		" "	Aug.	28	0.3	Slight.	Distinct.	" "	0.71	.0130	.0382	.001	.0005	0.45	10.0	2.6	25.5	4.5	66.	23.	1238
	98		" "	Sept.	30	0.2	None.	Slight.	Musty.	0.47	.0078	.0208	None	.0004	0.45	12.4	1.2	24.5	4.0	72.	16.	7700
	130		" "	Oct.	28	0.3	Slight.	"	Slightoffensive.	0.45	.0244	.0268	.006	.0011	0.62	14.0	0.3	25.0	4.0	54.	14.	7140
	138		" "	Nov.	27	1.0	V'ry m'rk'd	Marked.	Faint musty.	1.12	.0096	.0516	.088	.0009	0.33	5.4	4.2	23.3	5.0	90.	8.	14920
			Average							**0.82**	**.0136**	**.0398**	**.021**	**.0008**	**0.38**	**9.2**	**2.1**	**22.0**	**4.3**	....	....	....

491.	46	45	Niles	July	24	1.0	Marked.	Marked.	Sour earthy.	1.43	.0204	.0552	.028	.0010	0.21	4.0	3.6	17.0	5.5	70.	23.	3812
	67		"	August	28	0.35	Very slight	Very slight	None.	0.71	.0096	.0430	.006	.0004	0.45	9.0	2.6	23.5	5.0	92.	21.5	443
	99		"	Sept.	30	0.15	"	Slight.	Slight musty.	0.43	.0070	.0194	None	.0005	0.87	12.6	1.8	27.5	4.0	89.	15.	303
	132		"	Oct.	28	0.30	Slight.	"	Slight earthy.	0.51	.0102	.0304	.013	.0017	4.25	13.8	3.0	33.5	4.5	70.	13.	599
	140		"	Nov.	27	0.8	Marked.	Marked.	Musty.	0 97	.0098	.0454	.086	.0017	0.50	5.6	5.6	27.0	4.5	81.	8.	7857
			Average							**0.81**	**.0114**	**.0387**	**.027**	**.0011**	**1.26**	**9·0**	**3.3**	**25.7**	**4.7**			
488.	20	48	Girard—Above	June	18	0.6	None.	Distinct.	Slight musty.	0 92	.0072	.0464	.005	.0002	0.58	7.6	3.2	20.0	5.5			1012
482.	18	53	Youngstown—Above	June	18	0.5	None.	Slight.	Musty.	0.93	.0094	.0424	.005	.0001	0.53	9.0	2.8	24.5	6.5			2250
	42		" "	July	23	2.5	Very turbid	Heavy.	Slight musty.	1.68	.0120	.0716	.018	.0005	0.03	2.2	2.0	14.5	3.5	86.	21.5	14178
	72		" "	August	28	x	Trace.	Marked.	"	1.04	.0112	.0436	.007	.0003	0.40	5.6	2.4	20.0	3.5	82.	26.	576
	100		" "	Sept.	30	0.15	None.	Slight.	Musty.	0.40	.0056	.0192	Trace	.0004	1.35	8.8	8.6	37.0	6.0	93.	20.5	1160
	133		" "	Oct.	28	0.3	"	Distinct.	Slight musty.	0.43	.0052	.0194	.004	.0004	1.52	10.6	6.6	38.0	5.0	76.	16.	2630
	141		" "	Nov.	27	2.0	Turbid.	Marked.	Faint sweetish.	0.85	.0096	.0386	.046	.0009	0 50	6.4	5.4	25.5	5.0	90.	7.5	5523
			Average							**0.89**	**.0088**	**.0391**	**.013**	**.0004**	**0.72**	**7.1**	**4.6**	**26.6**	**4.9**			
484.	18	55	Haselton Bridge	June	18	0.4	None.	Slight.	Sour musty.	0.83	.0166	.0436	.010	.0015	0.70	9.6	2.8	22.5	3.5			2395
	41		" "	July	23	2.5	Very turbid	Heavy.	Slight earthy.	1.94	.0120	.0908	.031	.0010	0.05	2.6	3.8	20.0	4.5	72.	21.5	12428
	71		" "	August	28	0.85	Trace.	Marked.	" sweetish.	1.06	.0218	.0456	.027	.0015	0.65	6.4	2.8	21.5	5.0	65.	26.	5164
	101		" "	Sept	30	0.2	None.	Slight.	Sour musty.	0.52	.0230	.0268	.018	.0030	1.80	11.4	7.0	39.0	5.5	77.	22.	6350
	134		" "	Oct.	28	0.5	Slight.	Distinct.	Offensive.	0.55	.0750	.0454	.027	.0092	2.52	13.0	7.8	40.5	6.0	51.	18.	30460
	142		" "	Nov.	27	2.0	Turbid.	Very m'kd.	Musty.	1.02	.0150	.0460	.056	.0017	0.57	5.2	5.8	28.3	5.5	84.	7.	13150
			Average							**0.99**	**.0272**	**.0497**	**.028**	**.0030**	**1.05**	**8.0**	**5.0**	**28.6**	**5.0**			

SPECIAL ANALYSES.

Number of Sample.	Locality.	Date of Sampling.		Color.	Turbidity.	Sediment.	Odor.	Oxygen required.	Ammonia.		Nitrogen as		Chlorine.	Hardness.		Total solids.	Vol. solid.	Bacteria per cubic centimeter.	Temperature cent.
		Month.	Day.						Free.	Albuminoid	Nitrates.	Nitrites.		Temporary.	Permanent.				
17	Warren—Filtered water	June	18	0.35	None.	Slight.	Faint musty.	0.64	.0086	.0320	.007	.0004	0.20	9.4	2.4	17.5	3.0	538	....
43	" "	July	23	0.1	"	None.	" "	0.39	.0064	.0180	.030	.0007	0.07	1.0	4.2	10.5	3.0	1968	23.5
68	" "	August	28	0.2	"	"	Slight earthy.	0.59	.0052	.0288	Trace	None	0.30	10.0	2.8	24.5	4.5	50	22.5
131	" "	October	29	0.15	"	"	Earthy.	0.35	.0026	.0160	None	"	0.40	14.2	2.6	24.5	4.0	330	13.0
139	" "	Nov.	27	0.10	"	"	None.	0.37	.0048	.0176	.093	.0015	0.24	2.2	5.8	15.5	3.5	875	8.5
	Average							**0.47**	**.0055**	**.0225**	**.026**	**.0005**	**0.24**	**7.4**	**3.6**	**18.5**	**3.6**	....	....
23	Alliance—Sewage	June	19	0.3	Slight.	Very mar'd	Offensive.	1.92	1.0592	.2640	None	.0019	3.00	21.2	x	49.0	11.0	196260	....
49	" "	July	24	0.3	None.	Marked.	"	0.98	.1636	.0864	.044	.0185	2.55	15.8	12.8	47.5	8.0	105600	....
73	" "	Sept.	2	0.2	Slight.	"	Oily & slight offen'e	0.83	.0828	.0708	.061	.0150	1.65	17.8	9.4	49.0	8.5	80800	....
102	" "	Oct.	2	0.3	Distinct.	"	Slight offensive.	0.85	.3180	.1970	None	None	1.85	20.0	9.4	52.5	10.0	* 152900	....
106	" "	Oct.	29	0.25	Trace.	"	Oily.	1.00	.2370	.1380	.009	.0300	1.50	18.6	10.0	49.0	10.0	† 146200	....
	Average							**1.12**	**.3721**	**.1512**	**.023**	**.0131**	**2.11**	**18.7**	**10.4**	**49.4**	**9.5**	....	....
24	Alliance—Effluent	June	19	0.25	Slight.	Slight.	Earthy.	0.69	.3520	.0748	None	.0401	2.10	14.6	12.0	39.5	6.5	71360	23.
50	" "	July	24	0.2	None.	Marked.	Faint musty.	0.65	.1480	.0600	.036	.0332	3.25	13.4	14.0	49.0	9.0	459680	22.
74	" "	Sept.	2	0.2	Very slight.	"	Sl. greasy & musty.	0.73	.1608	.0748	.053	.0225	2.23	17.8	11.0	48.0	9.5	561400	19.
103	" "	Oct.	2	0.25	Slight.	Slight.	Faint musty.	0.72	.2900	.0870	None	None	1.90	15.0	8.4	44.0	6.5	* 611000	17.
107	" "	Oct.	29	0.25	Very slight	"	Musty.	0.77	.2350	.0950	"	.0015	1.70	14.2	10.2	42.0	8.5	†1111500	....
	Average							**0.71**	**.2372**	**.0783**	**.018**	**.0194**	**2.23**	**15.0**	**11.1**	**44.5**	**8.0**	....	....

* September 29. † October 27.

An examination of the table of results shows that the scheme of the work consisted in analyzing monthly samples taken at a series of points along the three streams, the object sought being a record of the chemical character of the water sufficiently complete to show the changes in the composition of the stream produced by the towns and rural drainage areas, how far the streams were sewage polluted, and what inferences could be drawn as to their value as sources of water supply from a sanitary standpoint. In the interpretation of these chemical analyses the weather is an important factor. The period of sampling covered one of the most severe droughts that has occurred in years, and also periods of severe local storms and general rainfall. In order to exhibit the rainfall conditions which existed over the areas drained by the Scioto, Olentangy and Mahoning rivers during the summer of 1897, the following table has been compiled from the monthly reports of the weather bureau, kindly furnished by Mr. H. W. Richardson. The table includes all the stations, furnishing complete rainfall records during the time of the investigation and located within or near the areas under investigation. Those days in each month are given on which there was a rainfall of one-tenth of an inch or over at any of the stations. The December record only includes the first ten days of the month, as this covered all the time of sampling. The entire precipitation for each month at each station is also given. In many cases this exceeds the sum of the daily precipitations, because there were days on which a few hundredths of an inch of rain fell, which are omitted from the table.

RAINFALL TABLE.

Days on which one-tenth inch or more Rainfall occurred.

SCIOTO RIVER BASIN.

Station.	June.	Rain.	July.	Rain.	Aug.	Rain.	Sept.	Rain.	Oct.	Rain.	Nov.	Rain.	Dec.	Rain.
KENTON.......	2	0.28	5	0.36	1	0.13	1	0.60	11	0.54	1	0.64		
	7	0.57	10	1.21	2	0.65			12	0.16	2	1.82		
	11	0.11	19	0.25	4	1.23			20	0.15	5	0.12		
	16	1.61	22	0.72	5	0.15					7	0.15		
	17	0.79	31	0.53	15	0.15					8	0.72		
	29	0.36			23	0.58					9	0.46		
											11	0.15		
											14	1.31		
											15	0.54		
											16	0.50		
											25	0.19		
											26	0.75		
Total rain fall by months..	...	3.94	......	3.54	......	2.91	......	0.60	......	0.85	......	7.50	......	2.53
Variation from the normal at the station	...	+0.14	......	+0.43	......	−0.48	......	−1.88	......	−1.11	......	+3.74		

SCIOTO RIVER—CONTINUED.

Station.	June.	Rain.	July.	Rain.	Aug.	Rain.	Sept.	Rain.	Oct.	Rain.	Nov.	Rain.	Dec.	Rain.
MARION	3	0.16	1	0.12	1	0.49	1	0.63	11	0.23	1	0.96		
	7	0.32	5	2.03	3	0.28	16	0.31	12	0.25	2	0.11		
	11	0.12	11	1.15	4	0.23					5	0 14		
	13	0.42	14	0.48	16	0.19					7	0.11		
	16	0.75	17	0.28	24	0.23					8	0.52		
	17	0.98	19	0.88							9	0.41		
	23	0.16	20	0.28							11	0.14		
	29	0.59	26	1.40							14	1.29		
			27	0.38							15	0.40		
											16	0.63		
											25	0.15		
											26	0.80		
Total rainfall by months.. } ...		3.50	......	7.28	......	1.50	......	0.94	......	0.53	......	5.73	......	2.04
Variation from the normal at the station } ...		—0.12	......	+3.40	......	—1.34	......	—1.49	......	—2.72	......	+2.06		
COLUMBUS ... Av. City and O. S. U. Stations.	3	0.28	5	0.27	1	0.13	1	0.34	11	0.31	1	1.07		
	16	0.90	11	2.08	2	0.12	16	0.35			2	1.07		
	19	0.14	17	0.37	4	0.38					5	0.12		
	29	1.15	18	0.18	15	0.23					7	0.12		
			21	1.42	16	0.12					8	0.59		
			26	0.13	23	0.21					9	0.29		
					25	0.45					14	1.27		
					29	0.30					15	0.52		
											16	0.51		
											25	0.67		
											26	1.61		
Total rainfall by months.. } ...		2.65	......	4.84	......	2.06	......	0.71	......	0.42	......	7.42	......	2.51
Variation from the normal at the station } ...		—1.33	......	+1.77	......	—0.58	......	—2.15	......	—1.88	......	+3.96		
CIRCLEVILLE	16	0.30	1	0.36	2	0.10	2	0.43	11	0.10	1	1.14	4	0.34
	17	0.15	4	0.88	9	0.10	19	0.29	12	0.50	2	0.54		
	19	0.52	5	0.15	15	0.30			28	0.22	5	0.18		
	29	0.12	9	0.50	16	1.07					7	0.42		
	30	0.12	11	0.36	23	0.27					8	1.84		
			12	0.25	25	0.35					9	0.16		
			17	1.67							14	0.76		
			18	0.11							15	0.64		
			19	0.13							16	0.64		
			21	1.10							26	0.52		
			26	0.30										
Total rainfall by months.. } ...		1.45	......	6.06	......	2.38	......	0.72	......	0.99	......	7.05	......	2.89
Variation from the normal at the station } ...		—1.73	......	+1.93	......	....	......	—0.83	......	—1.02	......	+4.10	......	
Total for whole Basin by months......... } ...		2.88	......	5.43	......	2.21	......	0.74	......	0.68	......	6.92		
Variation from normal for Basin.......... } ...		—0.76	......	+1.88	......	—0.80	......	—1.58	......	—1.68	......	+3.46	......	

RAIN FALL TABLE—CONTINUED.

MAHONING RIVER BASIN.

Station.	June.	Rain.	July.	Rain.	Aug.	Rain.	Sept.	Rain.	Oct.	Rain.	Nov.	Rain.	Dec.	Rain.
AKRON.........	7 11 13 17 29 30	0.12 0.12 0.10 0.49 0.25 0.35	5 11 12 16 17 21 26 27 28	2.05 0.15 0.86 0.20 0.29 0.70 0.35 0.19 0.11	4 5 11 12 15 16 19 24 25	0.75 0.11 0.31 0.11 0.18 0.98 0.14 0.10 0.17	1 16 20	0.41 0.48 0.11	12 20	1.33 0.27	1 2 3 5 8 9 11 14 15 16 25 26	0.90 0.65 0.18 0.13 0.29 0.52 0.15 0.29 0.21 0.48 0.23 0.70		
Total rainfall by months.. }	...	1.55	......	5.06	......	2.98	......	1.07	......	1.65	......	4.85	......	1.74
Variation from the normal at the station }	...	−2.81	......	+1.20	......	−0.35	......	−2.12	......	−0.77	......	+1.69	......	
WARREN......	7 11 17 19	0.96 0 19 0.39 0.30	1 5 6 12 14 18 19 20 21 22 26 27	0.86 0.19 0.16 1.22 0.14 0.20 0.86 0.37 0.22 2.37 0.14 1.38	4 9 10 15 16 17 10 23 24 25	0.89 0.10 0.43 0.63 0.34 0.73 0.75 0.24 0.19 0.22	2 16 20	1.07 0.26 0.19	12 21	0.23 0.17	1 2 3 6 8 9 11 12 14 15 16 25 26	0.83 0.36 0.17 0.11 0.34 0.36 0.35 0.83 0.53 0.29 0.27 0.47 0.58	4 7	0.11 0.10
Total rainfall by months.. }	...	1.91	......	8.23	......	4.68	......	1.55	......	0.51	......	5.73	......	2.90
Variation from the normal at the station }	...	−2.60	......	+2.50	.....	+2.36	.....	−1.76	......	−1.77	......	+2.61	......	
YOUNGST'WN	7 9 11 14 17 29	1.10 0.15 0.10 0.50 0.50 0.15	5 11 14 16 18 19 20 21 22 26 27	0.98 1.20 0.30 0.35 0.40 0.60 0.50 0.30 1.70 0.10 1.00	4 9 10 14 15 16 19 23 24 29	0.43 1.50 1.00 0.65 0.60 0.34 0.43 0.11 0.11 0.35	1 16	0.80 0.20	12	0.10	1 2 5 8 10 11 12 14 15 16 25 26	1.00 0.10 0.10 0.50 0.15 0.42 0.10 0.80 0.60 0.26 0.40 0.30	4	0.10
Total rainfall by months.. }	...	2.65	......	7.48	......	5.57	......	1.04	......	0.25	......	4.84	......	2.54
Variation from the normal at the station }	...	—0.47	......	+4.30	......	+2.48	......	−2.15	......	−1.92	......	+2.03	......	

MAHONING RIVER BASIN—CONTINUED.

Station.	June.	Rain.	July.	Rain.	Aug.	Rain.	Sept.	Rain.	Oct.	Rain.	Nov.	Rain.	Dec.	Rain.
COLEBROOK..	4 7 8 11 17 18 30	0.11 1.63 0.17 0.15 0.20 0.11 0.11	5 6 11 16 18 19 21 22 23 25 27 28	0.90 0.15 0.80 0.12 0.35 0.44 0.15 2.64 0.61 0.38 0.15 0.19	4 10 15 16 17 19 23 24 29 30	0.35 0.89 0.61 2.43 0.23 0.18 2.55 0.10 0.10 0.84	1 14 16	0.35 0.14 0.78	7 12 21 22	0.10 0.88 0.20 0.20	1 2 3 9 11 12 14 15 16 25 26	0.65 0.70 0.49 0.71 0.22 0.22 0.25 0.98 0.42 0.31 1.42		
Total rainfall by months..	...	2.53	......	7.14	......	8.40	......	1.27	......	1.43	......	6.77	......	2.44
Variation from the normal at the station	...	....	......	....	......	....	......	−2.04	......	−1.19	......	+3.19		
Average for whole Basin by months..	...	2.16	......	6.98	......	5.41	......	1.23	......	0.96	......	5.54	......	
Variation from normal for Basin.........	...	−1.96	......	+2.66	......	+1.50	......	−2.02	......	−1.28	......	+2.38		

In addition to the facts given in the above table, the following statements are taken from the monthly reports of the United States weather service, and describe the general character of the weather for each month over the state at large.

For June. The temperature was two degrees below normal, it being the coolest June in eleven years. The precipitation over the state was 0.97 inches below the normal.

For July. The temperature was two and four-tenths degrees above the normal, it being the warmest July in ten years. Precipitation was 1.09 above the normal.

For August. The temperature was one degree below the normal, and precipitation was 0.34 below the normal. The precipitation of the northern section, however, was 0.53 above the normal.

September. The temperature was above the normal 2.1 degrees, while the precipitation was 2.07 below the normal, it being the driest September on record in fifteen years.

October. The temperature was 6.4 degrees above the normal, it being the warmest October on record. The precipitation was 1.62 inches below the normal. This is the driest October in fifteen years, and also the driest month on record for the same period.

November. The temperature was 1.5 degrees above the normal, and the precipitation was 3.36 inches above the normal, this being the wettest November on record since the organization of the state service.

From the foregoing data the weather history of the samples may be stated as follows.

SCIOTO, LITTLE SCIOTO AND OLENTANGY RIVERS.

The June sampling: The weather for this month was cool, and the June precipitation much below the normal. The sampling extended from June 12th, at Marion and Kenton to June 18th at Chillicothe. There were rains on the upper water-shed on the second and seventh. These were not felt to any extent in the lower portions. The rainfall on the upper part of the river was above normal during the month, while much below the normal around Columbus and Circleville. Slight rains fell on the eleventh just before taking the samples at Kenton, Marion and Delaware. The samples at Wyandotte, Jones' Dam, above and below Columbus and at Circleville were taken after several days of dry weather. The Chillicothe samples on the 18th, were taken after general rains on the 16th and 17th. The June samples thus represent dry weather conditions, with the exception of the one taken at Chillicothe.

The July sampling: The sampling extended from July 15th to July 22d. There were general rains on the fifth and eleventh, and heavy rains at Kenton on the tenth, no rain fell immediately before taking the Kenton samples, light rains fell on the fourteenth just before taking the samples at Marion and Galion. The samples in the neighborhood of Columbus were taken during light rains on the seventeenth. The Circleville samples were taken July 22d, shortly after the heavy rains on the seventeenth and twenty-first, and light rains on the eighteenth and nineteenth. The July samples represent general conditions of fair weather preceded, but not immediately, by general rains. The Circleville samples are an exception, and were taken immediately after heavy local rains resulting in turbid waters and full streams.

The August sampling extended from Aug. 23d to Aug. 26th after a period of continued dry weather interrupted immediately before the time of sampling by light rains at Kenton, Marion and Delaware, and in the neighborhood of Columbus. At Circleville there were heavy rains on the sixteenth with lighter rains on the twenty-third and twenty-fifth immediately preceding the sampling.

The September sampling extended from September 23d to September 27th. No rain of any moment had fallen for several days before sampling at any of the stations.

The October sampling extended from the twenty-third to the twenty-sixth, and no rain fell during or before the time of sampling. The samples represent the condition of the stream after a long and severe drought.

November samples: These were taken from October 30th to December 4th. The month had been wet and warm, and there were general rains on the 25th and 26th, which were particularly heavy on the lower portion of the water-shed. No rain of moment fell at the time of sampling. The November samples therefore represent a uniform condition of clear weather following heavy and general rains.

THE MAHONING RIVER.

In making up the data for this water-shed, the observations at Akron were taken as representing the Western portion of the field; though the station was not strictly within the area, it was the only point available. The June sampling extended from the nineteenth to the twenty-first. There were moderate general rains on the seventeenth, after a period of comparatively dry weather. No local storms occurred at or before the time of sampling at any of the stations.

The July sampling was done on the twenty-third and the twenty-fourth. Between the twenty-first and the twenty-second, there were general rains all over the water-shed. These were particularly heavy at Warren and Youngstown, but light at Akron, and by inference at Alliance, causing a great and general flushing of the streams at the lower points especially. The effect of these rains was least felt at Alliance.

The August samples were taken from August 28th to September 2d. No rains of any moment fell at or nearly preceding the time of sampling; the samples all represent settled clear weather.

The September samples were drawn on September 29th and 30th. There were no general rains at or near the time of sampling, the samples representing the conditions of the streams after a long period of dry weather.

October sampling; this covered October 27th and 28th. There were no rains at or shortly before the time of sampling. The samples representing the condition of the streams after a long drought.

The November samples were drawn on the twenty-sixth and twenty-seventh. There was general moderate rainfall on the twenty-fifth and twenty-sixth following a week of comparatively dry weather. The early part of the month was very wet and the streams high. The samples represent the condition of the streams after recent rains all over the water-shed.

In the above statement light rains include all those in which less than five-tenths of an inch fell in twenty-four hours. Moderate rains include those in which between five-tenths and one inch fell, and heavy rains, those in which the rainfall amounted to over one inch in the same period of time. These limits are those set by Mr. Richardson of the weather bureau, and correspond to his usage.

THE DRAINAGE AREA AND THE POPULATION ABOVE THE POINTS IN THE STREAM AT WHICH THE SAMPLES WERE TAKEN.

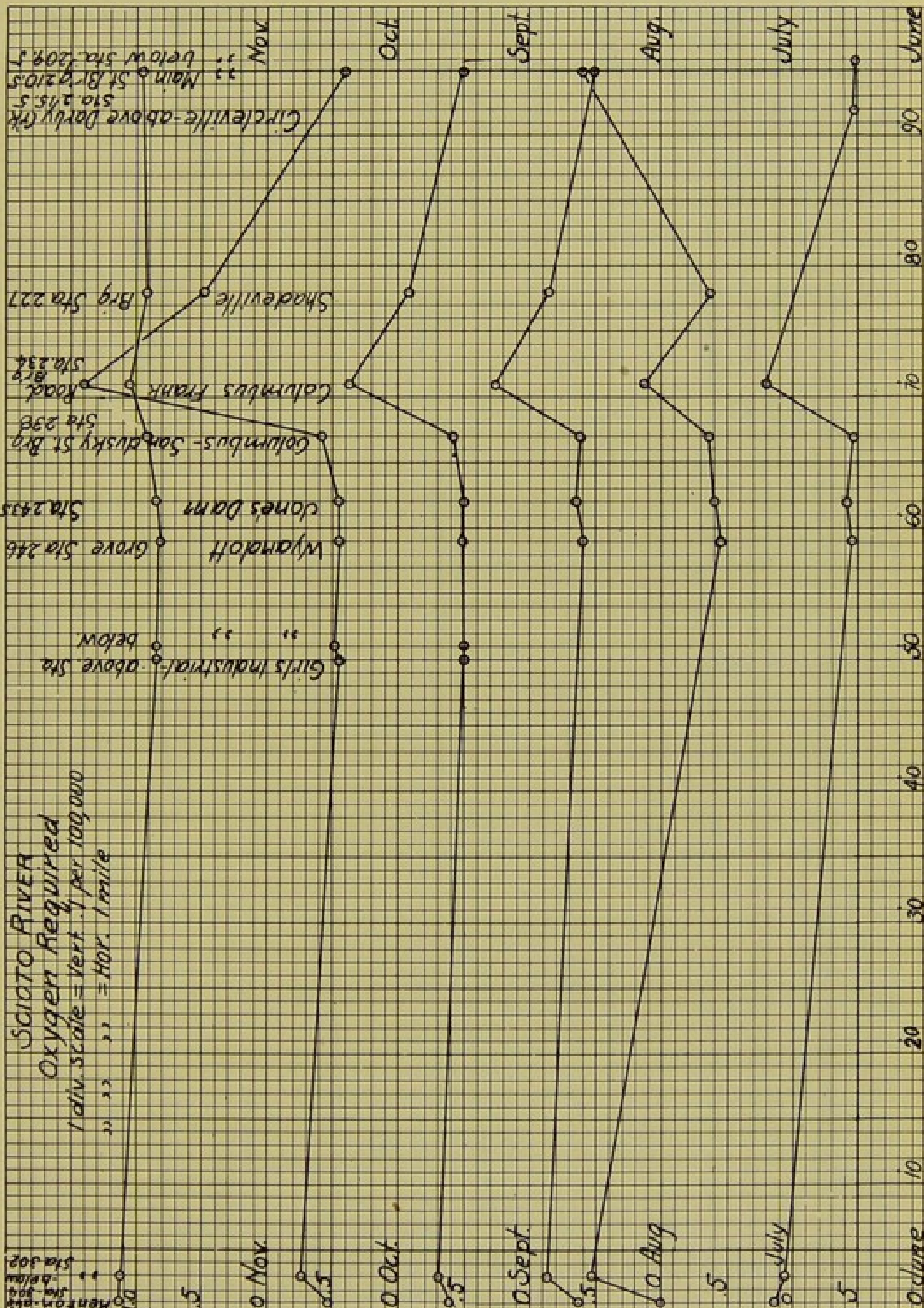
In the report of Mr. Hazen the figures are given for the areas of the principal water-sheds and the estimated average rural populations per square mile for each. The following table is compiled from these data and from special measurements by the planimeter on the large map, and shows the drainage area above each of the points at which samples were taken together with its total population estimated from the average rural population for the water-shed as given by Mr. Hazen and the estimated populations of the cities on the streams. In making this estimate the average rural population of the Scioto water-shed including the Olentangy, was taken as forty-five per square mile, of the Mahoning river as fifty-six per square mile.

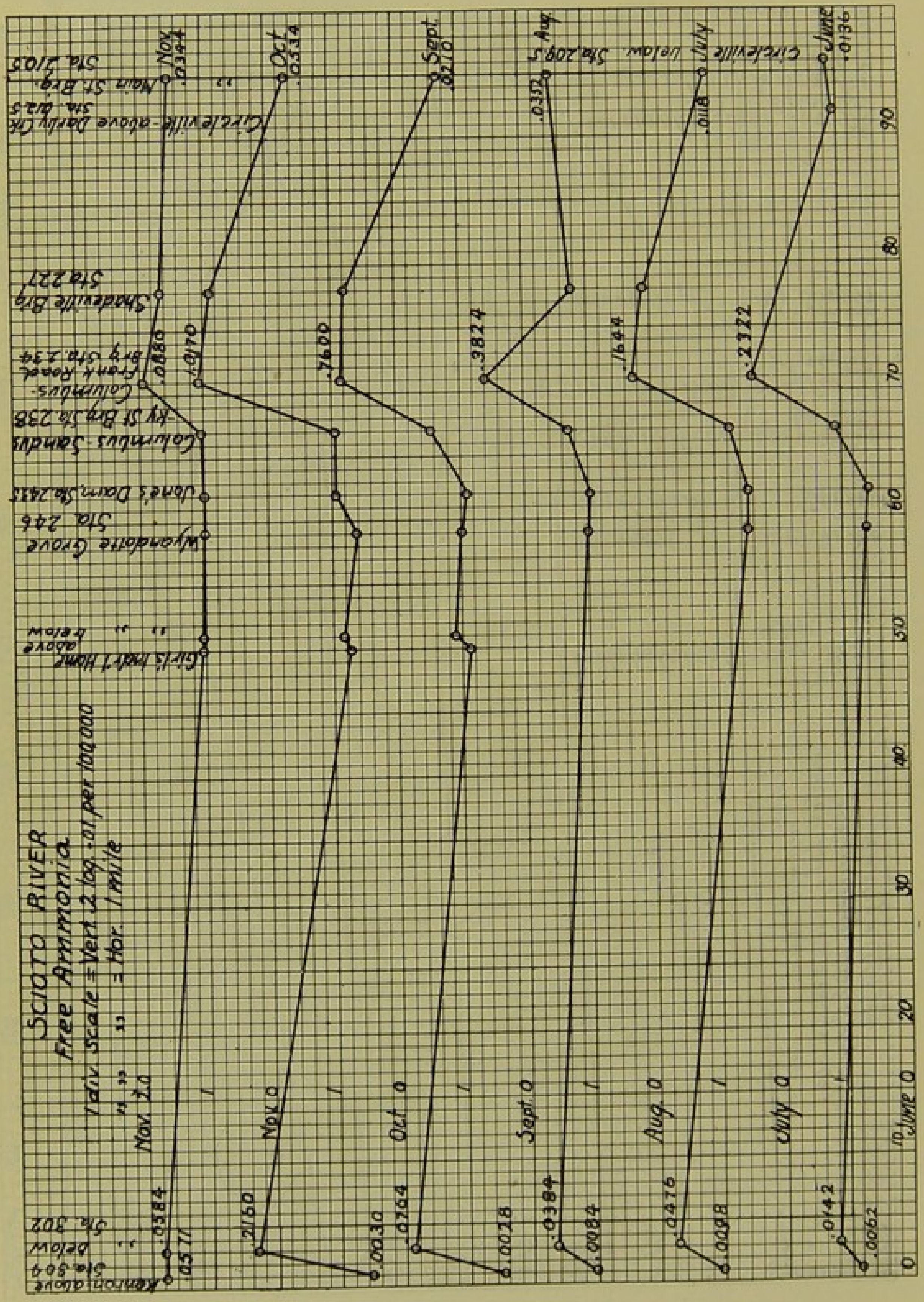
DRAINAGE AREA AND POPULATION ABOVE SAMPLING POINTS.

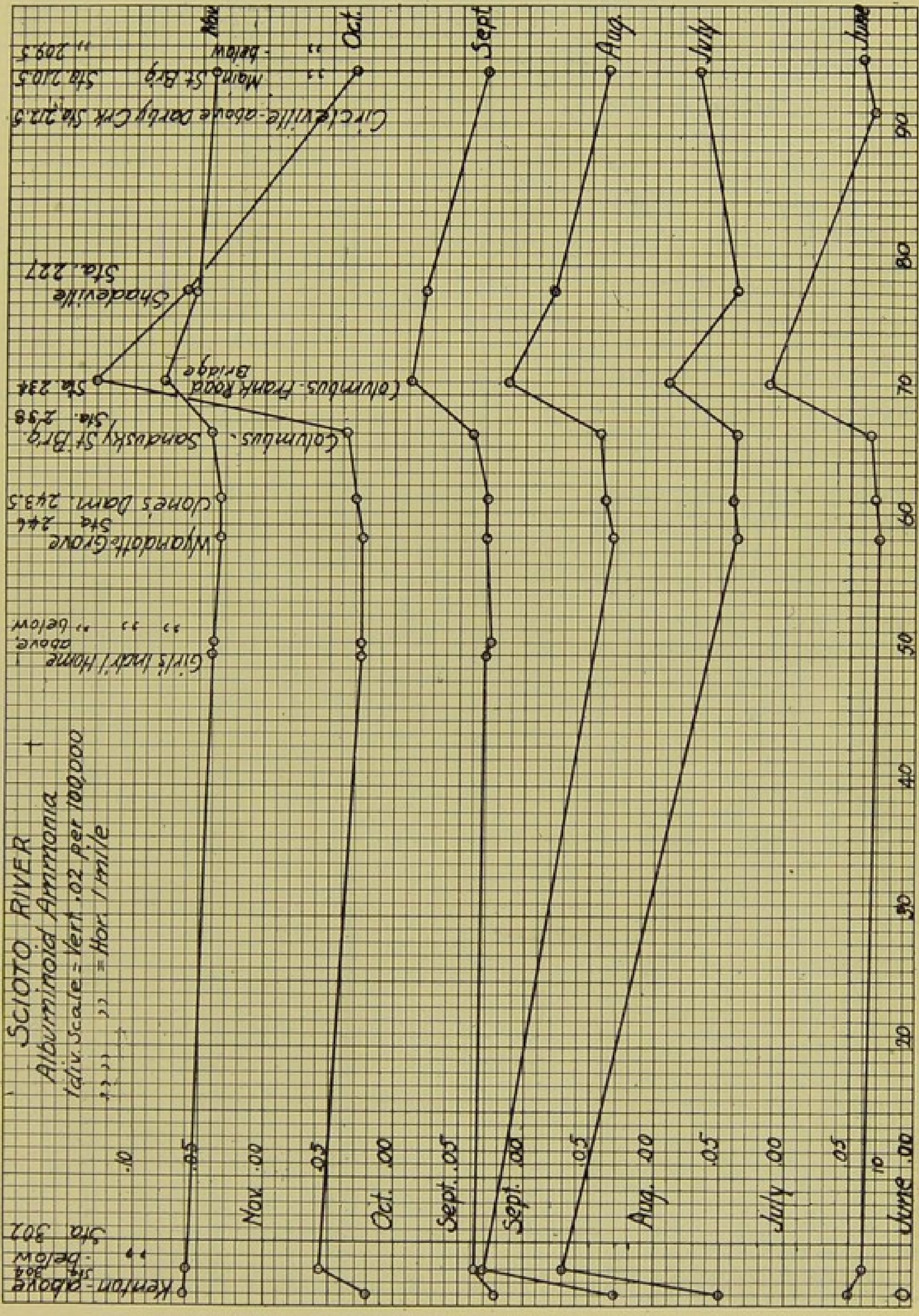
SCIOTO AND LITTLE SCIOTO RIVERS.

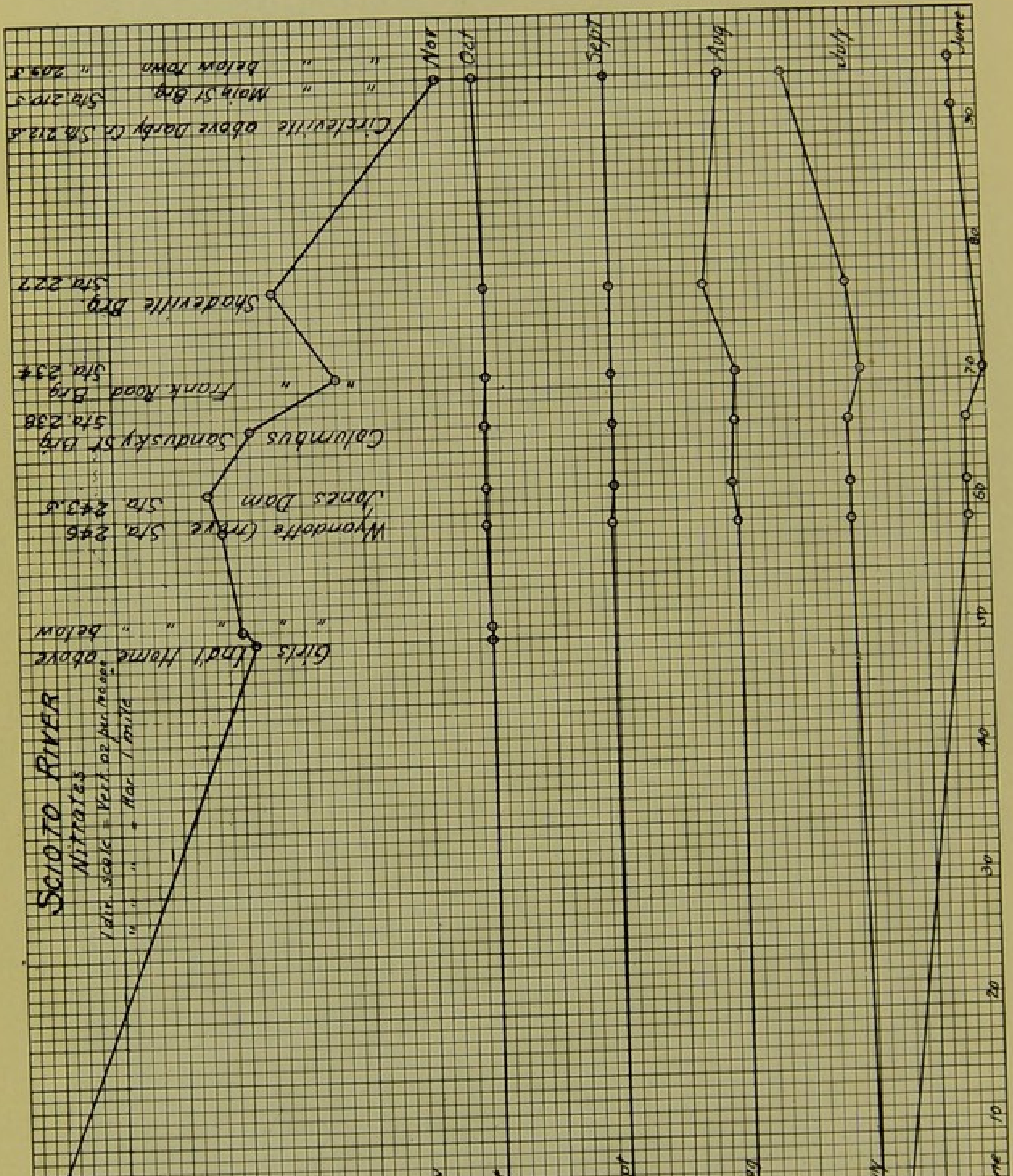
Station.	Area Drained.	Rural Population.	City Population.	Total Population.
Kenton, above	153	6,685	....	6,685
Kenton, below	153	6,685	7,838	14,525
Marion, above	109	4,905	....	4,905
Marion, below	109	4,905	17,783	22,688
Girls' Ind. Home	962	43,300	....	68,921
Wyandotte Grove	1,023	46,000	....	71,621
Jones' Dam	1,038	46,600	....	72,221
Sandusky St. Bridge	1,053	47,300	....	72,921
Columbus F. R. Bridge	1,565	70,400	150,452	263,419
Shadeville	1,650	80,200	....	273,200
Circleville, above Darby Cr'k	2,625	118,000	....	311,000
Circleville	3,160	142,000	7,109	342,000
OLENTANGY RIVER.				
Galion, above	29	1,305	....	1,305
Galion, below	29	1,305	7,109	8,407
Delaware, above	422	18,990	....	26,099
Delaware, below	422	18,990	9.810	35,909
Olentangy Park	488	21.960	....	38,879
Dublin Bridge	512	23,040	....	39,959
MAHONING RIVER.				
Alliance, above	82	4,592	....	4,592
Alliance, below	82	4,592	12,483	17,075
Warren, above	596	33,286	....	45,769
Warren, below	596	33,286	8,054	53,826
Niles	815	45,640	4 752	71,922
Youngstown, above	967	54,152	....	80,434
Youngstown, below	967	54,152	71,420	151,854

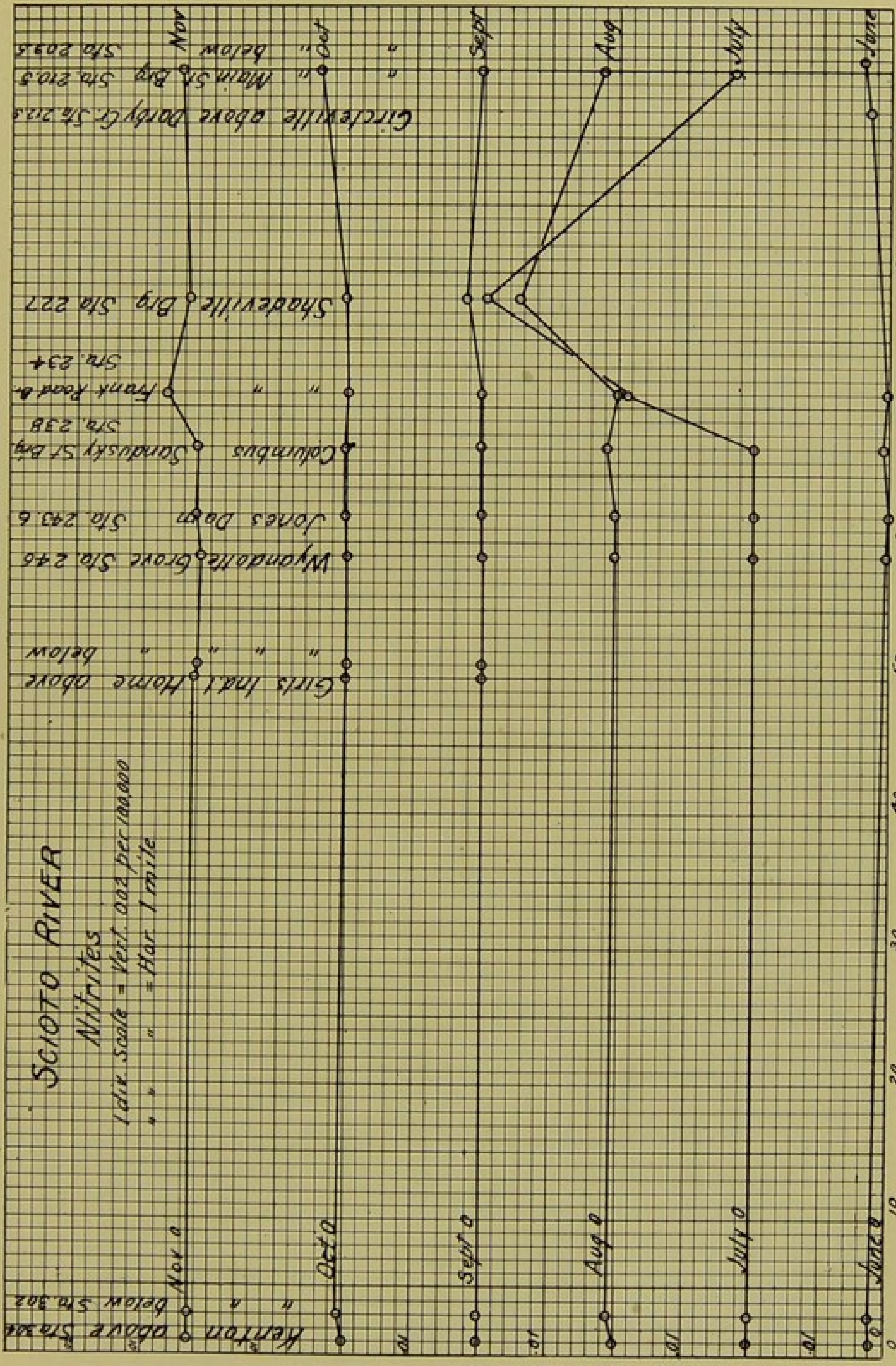
The figures in the above table are based on averages, and cannot claim great exactness, but are sufficient to indicate closely enough for the discussion of the analyses the distribution of the population along the stream from which the samples were taken. In order to exhibit plainly the changes which the various materials determined in the analysis undergo with the flow of the stream, the results given in the large table have been plotted in the series of plates which follow. In these plates the horizontal distances indicate the miles of flow measured along the stream; the vertical distances give the amounts of the element determined. The scale is varied on the different plates according to the absolute amount of material present, and the character of the substance, so as to bring all the curves to approximately the same extreme variation. On each plate the determinations for one month constitute a single line. These lines are placed one above the other, and show the variations from month to month. In plotting the free ammonias the variations were found to be so large that in order to bring the points on the plate and yet have a scale which would show the variations found in the purer waters, it was necessary to plot the logarithms of the determinations rather than the numbers themselves. On these plates the actual figures are inserted at the points of inflection of the lines.

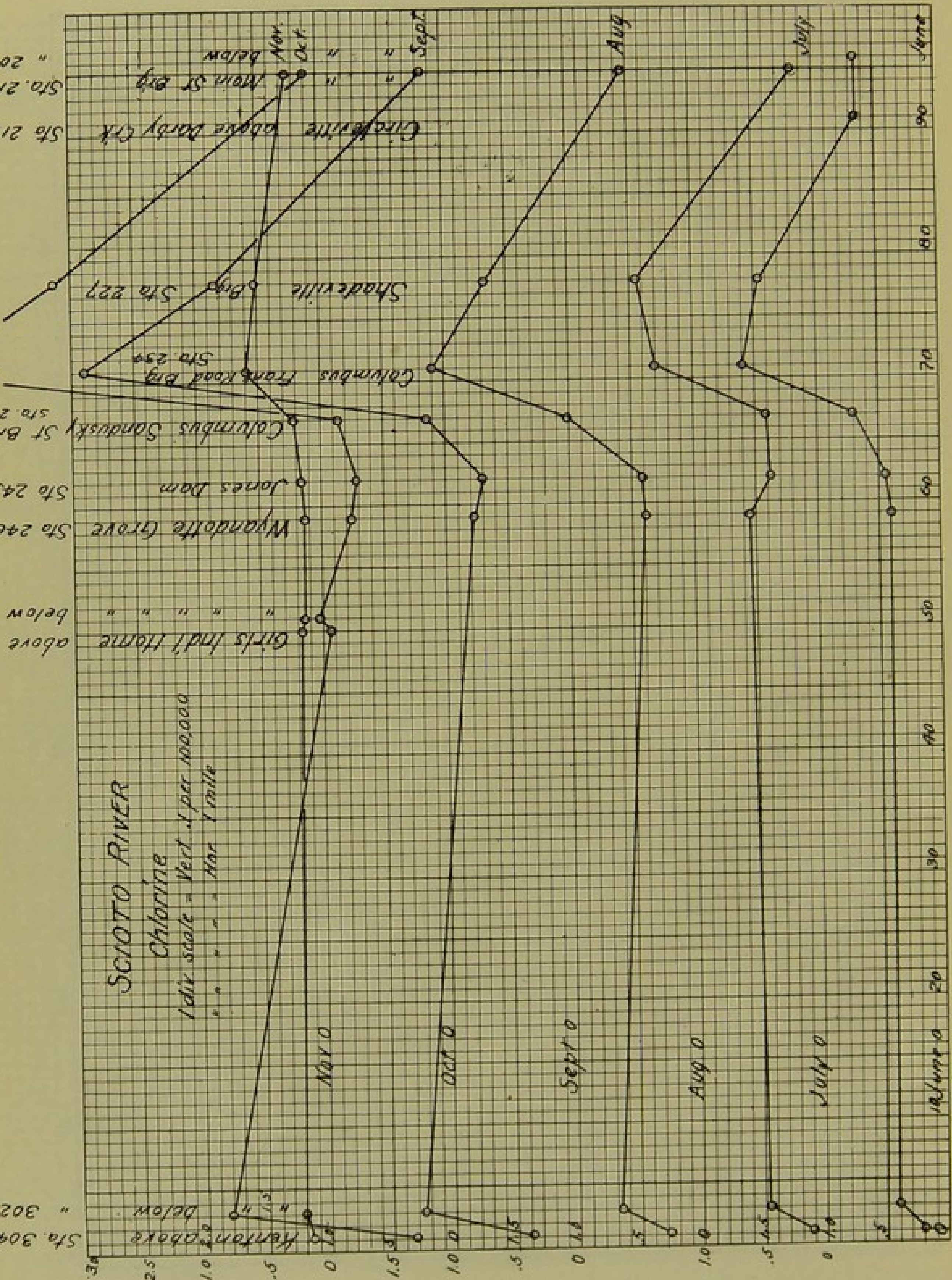

Scioto River
Oxygen Required
1 div. scale = Vert. 1 per 100,000
" " " = Hor. 1 mile
Circleville-above Darby Crk Sta. 216.5
Shadeville
Columbus Frank Road Brg Sta. 234
Columbus-Sandusky St. Brg Sta. 238
Jone's Dam Sta. 243.5
Wyandott Grove Sta. 246
Girls Industrial-above Sta. below
Nov.
Oct.
Sept.
Aug.
July
June

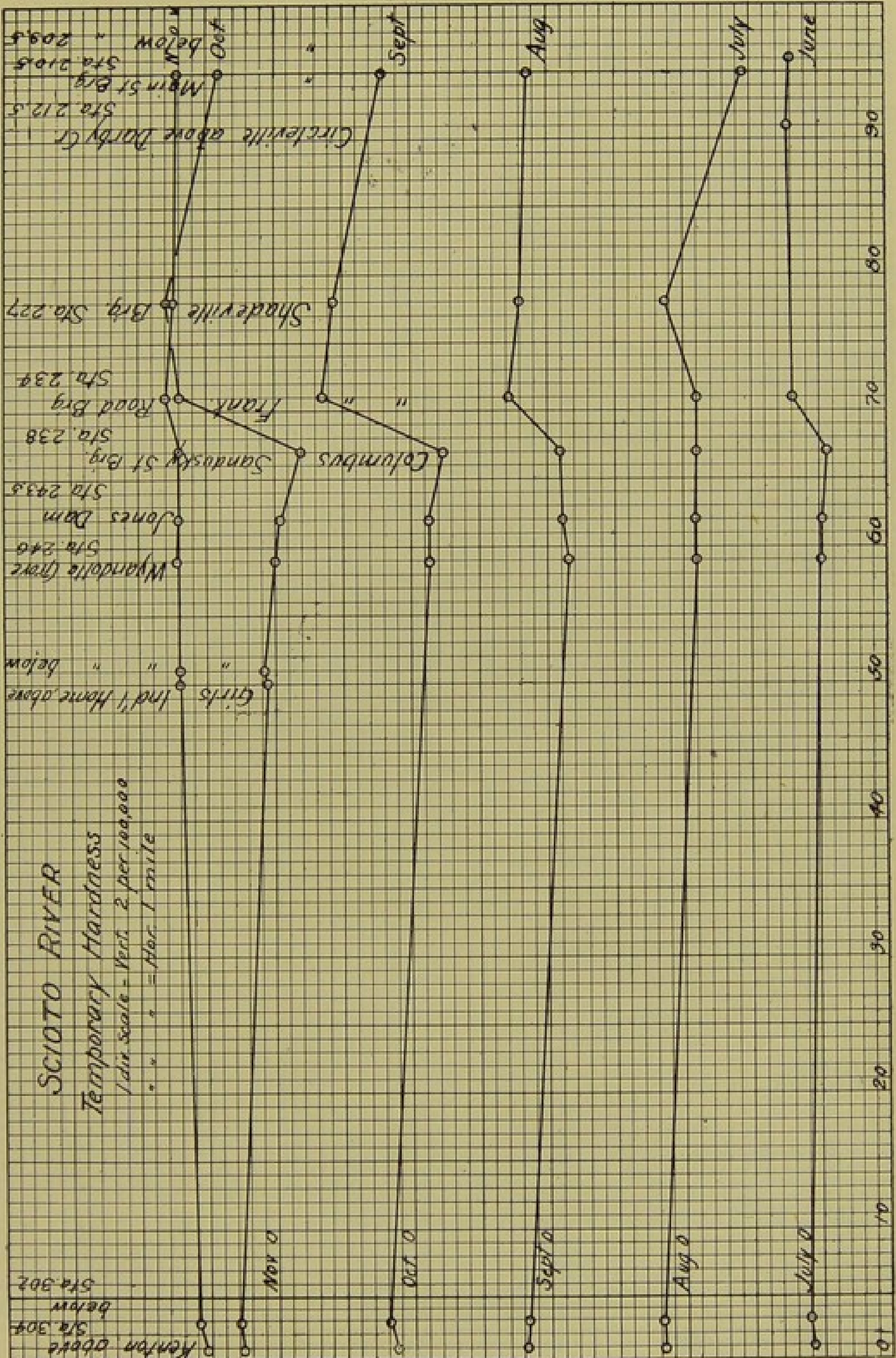

SCIOTO RIVER
Free Ammonia
Nov.
Oct.
Sept.
Aug.
July
June

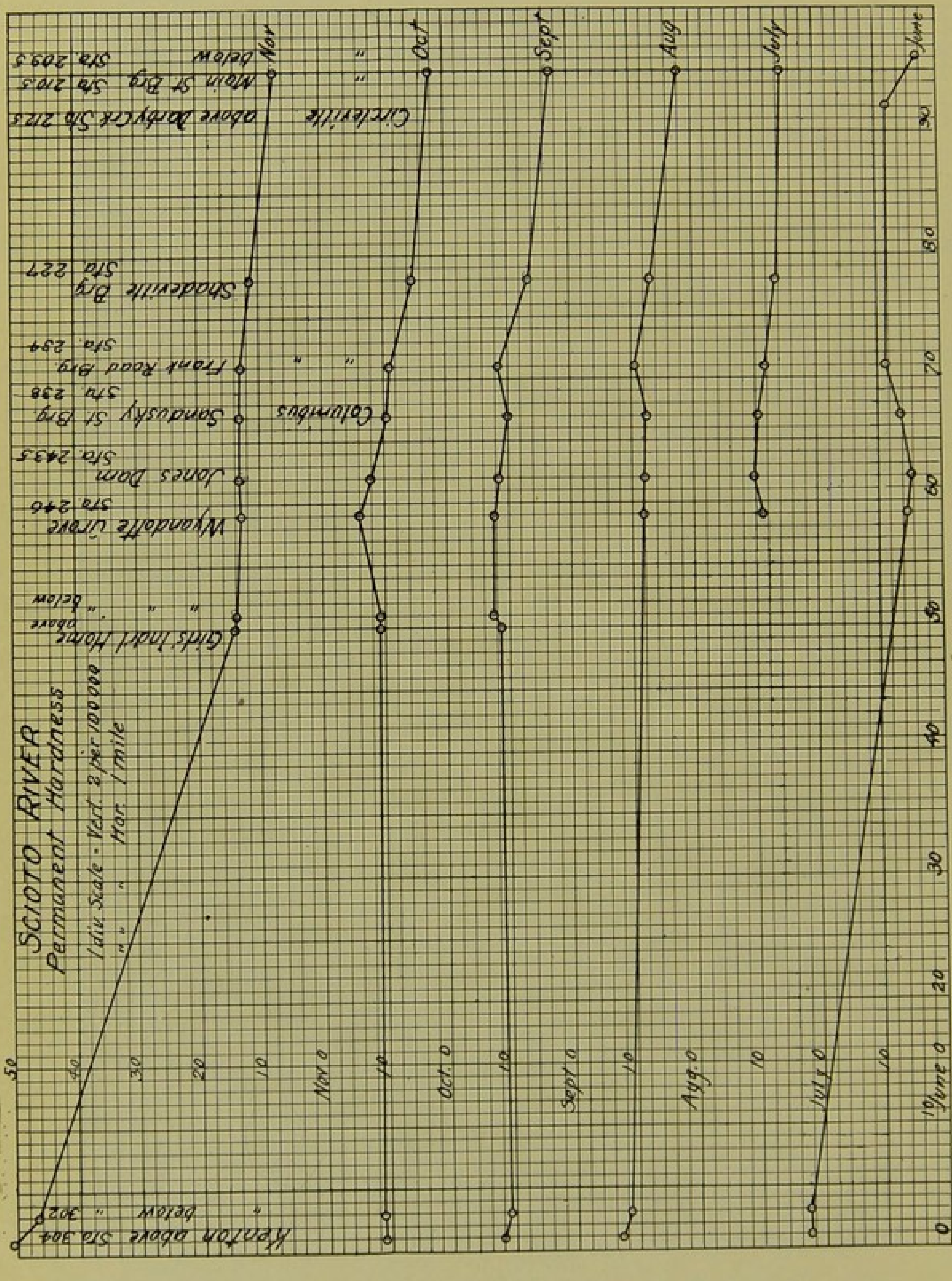

SCIOTO RIVER
Albuminoid Ammonia
1 div. Scale = Vert. .02 per 100,000
" " = Hor. 1 mile
Kenton - above
- below
Sta. 302
Girl's Ind'l Home
above
below
Wyandotte Grove Sta. 246
Clone's Dam. 243.5
Columbus - Sandusky St. Brg. Sta. 238
Columbus - Frank Road Bridge Sta. 234
Shadeville Sta. 227
Circleville - above Darby Crk Sta. 212.5
Main St. Brg Sta. 210.5
- below " 209.5
Nov.
Oct.
Sept.
Aug.
July
June


Scioto River
Nitrates
1 div. scale = Vert. .02 per 1000000
" " " = Hor. 1 mile
Kenton above Sta 304
" below " 302
Girls Ind'l Home above
" " " below
Wyandotte Grove Sta. 246
Jones Dam Sta. 243.5
Columbus Sandusky St Brg Sta. 238
" Frank Road Brg Sta. 234
Shadeville Brg Sta. 227
Circleville above Darby Cr Sta. 212.8
" " Main St Brg Sta. 210.5
" " below town " 209.5
Nov
Oct
Sept
Aug
July
June

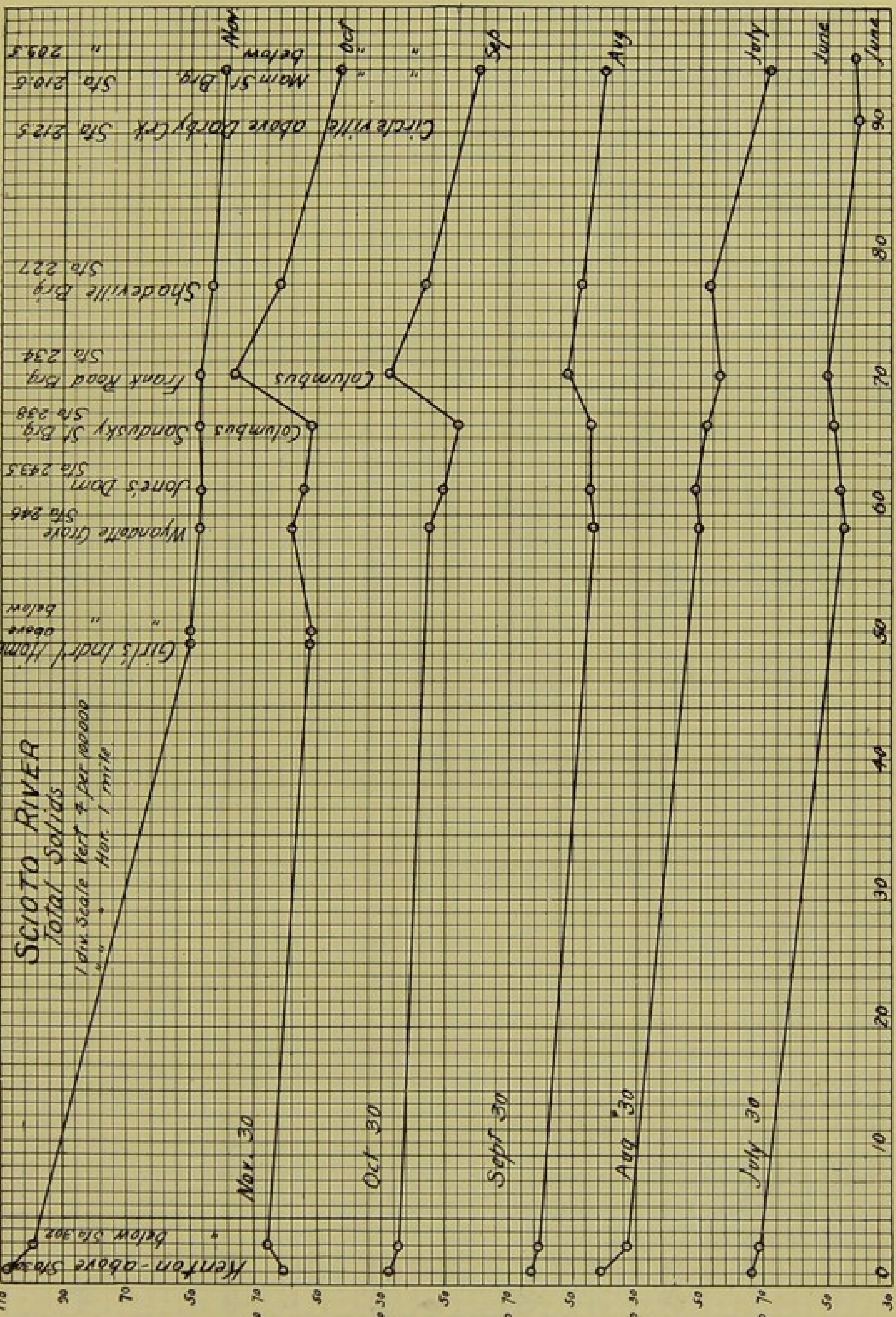

SCIOTO RIVER
Nitrites
1 div. Scale = Vert. .002 per 100,000
" " " = Hor. 1 mile
Kenton above Sta. 306
" below Sta. 302
Girls Ind'l Home above
" " " below
Wyandotte Grove Sta. 246
Jones Dam Sta. 240.6
Columbus Sandusky St. Brg. Sta. 238
" " Frank Road Br. Sta. 234
Shadeville Brg. Sta. 227
Circleville above Darby Cr. Sta. 213.5
" Main St. Brg. Sta. 210.5
" below Sta. 209.5
Nov
Oct
Sept
Aug
July
June
0
10
20
30
40
50
60
70
80
90

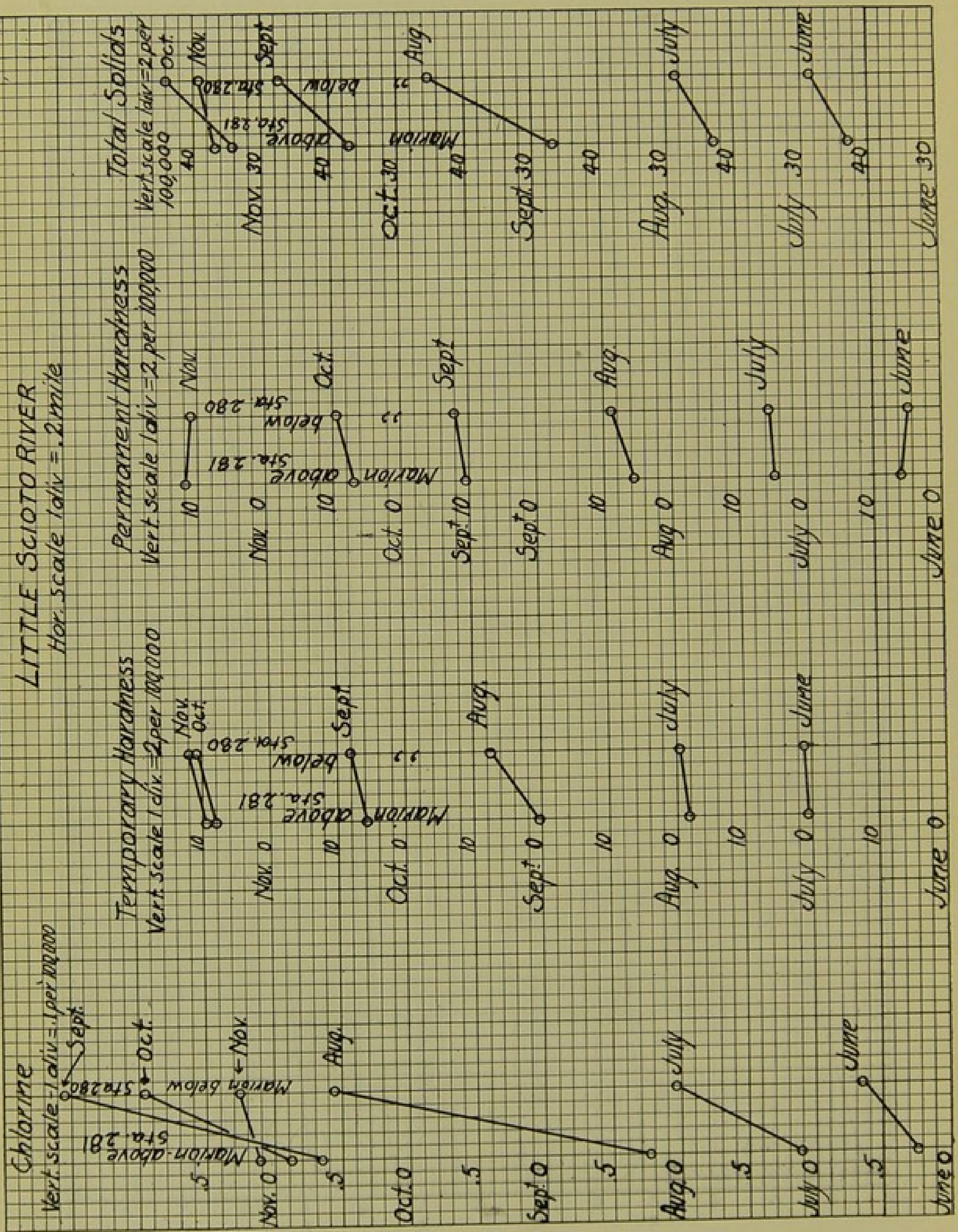

SCIOTO RIVER
Chlorine
1 div. scale = Vert .1 per 100,000
" " " = Hor 1 mile
Sta. 304 Kenton above
" 302 below
above Girls Ind'l Home
below
Sta 246 Wyandotte Grove
Sta 243.5 Jones Dam
Sta. 238 Columbus Sandusky St Brg
Sta. 234 Columbus Frank Road Brg
Sta 227 Shadeville Brg
Sta 212.5 Circleville above Darby Crk
Sta. 210.5 Main St Brg
" 209.5 below
June
July
Aug
Sept
Oct.
Nov.
June 0
July 0
Aug 0
Sept 0
Oct 0
Nov 0

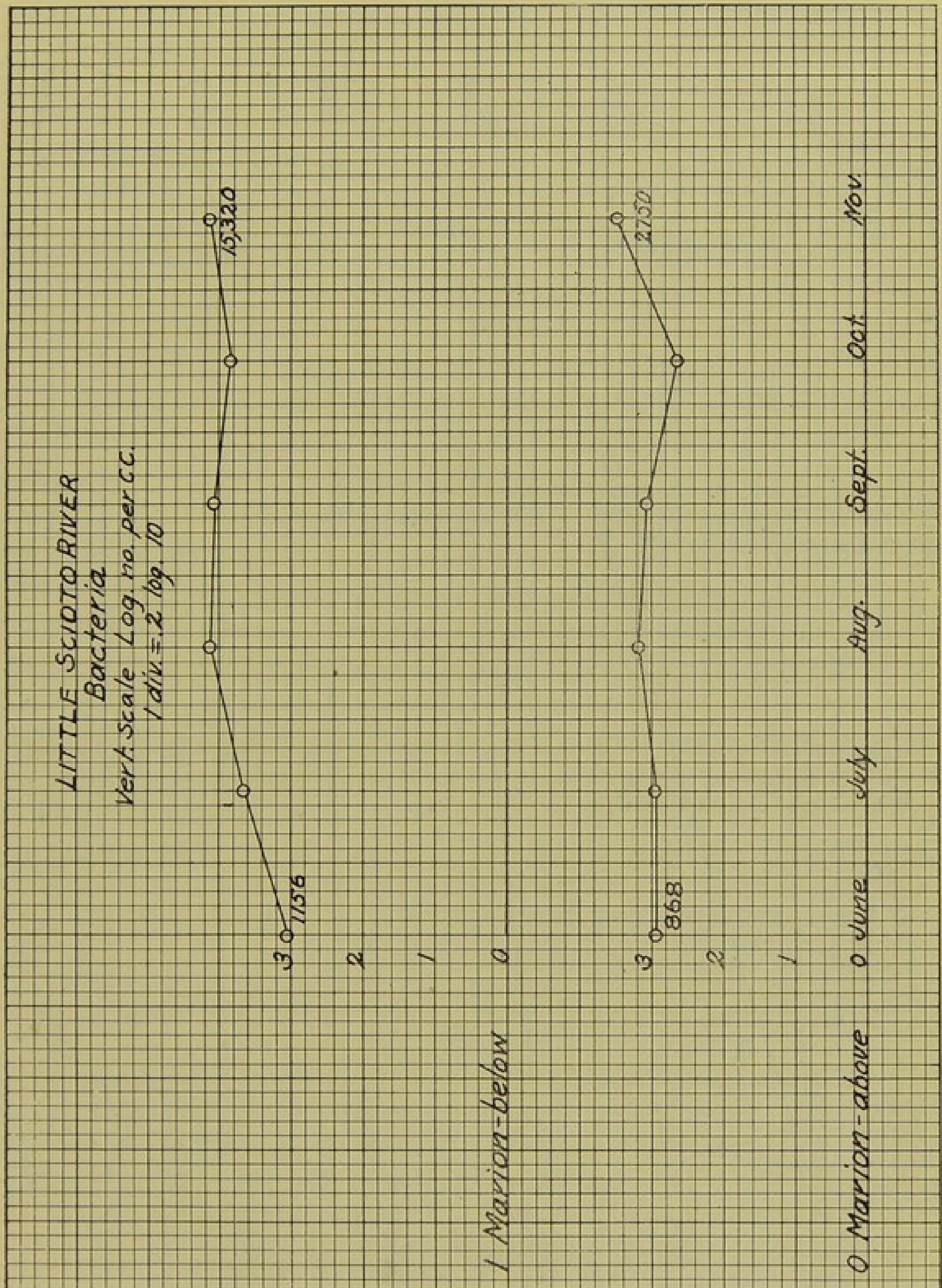

SCIOTO RIVER
Temporary Hardness
1 div. Scale - Vert. 2 per 100,000
" " " = Hor. 1 mile
Kenton above
Sta. 304
below
Sta. 302
Girls Ind'l Home above
" " " below
Wyandotte Grove
Sta. 246
Jones Dam
Sta. 243.5
Sandusky St. Brg.
Sta. 238
Columbus Frank Road Brg.
Sta. 239
Shadeville Brg. Sta. 227
Circleville above Darby Cr.
Sta. 212.5
Main St. Brg.
Sta. 210.5
below " 209.5
Nov 0
Oct. 0
Sept 0
Aug 0
July 0
Oct.
Sept
Aug
July
June
0
10
20
30
40
50
60
70
80
90

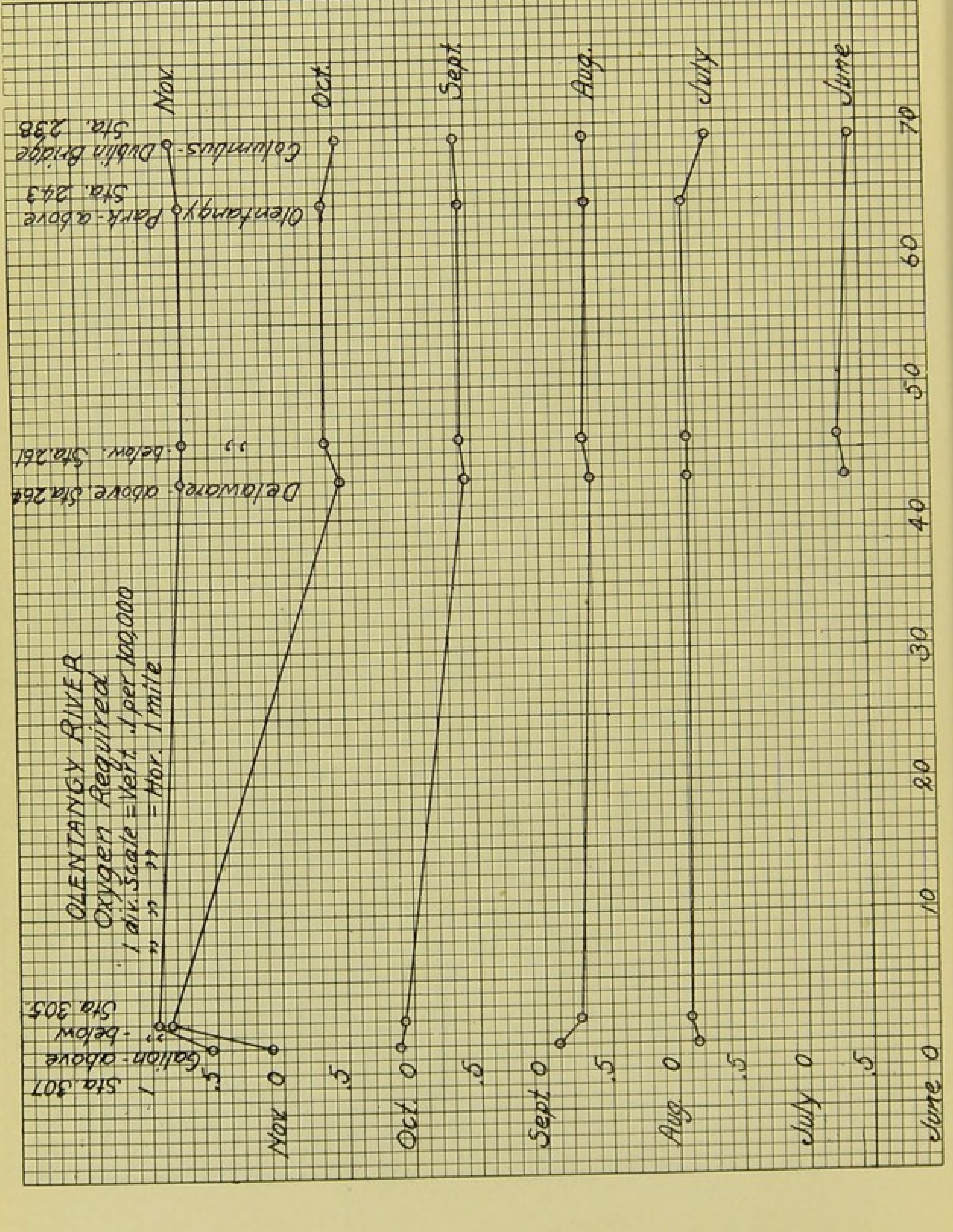


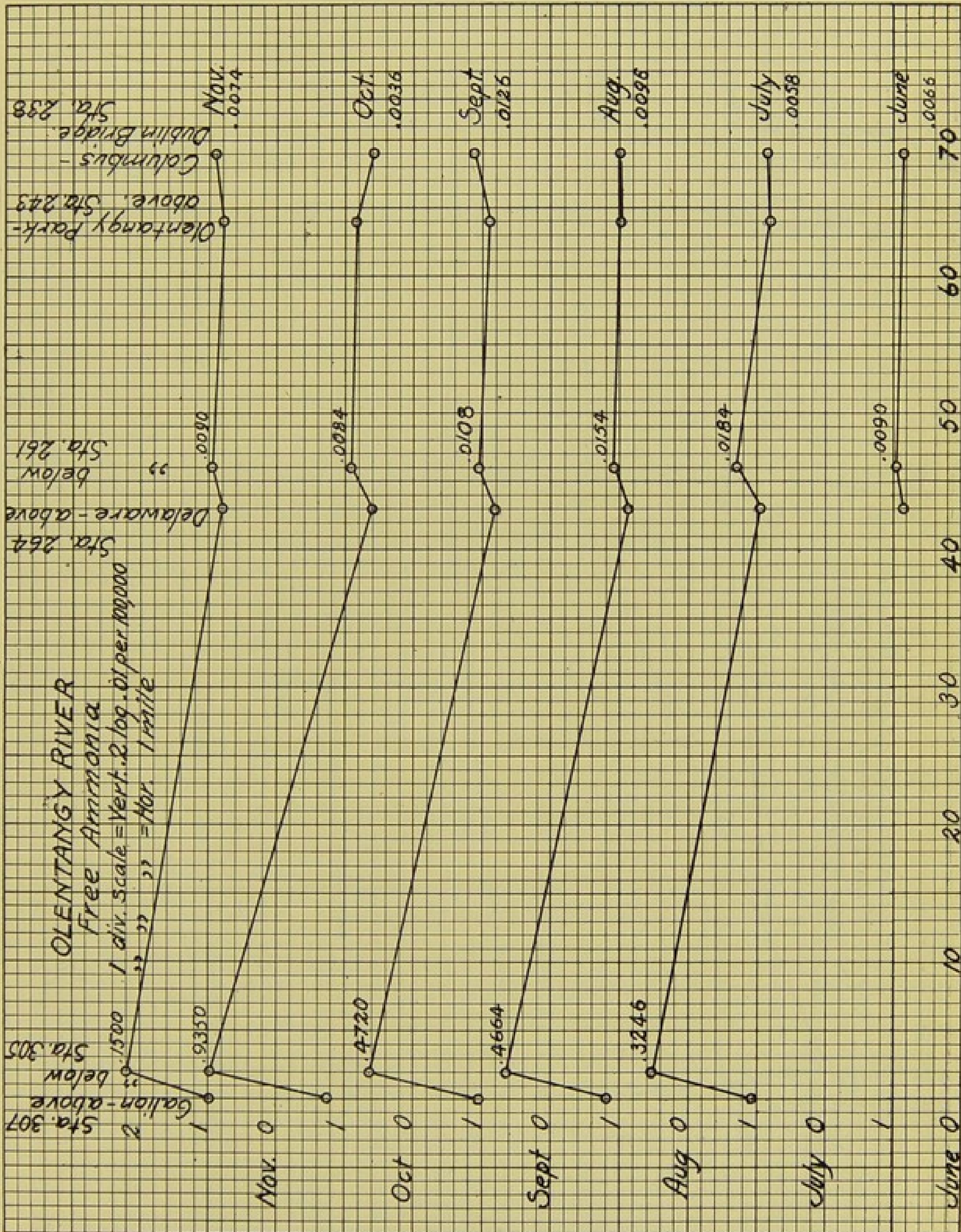
SCIOTO RIVER
Permanent Hardness
1 div. Scale - Vert. 2 per 100000
" " Hor. 1 mile
Kenton above Sta. 304
" below " 302
Girls' Indtl Home above
" " below
Wyandotte Grove Sta. 246
Jones Dam Sta. 243.5
Sandusky St Brg. Sta. 238
Frank Road Brg. Sta. 234
Columbus
Shadeville Brg Sta. 227
Circleville above Darby Crk Sta. 217.5
" Main St Brg. Sta. 210.5
" below Sta. 209.5
Nov
Oct
Sept
Aug
July
June

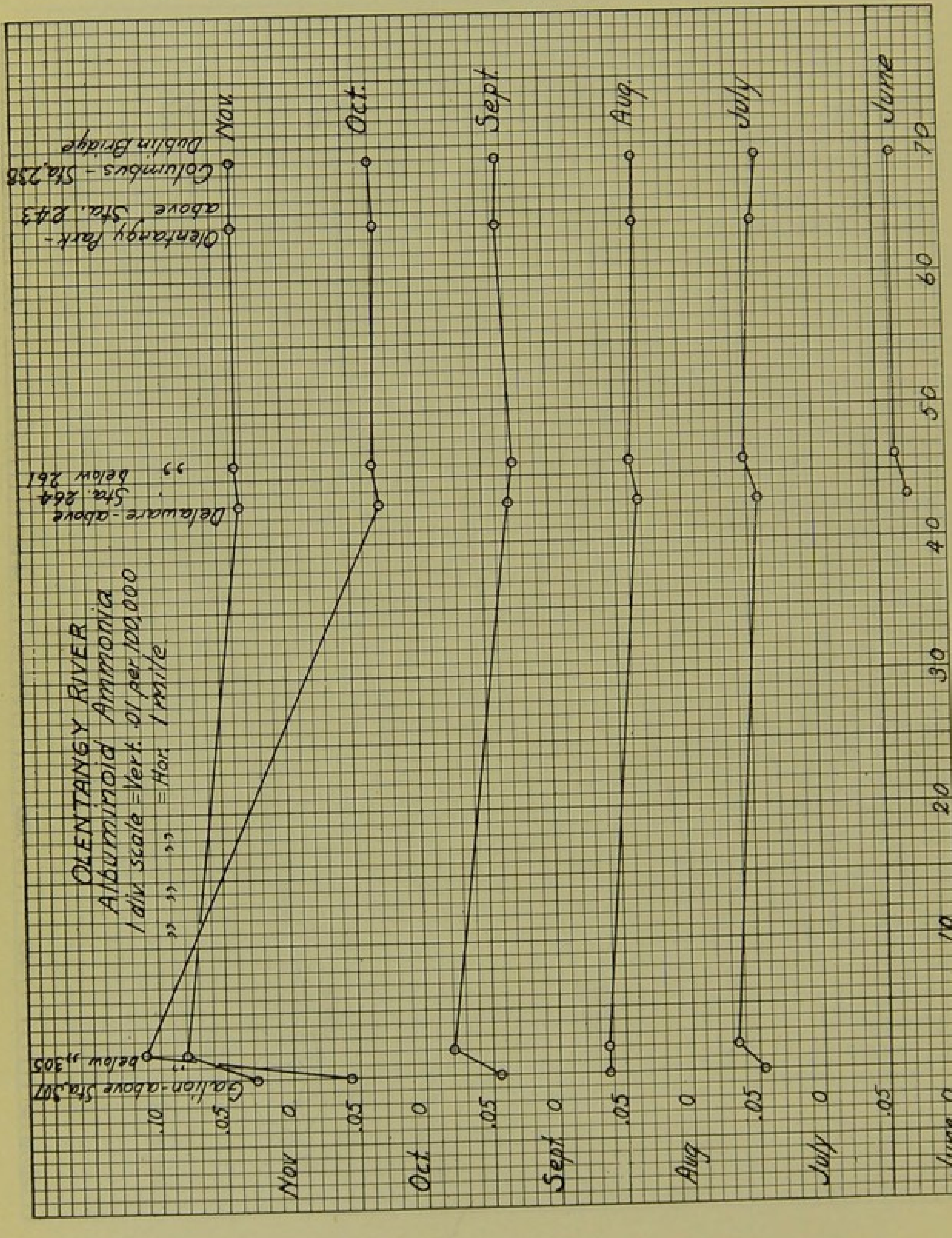

SCIOTO RIVER
Total Solids
1 div. Scale Vert 4 per 100000
Hor. 1 mile
Nov. 30
Oct 30
Sept 30
Aug 30
July 30
Kenton-above
Girl's Indn'l Home
Wyandotte Grove
Jone's Dam
Sandusky St Brg.
Frank Road Brg.
Columbus
Shadeville Brg
Circleville above Darby Crk.
Main St. Brg.
below

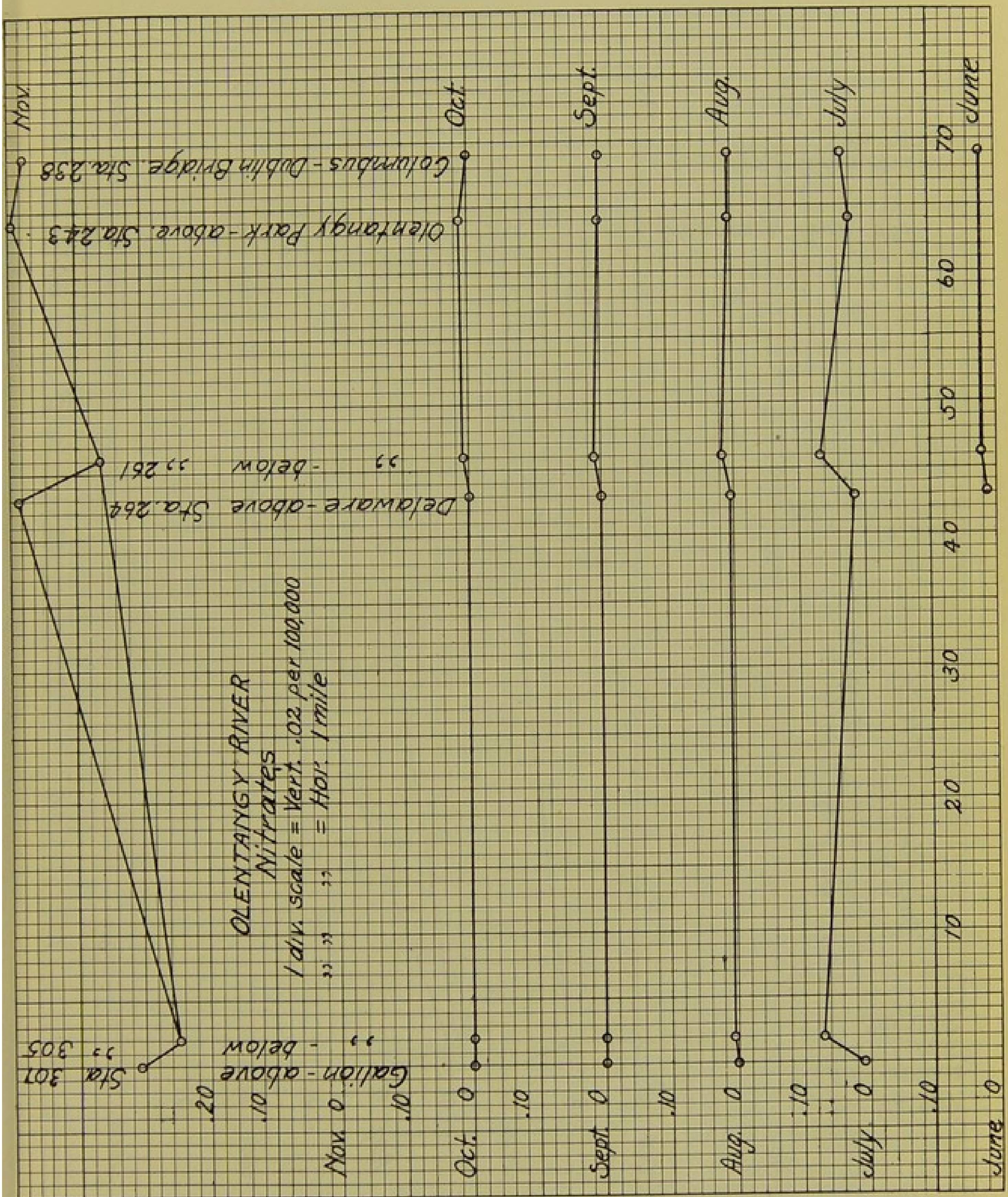

LITTLE SCIOTO RIVER
Hor. Scale 1 div. = .2 mile
Chlorine
Vert. scale-1 div.=.1 per 100,000
Temporary Hardness
Vert. scale 1 div.=2 per 100,000
Permanent Hardness
Vert. scale 1 div.=2, per 100,000
Total Solids
Vert. scale 1 div.=2 per 100,000
Marion-above Sta. 281
Marion below Sta. 280

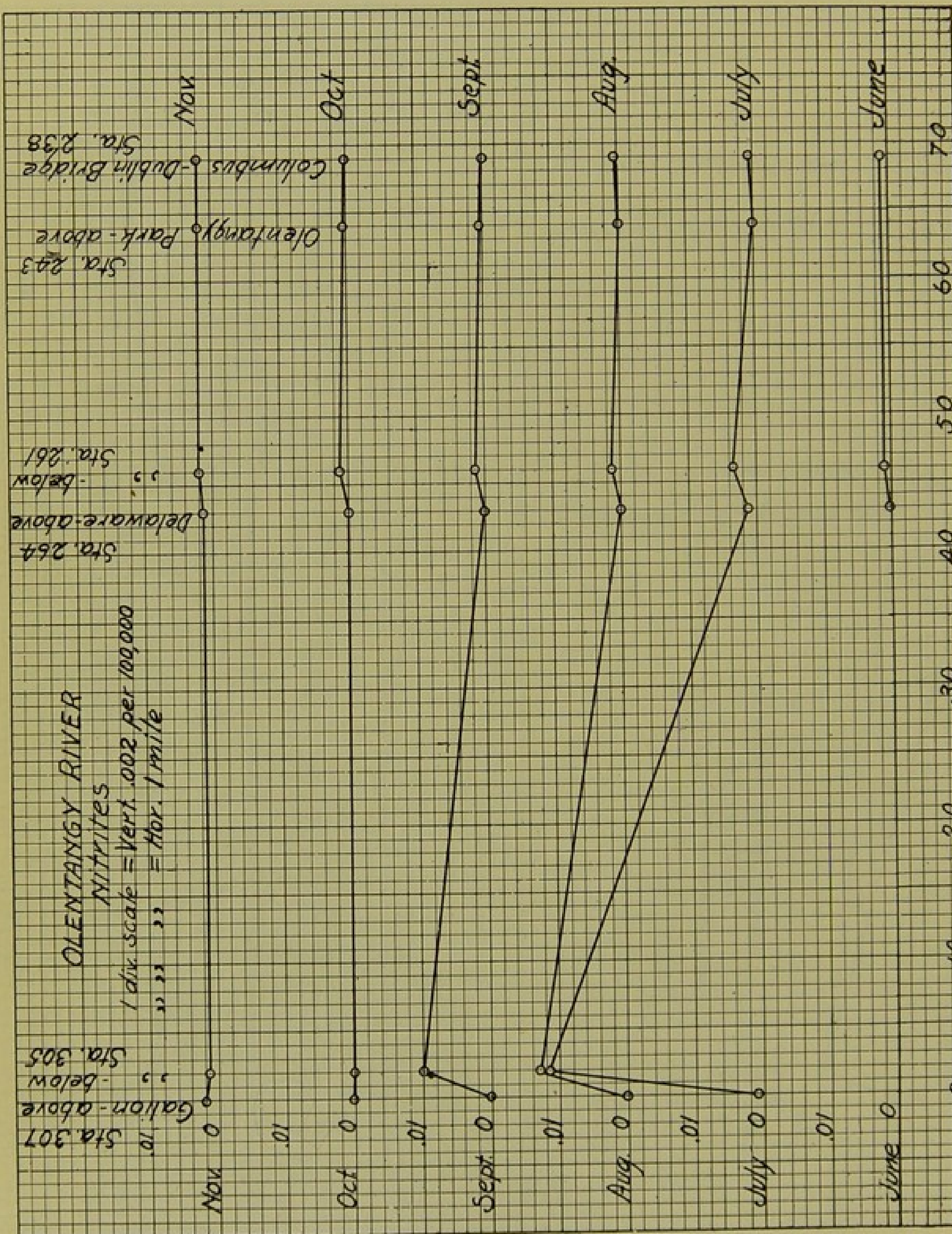

LITTLE SCIOTO RIVER
Bacteria
Vert. Scale Log. no. per C.C.
1 div. = .2 log. 10
1 Marion-below
0 Marion-above
3
2
1
0
1156
15,320
868
2750
June
July
Aug.
Sept.
Oct.
Nov.

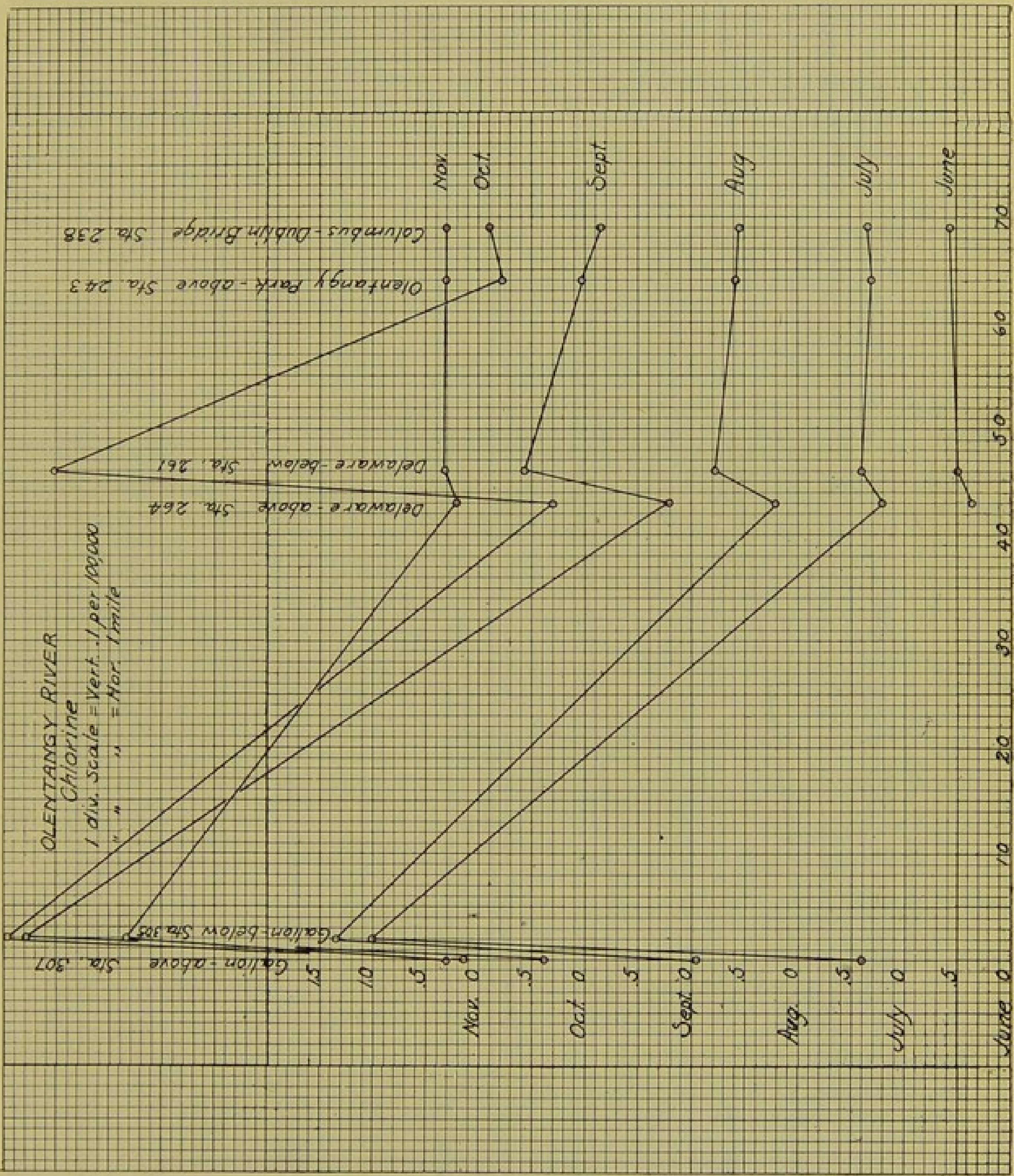

OLENTANGY RIVER
Oxygen Required
1 div. Scale = Vert. .1 per 100,000
" " " = Hor. 1 mile
Sta. 307 Galion-above
" -below Sta. 305
Delaware-above Sta. 264
" -below Sta. 261
Olentangy Park-above Sta. 243
Columbus-Dublin Bridge Sta. 238
Nov.
Oct.
Sept.
Aug.
July
June
10
20
30
40
50
60
70

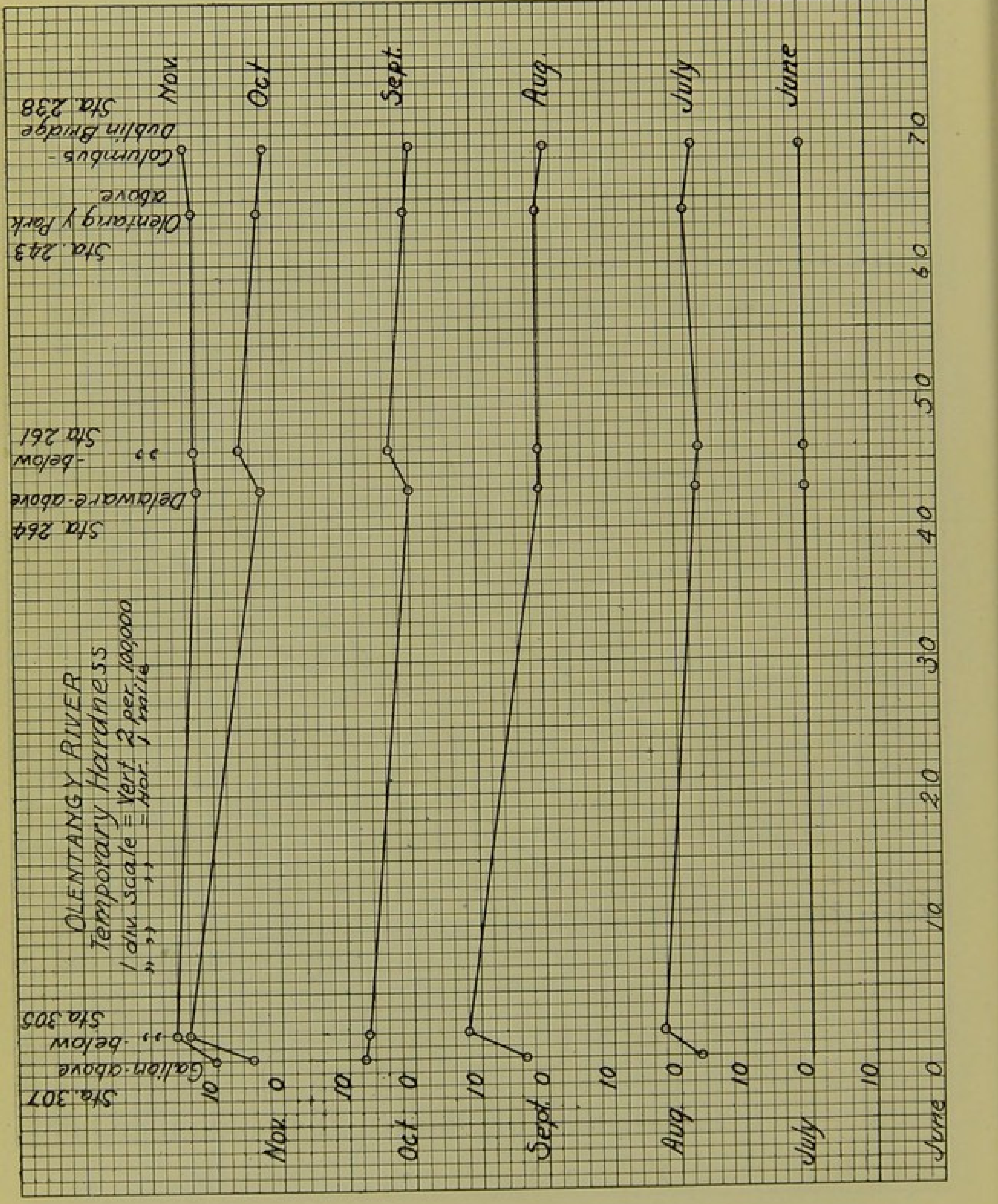

OLENTANGY RIVER
Free Ammonia
1 div. Scale = Vert. 2 log. .01 per 100,000
" " " = Hor. 1 mile
Sta. 307 Galion - above
" below Sta. 305
Sta. 264 Delaware - above
" below Sta. 261
Olentangy Park - above. Sta. 243
Columbus - Dublin Bridge. Sta. 238
Nov. .0074
Oct. .0036
Sept .0126
Aug. .0096
July .0058
June .0065
.1500
.9350
.4720
.4664
.3246
.0090
.0084
.0108
.0154
.0184
.0090
Nov. 0
Oct 0
Sept 0
Aug 0
July 0
June 0
10
20
30
40
50
60
70

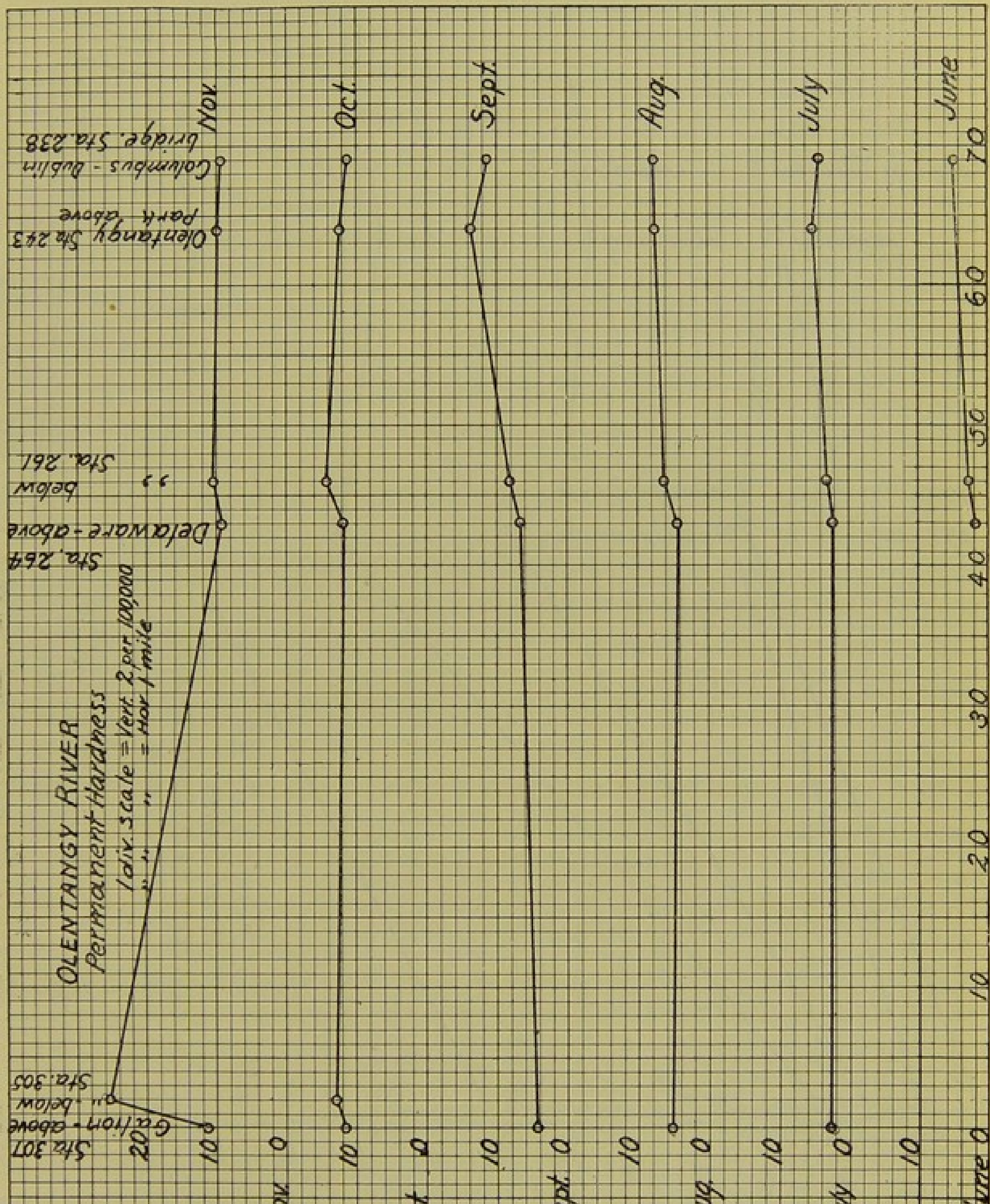

OLENTANGY RIVER
Albuminoid Ammonia
1 div. scale = Vert. .01 per 100,000
" " " = Hor. 1 mile
Galion-above Sta. 307
below " 305
Delaware-above Sta. 264
" below 261
Olentangy Park-above Sta. 243
Columbus - Sta. 238 Dublin Bridge
Nov.
Oct.
Sept.
Aug.
July
June
10
20
30
40
50
60
70

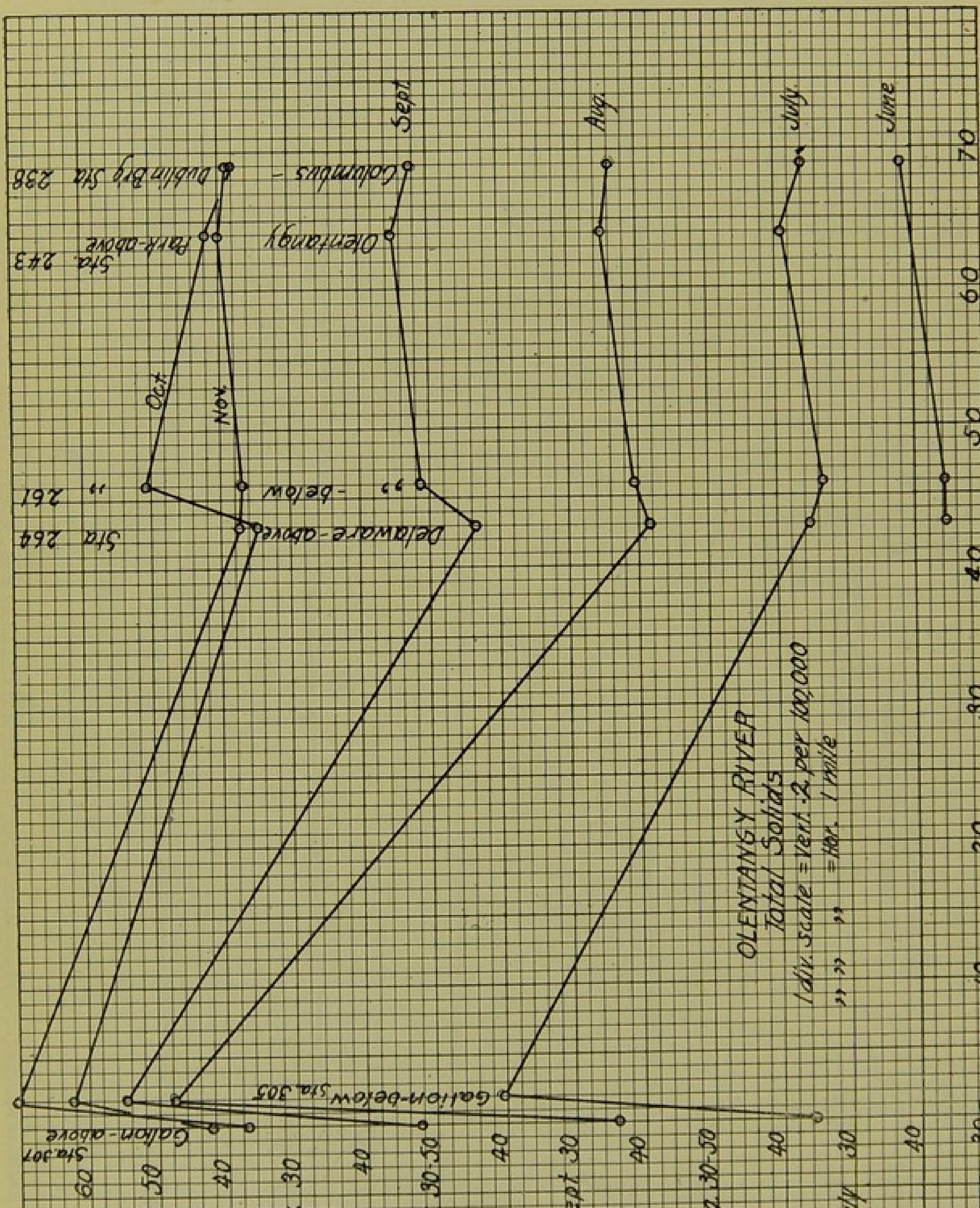

OLENTANGY RIVER
Nitrates
1 div. scale = Vert. .02 per 100,000
" " " = Hor. 1 mile
Columbus - Dublin Bridge. Sta. 238
Olentangy Park - above. Sta. 243
" - below " 261
Delaware - above Sta. 264
Galion - above Sta. 301
" - below " 305
Nov.
Oct.
Sept.
Aug.
July
June
0
.10
.20
10
20
30
40
50
60
70

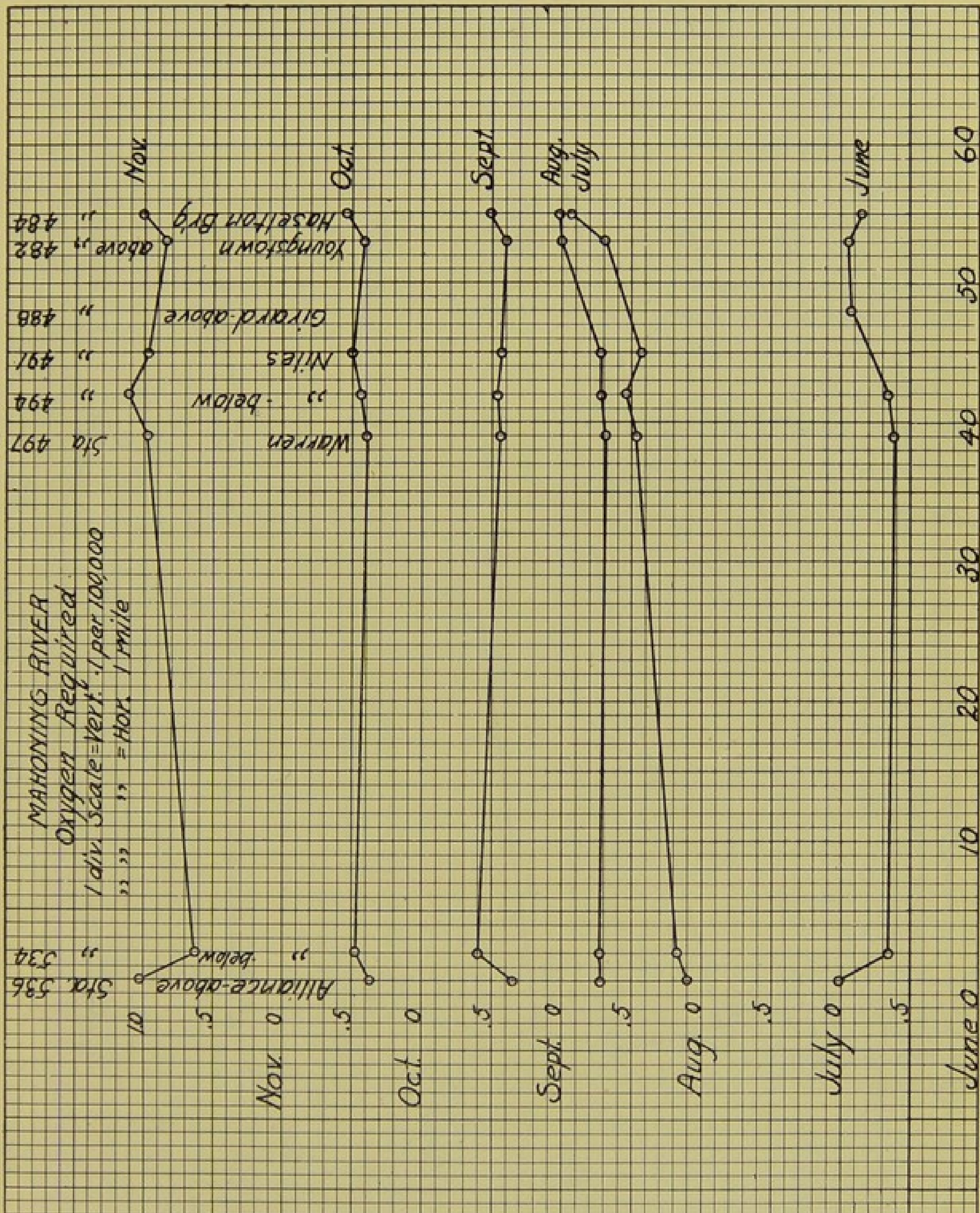

OLENTANGY RIVER
Nitrites
1 div. Scale = Vert. .002 per 100,000
" " " = Hor. 1 mile
Sta. 307 Galion-above
" -below Sta. 305
Sta. 264 Delaware-above
" -below Sta. 261
Sta. 243 Olentangy Park-above
Columbus-Dublin Bridge Sta. 238
Nov.
Oct.
Sept.
Aug.
July
June
0
.01
0 10 20 30 40 50 60 70

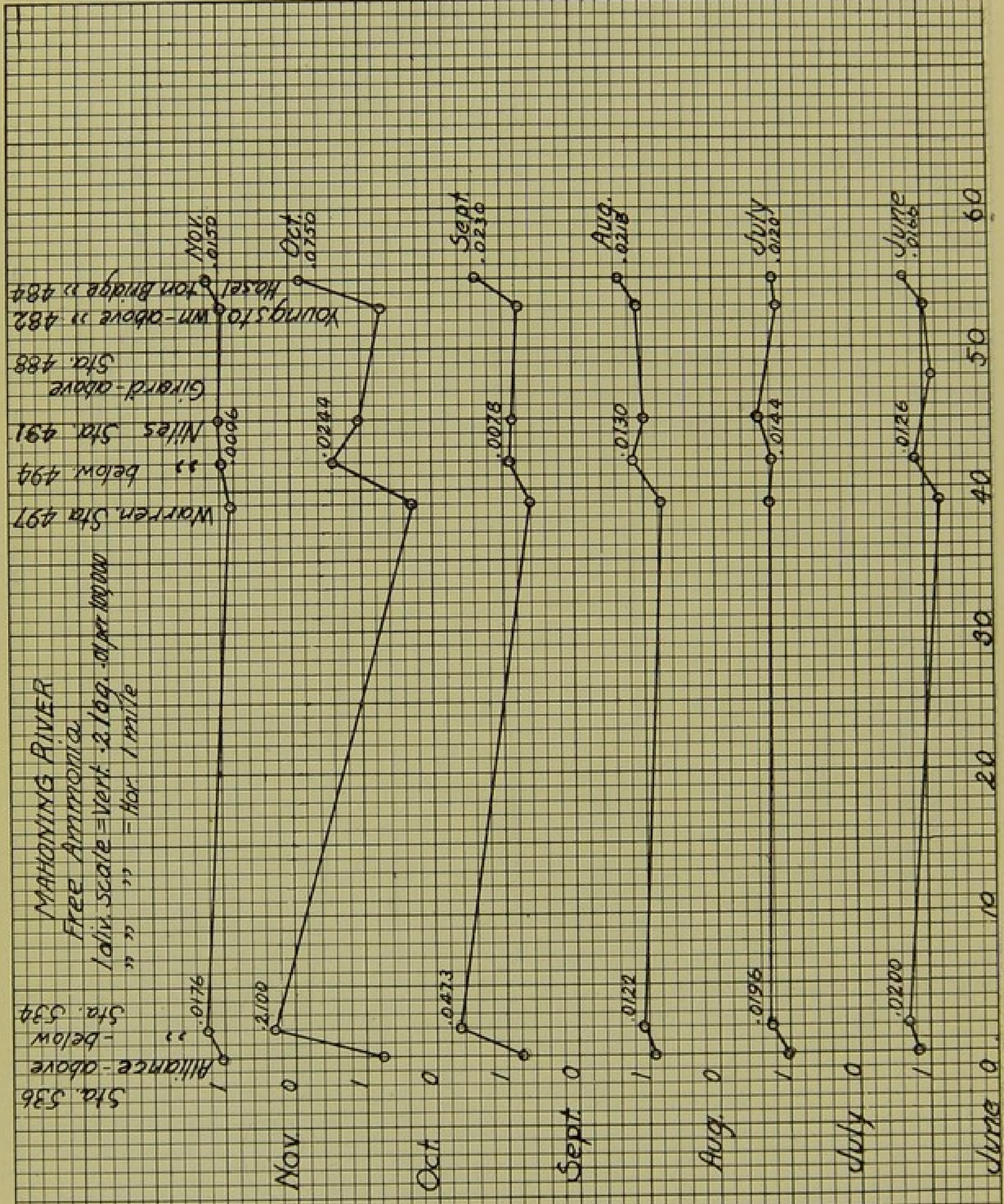

OLENTANGY RIVER
Chlorine
1 div. Scale = Vert. .1 per 100,000
" " " = Hor. 1 mile
Columbus - Dublin Bridge Sta. 238
Olentangy Park - above Sta. 243
Delaware - below Sta. 261
Delaware - above Sta. 264
Galion - below Sta. 305
Galion - above Sta. 307
Nov.
Oct.
Sept.
Aug.
July
June

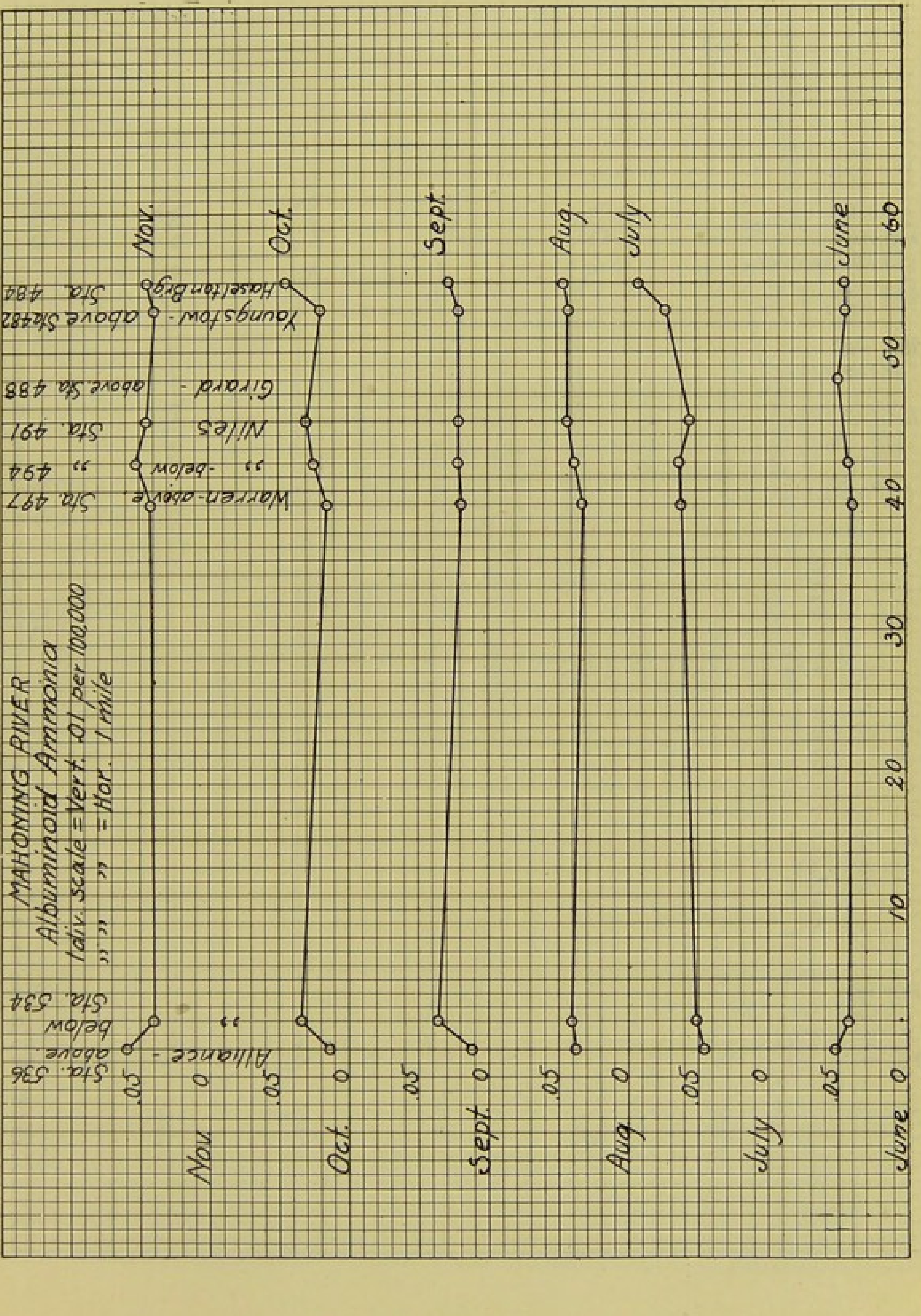

OLENTANGY RIVER
Temporary Hardness
1 div. scale = Vert. 2 per. 100,000
" " " = Hor. 1 mile
Sta. 307 Galion-above
" -below Sta. 305
Sta. 264 Delaware-above
" -below Sta. 261
Sta. 243 Olentangy Park above
Columbus-Dublin Bridge Sta. 238
Nov. Oct. Sept. Aug. July June
0 10 20 30 40 50 60 70

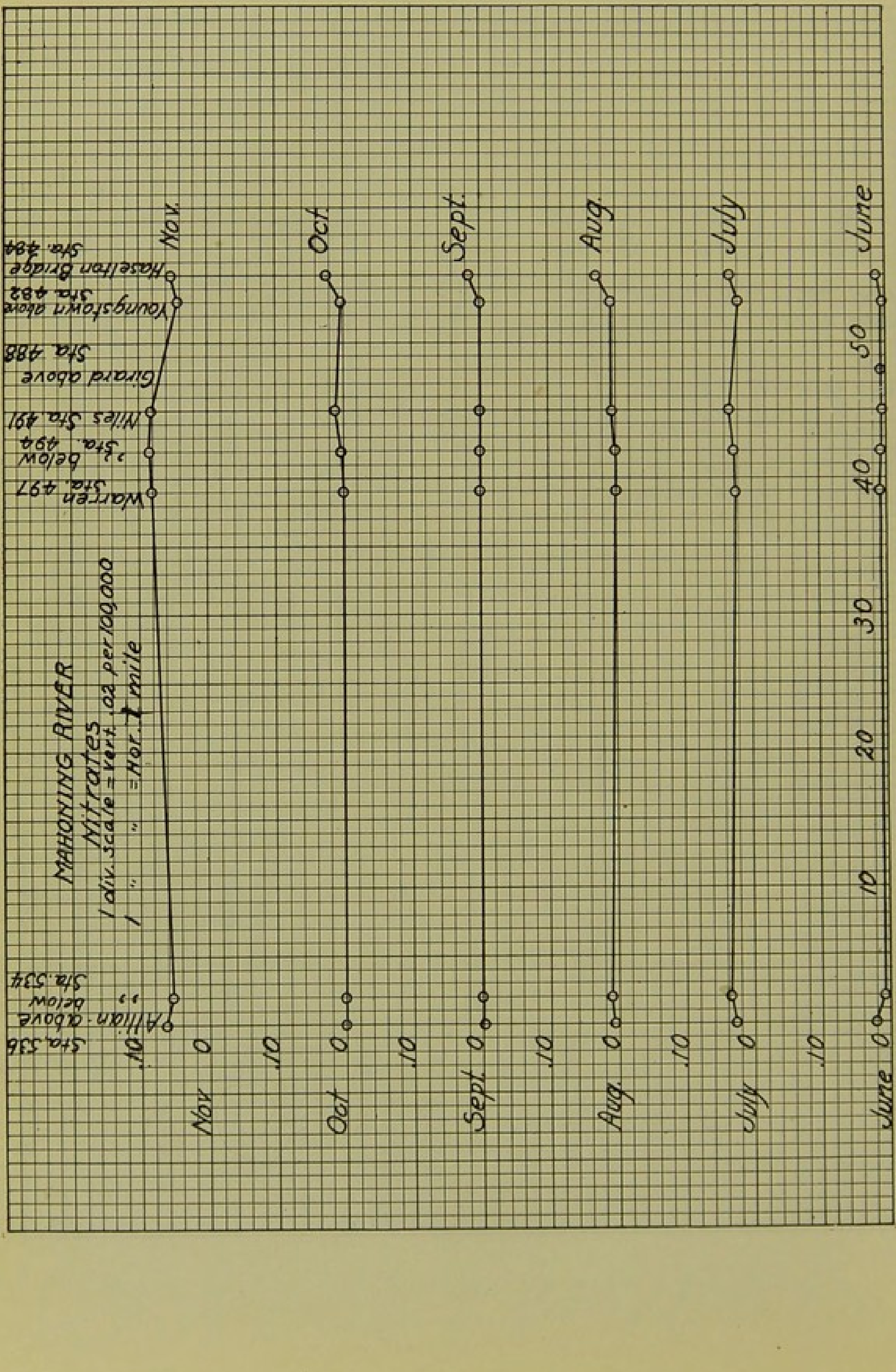

OLENTANGY RIVER
Permanent Hardness
1 div. scale = Vert. 2 per 100,000
" " = Hor. 1 mile
Sta. 307 Galion - above
" below Sta. 305
Sta. 264 Delaware - above
" below Sta. 261
Olentangy Sta. 243 Park above
Columbus - Dublin bridge. Sta. 238
Nov.
Oct.
Sept.
Aug.
July
June

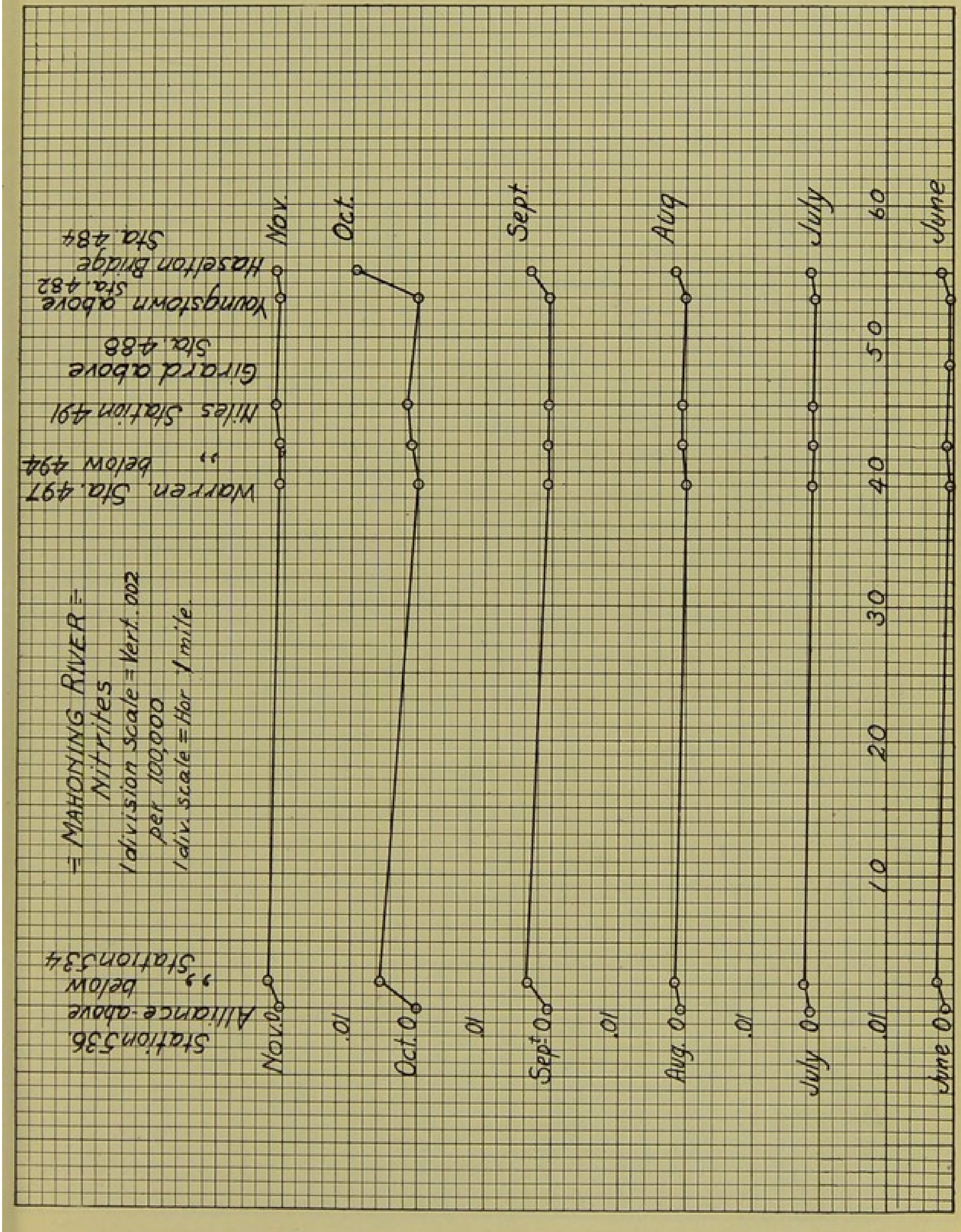

OLENTANGY RIVER
Total Solids
1 div. scale = Vert. 2 per 100,000
" " " = Hor. 1 mile
Dublin Brg Sta 238
Sta. 243 Park-above
Sta 264 Delaware-above
" 261 " -below
Columbus - Olentangy
Galion-below Sta. 305
Sta. 307 Galion-above
Oct.
Nov.
Sept
Aug.
July
June

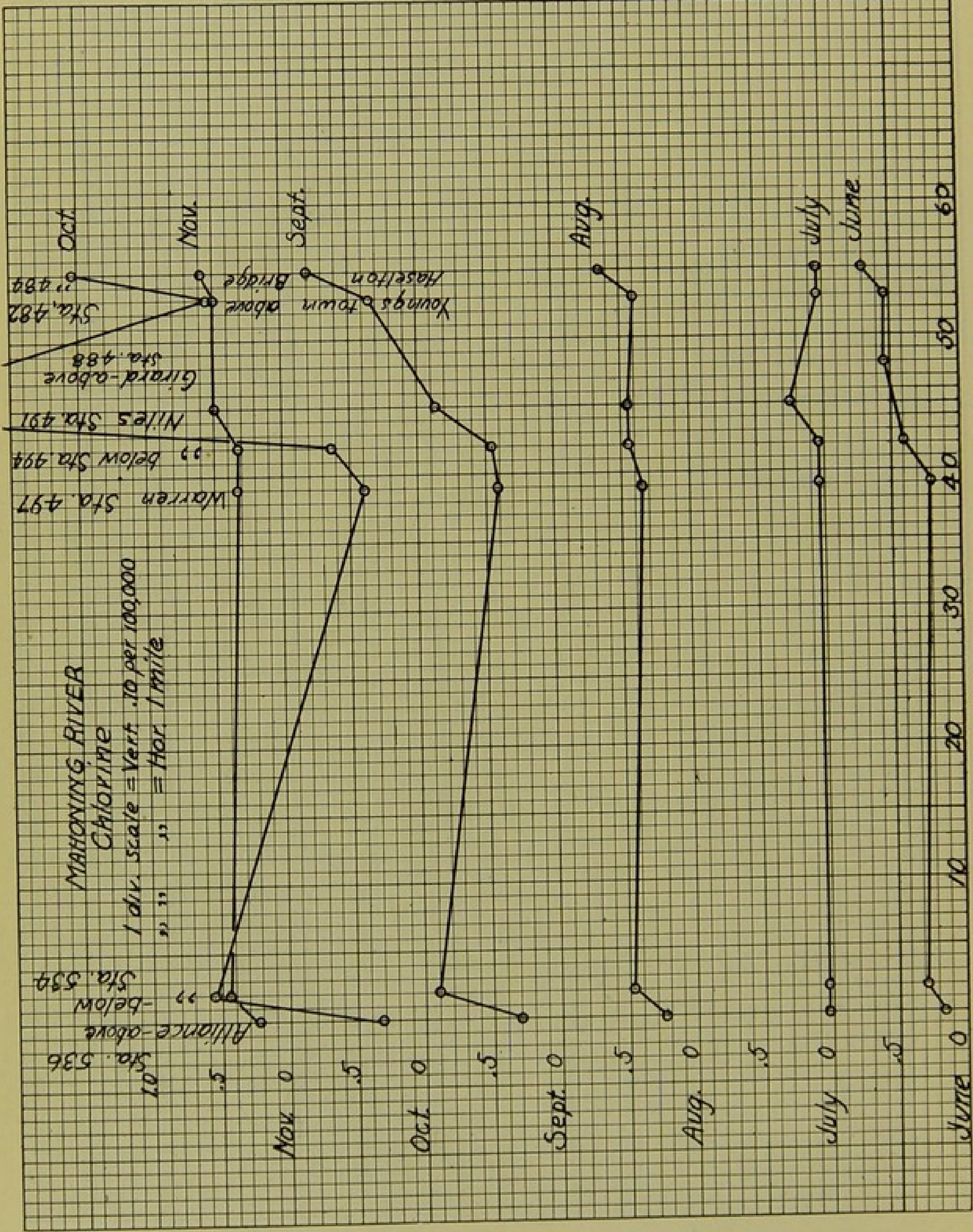

MAHONING RIVER
Oxygen Required
1 div. Scale = Vert. .1 per 100,000
" " " = Hor. 1 mile
Sta. 536 Alliance-above
534 below
Sta 497 Warren
494 below
491 Niles
488 Girard-above
482 Youngstown above
484 Haselton Brg
Nov.
Oct.
Sept.
Aug.
July
June
0
10
20
30
40
50
60

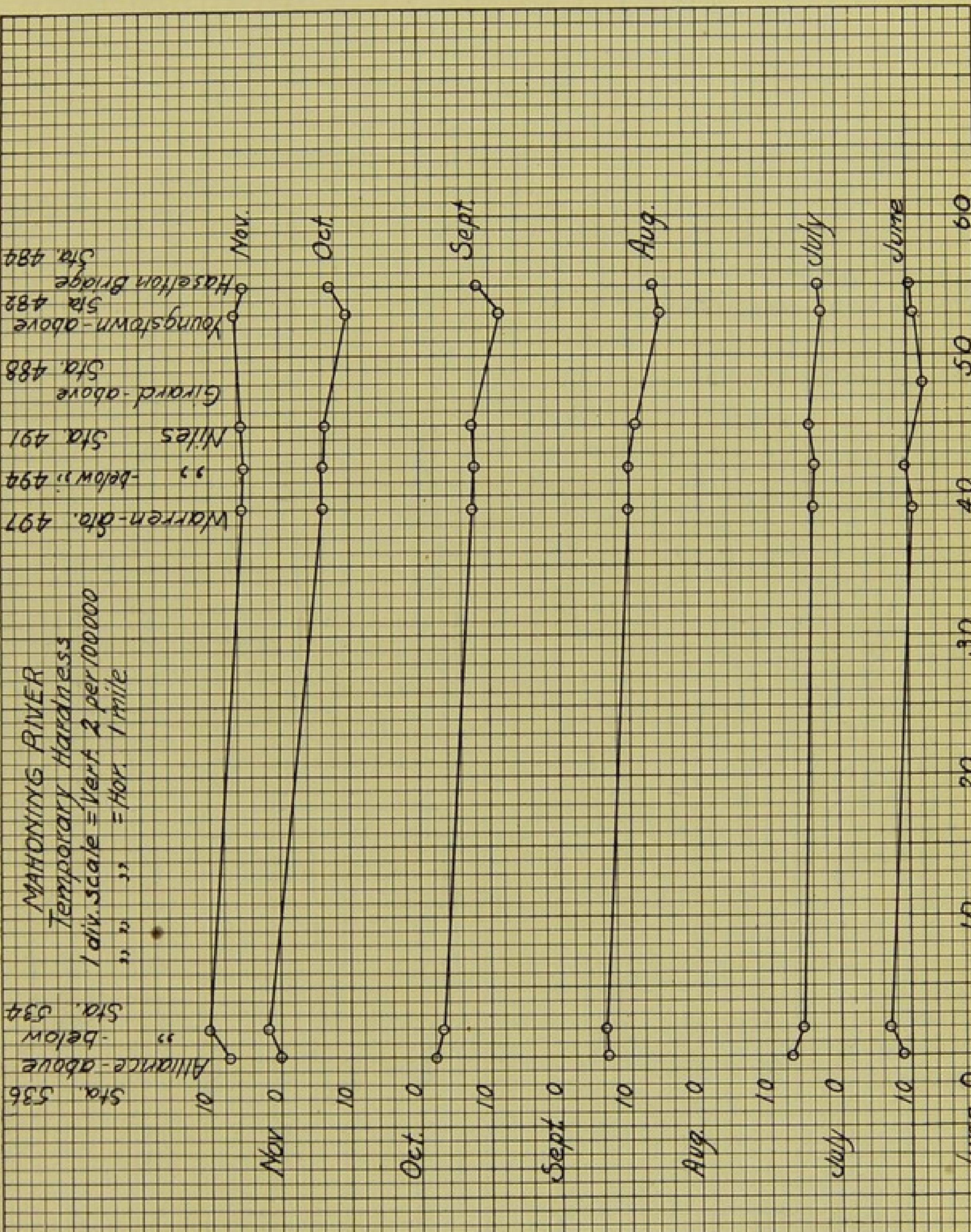

MAHONING RIVER
Free Ammonia
= Hor. 1 mile
Sta. 536 Alliance - above
- below Sta. 534
Warren Sta 497
below 494
Niles Sta. 491
Girard - above Sta. 488
Youngstown - above 482
Haselton Bridge 484
Nov
Oct
Sept
Aug
July
June

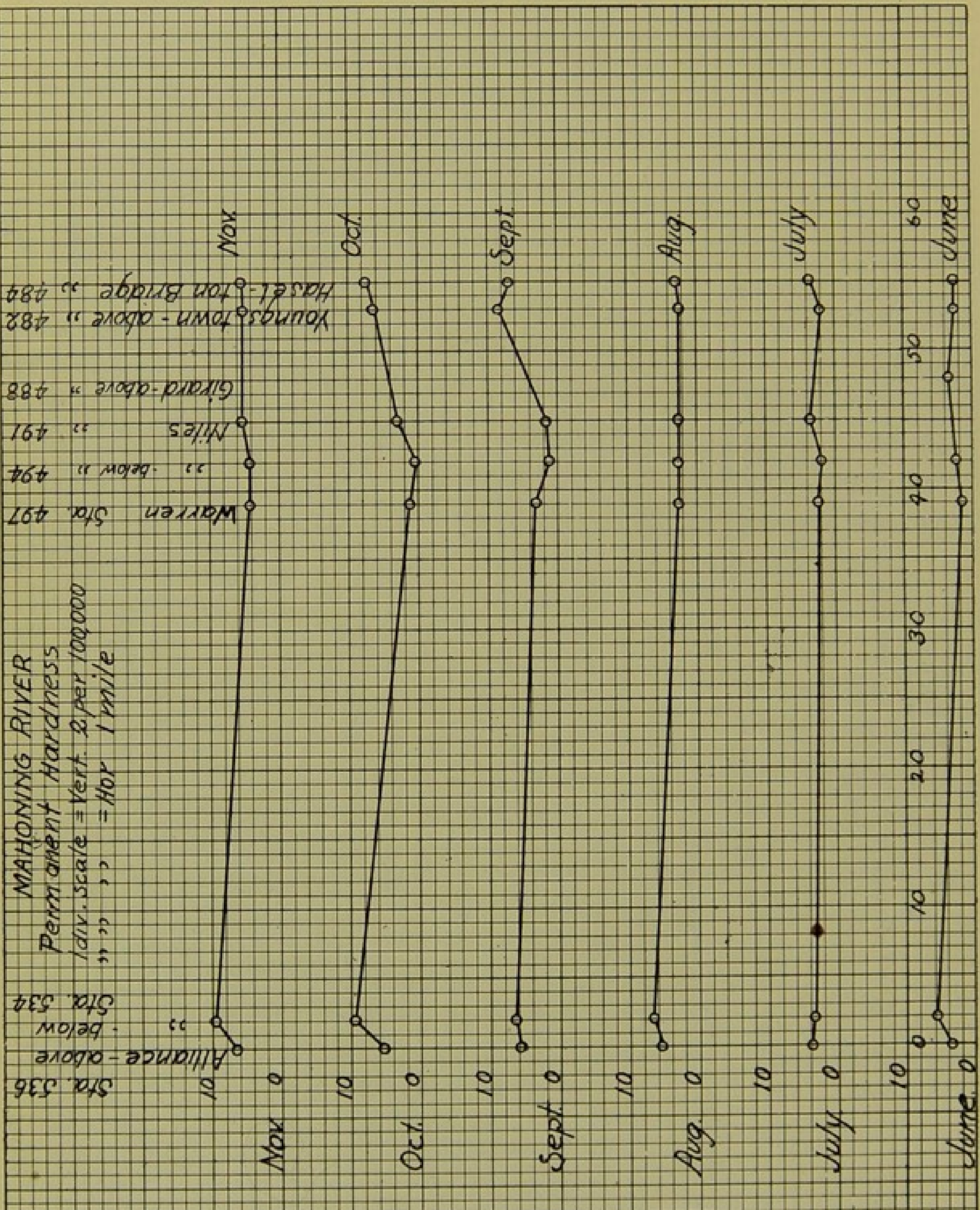

MAHONING RIVER
Albuminoid Ammonia
1 div. Scale = Vert. .01 per 100,000
" " " = Hor. 1 mile
Sta. 536 above
below Sta. 534
Alliance -
Warren-above, Sta. 497
" -below " 494
Niles Sta. 491
Girard - above Sta. 488
Youngstown - above Sta. 482
Haselton Brg. Sta. 484
Nov.
Oct.
Sept.
Aug.
July
June
.05
0
10
20
30
40
50
60

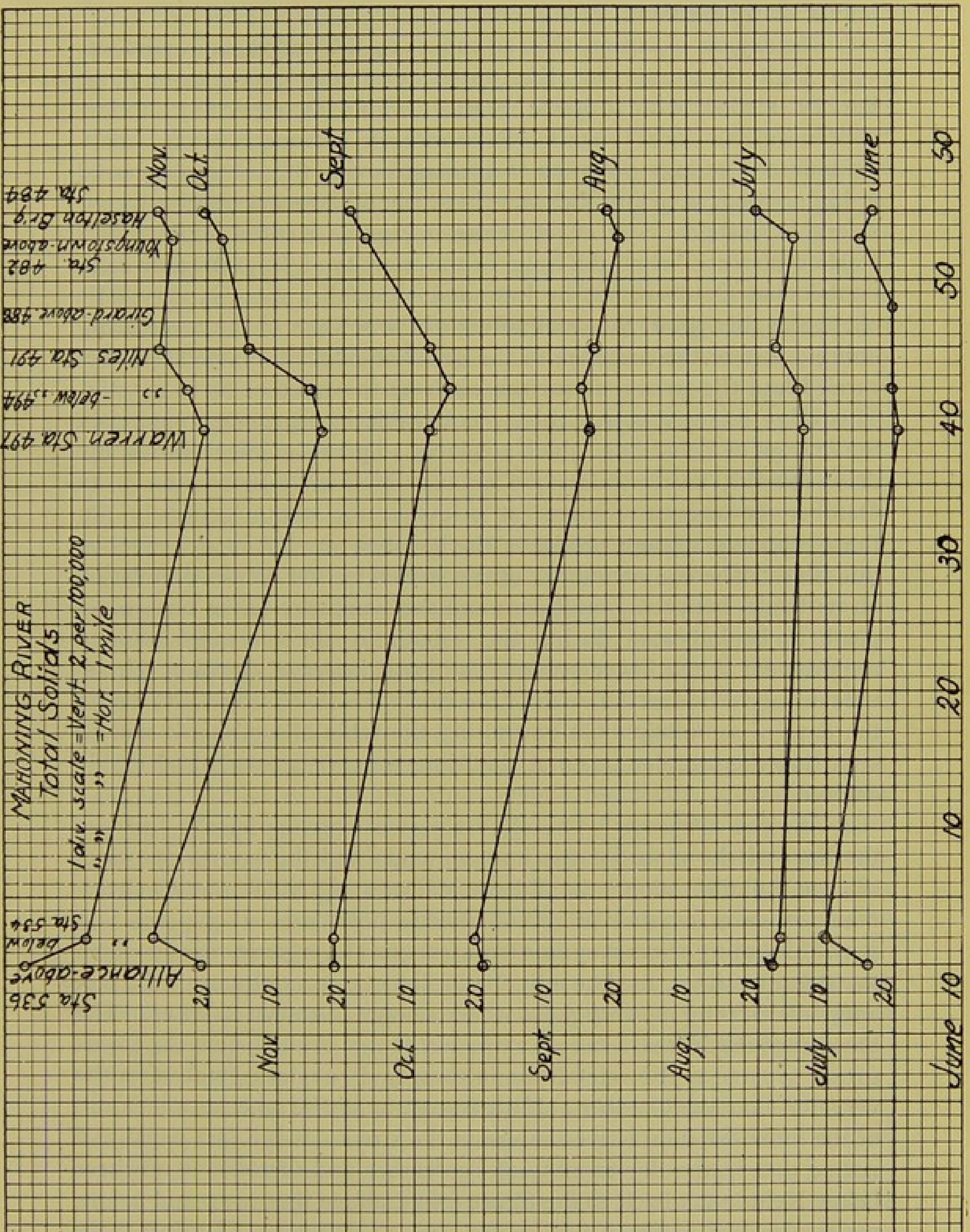

MAHONING RIVER
Nitrates
1 div. scale = Vert. .02 per 100,000
1 " " = Hor. 1 mile
Sta. 536 Alliance above
" below Sta. 534
Warren Sta. 497
" Sta. below 494
Niles Sta. 491
Girard above Sta. 488
Youngstown above Sta. 482
Haselton Bridge Sta. 484
Nov.
Oct.
Sept.
Aug.
July
June
10
20
30
40
50
0
.10


= MAHONING RIVER =
Nitrites
1 division Scale = Vert. .002
per 100,000
1 div. scale = Hor. 1 mile.
Station 536. Alliance-above
" below Station 534
Warren. Sta. 497
" below 494
Niles Station 491
Girard above Sta. 488
Youngstown above Sta. 482
Haselton Bridge Sta. 484
Nov.
Oct.
Sept.
Aug.
July
June
Nov. 0
Oct. 0
Sept. 0
Aug. 0
July 0
June 0
.01
10
20
30
40
50
60


MAHONING RIVER
Chlorine
1 div. scale = Vert. .10 per 100,000
" " " = Hor. 1 mile
Sta. 536 Alliance-above
" -below Sta. 534
Warren Sta. 497
" below Sta. 494
Niles Sta. 491
Girard-above Sta. 488
Youngstown above Haselton Bridge
Sta. 482
" 484
Nov.
Oct.
Sept.
Aug.
July
June
0
10
20
30
40
50
60


MAHONING RIVER
Temporary Hardness
1 div. scale = Vert. 2 per 100000
" " " = Hor. 1 mile
Alliance-above Sta. 536
" -below Sta. 534
Warren-Sta. 497
" -below " 494
Niles Sta. 491
Girard-above Sta. 488
Youngstown-above Sta. 482
Haselton Bridge Sta. 484
Nov.
Oct.
Sept.
Aug.
July
June
0
10
20
30
40
50
60


MAHONING RIVER
Permanent Hardness
1 div. Scale = Vert. 2 per 100,000
" " " = Hor 1 mile
Sta. 536 Alliance - above
" below Sta. 534
Warren Sta. 497
" below " 494
Niles " 491
Girard-above " 488
Youngstown - above " 482
Haselton Bridge " 484
Nov.
Oct.
Sept.
Aug.
July
June
10
0
20
30
40
50
60


MAHONING RIVER
Total Solids
1 div. scale = Vert. 2 per 100,000
" " = Hor. 1 mile
Sta. 536 Alliance-above
below Sta. 534
Warren Sta. 497
-below " 494
Niles Sta. 491
Girard-above 488
Sta. 482 Youngstown-above
Haselton Br'g Sta. 484
Nov.
Oct.
Sept.
Aug.
July
June

In reviewing the foregoing plates they can be best considered one river at a time. Beginning with the Scioto river, the following points may be noted:

The oxygen required: this, as shown by the curves, is in all cases very high, showing that the waters examined were throughout heavily loaded with organic matter. This is especially noticeable near the head waters of the stream. Above Kenton, where no source of sewage pollution is known to exist, the oxygen required is higher than at points below, where the stream has received considerable sewage. The effect of the sewage at Kenton appears in a marked increase below the town in the months of July, August, September and October; but in June and November there is very little change at this point, the small effect of the sewage of the town being entirely lost in the presence of the great amount of vegetable matter carried into the stream as surface wash by the rains of these months. This large increase is particularly noticeable in November; and even the sewage of Columbus, which produces so great an effect during the drier months, hardly raises the amount of this determination. In October the oxygen requirement is less for the stream generally, but the Columbus sewage produces the greatest proportionate effect at this time. The contamination of the stream by the denser population on its banks between Jones' dam and the Sandusky street bridge appears to be indicated during this month by the increased oxygen requirement at the lower point. The great increase shown at Circleville in July is due to the wash of the storm which occurred just before the date of sampling. On consulting the table of analysis it will be seen that the samples taken at this time were very turbid and highly colored.

The free ammonia: The almost perfect correspondence between the lines of the plate for the free ammonia and the known points of sewage pollution along the stream indicates the value of this determination as a measure of recent sewage pollution. It appears that notwithstanding the heavy burden of vegetable organic matter which the stream carried, as shown by the high oxygen requirement, the free ammonia runs up at every point where sewage is known to enter. The amount of the increase in free ammonia at the points below the towns grows greater as the rainfall diminishes, and becomes greatest in the very dry month of October. If the free ammonia be taken as a measure of the unoxidized or active sewage in the stream, it is a fact worthy of notice that in the dry months of September and October it nowhere below Kenton fell back to the figure found above that town and before the stream had received any known sewage pollution. During these months the free ammonia continues high to Circleville, even after the stream had undergone the great dilution due to the large amount of water furnished by Alum creek, the Big Darby, and the Big Walnut. The only exception to the regularity with which the free ammonia follows the sewage introduced into the stream is found in the sample taken at Shadeville during the month of August. In this sample there is an unusual reduction in the free ammonia. Inspection of the curve for nitrates and nitrites shows that the low August ammonia at Circleville corresponds to the great increase in these factors in that month for that point. In the table of analysis it will be seen that the dissolved oxygen in the water at Shadeville at this date for the first and only time shows complete saturation. Consulting the weather table, it appears that there had been at Circleville a heavy local rain a few days before. This rain was very light at Columbus. So that this particular and somewhat anomalous result is possibly explained by the large addition of water entering the stream below Columbus; this water being fully saturated with oxygen would account for the destruction of the ammonia and the appearance of nitrates. In support of this explanation it may be further noticed that there was a large drop in the chlorine below that found in the Columbus samples taken at the same date. The water of Alum creek entering in large volume just below Shadeville may have increased this effect by checking the flow and giving increased time for the oxidation of the ammonia. The generally high ammonia of the November samples would seem to be related to the cold weather and the November storms. A minor point of interest is the uniform increase of free ammonia shown at the Sandusky St. bridge over that found at Jones' dam, three miles above, indicating fresh sewage pollution above the city of Columbus.

The albuminoid ammonia: This is high in all the samples examined, and taken with the high oxygen requirement, would appear to be in large part of vegetable origin, and therefore not associated directly with sewage pollution; but, as the amount of organic nitrogen in proportion to the oxygen required is much greater in sewage than in vegetable matter, the increase in the albuminoid ammonia below the points where sewage is known to have been introduced into the streams is much more marked than in the oxygen requirement, though in the wet weather of June and November the effect of this sewage, as measured by this albuminoid ammonia, is not shown to anything like the degree that it is in the dry months.

Nitrates and nitrites: These two substances should be considered together; the nitrites are always transition products between the ammonia and the nitrates, occurring when ammonia is changing to nitric acid, or where nitric acid is being reduced to ammonia. The reaction may proceed either way, depending on whether the action is reducing or oxidizing. The plates exhibiting these ingredients are remarkably interesting, as they show the variation due to the season of the year.

In June considerable nitric acid is found in the upper stream accompanied by small amounts of nitrites. Both of these ingredients disappear from the stream below Columbus, probably owing to their entire reduction by the Columbus sewage, there having been no heavy rains at this point to introduce highly oxidized surface waters. At Circleville the nitrites and nitrates reappear, probably due to the oxidizing action of water from the lower water-shed. In July, August, September and October the upper river is almost free from both of these substances, even though the disappearance of the ammonia introduced into the stream at Kenton and Galion must have resulted in the presence of considerable amounts. It would seem probable that this complete removal of the nitrates might be due to the active growth of vegetation which rapidly absorbs this form of nitrogen, and which would keep the stream free from it even though it were being continuously formed by the oxidation of organic matters. The efficiency of plant growth, both the microscopic algae in the water as well as the aquatic and shore plants along the stream, as absorbers of nitrogen is well known. That taken up by the shore plants of course remains. That appropriated by the algae appears as albuminoid ammonia. That in the aquatic plants is held more or less temporarily until it is liberated by their eventual decay. At Columbus and Shadeville the amount of nitrites in the July samples is unusually large; the river was high from a month of wet weather, this water being highly stored with oxygen, the sewage of the city is rapidily oxidized as shown by the great development of nitrites. That this action is not complete is shown by the practical absence of nitrates, which do not appear in any amount until Circleville is reached, where the large amount of surface water from the lower streams has not only diluted the impure water but has almost completed its oxidation. The August line shows that the amount of water in the river was unable even to start the oxidation of the Columbus sewage. The small amount of nitrates found in the water above the city was promptly reduced below; but at Shadeville the nitrates and nitrites are plenty, corresponding to the great loss in free ammonia, and the dilution by purer water. At Circleville both the nitrates and the nitrites have entirely disappeared, possibly due to the dilution and plant growth. During September and October the stream is nearly free from these ingredients. Oxidizing agencies below Columbus were apparently entirely unequal to the burden thrown upon them. In these months the river is high in free ammonia clear to Circleville, indicating that the Columbus sewage had reached that point practically unchanged. In November the streams are heavily loaded with nitrates; the month of cold, wet weather has apparently washed the nitrates from the soil, stopped plant growth, and, as a consequence, the nitrogen is present in large amount in nitric forms. The effect of the Columbus sewage on the water of the river is shown in the November samples by the great drop in the percentage of nitrates, possibly due to their reduction to nitrites, which increase greatly in the same samples. No quantitative relation is claimed for these figures, but the nitrites indicate transition between ammonia and nitrates, and the disappearance of the nitrates may be taken as indicating the direction of the change.

Chlorine: The regularity with which the amounts of chlorine increase in the stream at the points where sewage is known to enter, and fall with the effect of subsequent dilution is noticeable in all the lines. The great dilution of the Columbus water by the Big Darby and Alum creek explains the great drop in chlorine at Circleville noticed in each month. The effect of the dry weather in diminishing the absolute dilution while effecting but little its relative amount at the various points on the stream appears on comparing the lines of August, September and October; while after the heavy rains of November the chlorine appears to be nearly uniform throughout the stream, only showing marked changes at Kenton and Columbus. In these chlorine curves the change between Jones' dam and the Sandusky street bridge corresponds to the conclusions drawn from the increase in the ammonia and oxygen requirement that there is a marked sewage pollution of the stream above the Columbus station. This is a matter of moment if the present intake of the Columbus water works is to be continued. Further consideration of the chlorine contents of the river will be postponed to later in this report.

The temporary hardness: The temporary hardness represents the carbonates of lime and magnesia in the water with approximate accuracy. A marked increase in this hardness of the water is noticeable after the addition of the Columbus sewage. This effect appears to the greatest degree in the dry weather, and shows that the sewage of the city is much harder than the average river water.

Permanent hardness: This is an approximate measure of the sulphate of lime in the water, and runs with considerable regularity throughout the length of the stream except during the months of June and November, at which time there is an enormous increase in the sulphates in the upper stream. The cause of this is not apparent; it appears to be associated with wet weather and surface washing, these being the conditions which prevailed at both the above periods. It is well to remember that in June the rainfall of the upper water-shed was above the normal, and it is here that the high sulphates are shown, also that in November there had been several heavy rains a short time previous to sampling. Unfortunately the July determination of the permanent hardness was lost, but the high total solids found in the water at that time would indicate that the permanent hardness in this month of wet weather was also excessive.

Total solids: The amount of mineral matter dissolved in the water follows the lines of temporary and permanent hardness; it shows the effect of Columbus sewage and the high sulphates of Kenton in the months of June, July and November. The general tendency of the stream is to grow softer and freer from mineral matter as it proceeds.

THE LITTLE SCIOTO RIVER.

The effect of the sewage of the town of Marion is shown on the two plates on which the results are plotted. The free ammonia and chlorine seem to be, as before, the best indicators of the sewage pollution. The very high chlorine above the town found in September and October correspond to a period of practical cessation of current in the river; and the water above the city may have been concentrated by evaporation and contaminated by local drainage so as to account for this increase in chlorine. The nitrates and nitrites show effects of sewage corresponding to those found in the Scioto below Columbus, disappearing entirely in the dry months, and reappearing after the fall storms.

THE OLENTANGY RIVER.

The oxygen required in this stream is high throughout, so high as to be useless in drawing any conclusions as to sewage contamination based on this element. In two cases, at Galion and at Delaware there is a notable increase in passing the town; but as often there is a decrease, probably due to dilution by the water from the city. The amount of albuminoid ammonia diminishes toward the lower end of the stream. The albuminoid ammonia of the upper portion is associated with a flat and marshy country. The free ammonia of the Olentangy is enormously raised by the sewage of Galion. In October the stream below this town consisted of practically pure sewage. However it is noticeable that by the time the stream reaches Delaware the free ammonia has dropped to a small amount. This is raised a little by the drainage of Delaware. Delaware not being a sewered town the increase of free ammonia in the water is far below what its population would lead one to expect. Yet it is sufficient to show that fresh sewage gets into the stream in considerable quantity. At Olentangy park the excess of free ammonia has practically disappeared. The water at Columbus shows about the same proportion as at Olentangy park. The amounts of free ammonia shown by the stream are high throughout. The albuminoid ammonia in this river is high throughout, as was to be expected from the high oxygen requirement, indicating in the main that it is derived from vegetable sources. Of course this is not the case with the amount below Galion in the dry months when the water consisted of practically all sewage, as shown by the chlorine and the free ammonia. The nitrates and nitrites show general conditions similar to those existing in the Scioto river. They are almost absent in the hot and dry weather and increase to large amounts in and immediately after wet weather. The marked increase in nitrates and nitrites in the river below Delaware in every month except November is worthy of notice. Delaware not being a sewered town, the drainage in large part must reach the river in the form of soil seepage. The water coming in this way from the thickly populated area would naturally be heavily loaded with nitrites and nitrates due to the extensive oxidation of organic matters on passing through the soil. This will be especially true during the dry months when there is little direct surface flushing into the stream. In the wet month of November the surface wash diluting the water may account for the drop below the city, as the upper stream is shown to carry large amounts of nitrates for this month. The variation in the chlorine at different points in the stream is very great, noticeably at Galion. The chlorine in the water above Delaware is quite low, corresponding to great dilution by the large drainage area between that point and Galion. The great increase below Delaware, especially in the dry months, points again to water seeping from the city into the stream, and shows a great addition of sewage in a filtered and oxidized form. In fact the amount of subsoil, chlorine contaminated city water, that reaches the stream must be relatively large in the dry months, though there is no corresponding increase of ammonia to indicate the presence of unchanged sewage in such large amounts. The great reduction in the amounts of chlorine shown in the November samples corresponds to renewed wet weather and high water. Here the chlorine bearing Delaware soil water produces but a small effect. The great drop in chlorine noticed during the dry months between the water below Delaware and that at Olentangy Park must indicate very large dilution between these points, which may be explained by the presence of numerous springs furnishing chlorine free water. If this is the case the amount of water taken into the river below Delaware would appear to be far in excess of what would be expected from the increase in the drainage area between the two points. The temporary and permanent hardness do not appear to range through a wide variation on this stream, but during the months of September and October there appears to have been a distinct increase due to the influence of Delaware on the stream. The sewage of Galion appears as a rule harder than the water above that town. The great increase of the sulphates or permanent hardness at Galion during the wet month of November corresponds to that shown at Kenton on the Scioto. Unfortunately the determinations of permanent hardness in July, August and September were lost. In regard to the total solids the effect of the sewage at Galion and the chlorides at Delaware in increasing the amount of this determination is shown by the curves, which follow in a general way the change in hardness. There is reason to believe that the permanent hardness during July, August and September was high below Galion, and corresponds to the increase in total solids at that point.

THE MAHONING RIVER.

The oxygen required shows the same excessive amount in this river as in the others examined. This is especially noticeable in the July samples, particularly those taken at the lower stations. The waters at this time were turbid and highly colored, due to the heavy rains at the date of sampling. Consulting the chlorine curve for this month it will be noticed that the amount of that element was very small. This precludes the possibility of any important percentage of sewage entering the stream at that time, and indicates conclusively that the oxygen consumption was merely an index of the vegetable matter in the stream. The free ammonia in this river follows with great regularity the known sewage pollution, most noticeably in the dry months. In the wet month of July the figures for free ammonia are uniformly quite high, and show but slight increase below the points of known sewage pollution, a condition of affairs which is repeated in November, though in a less pronounced way, indicating that the general wash of the soil brought in by the storms contained very appreciable amounts of decomposing organic matter. In fact the free ammonia throughout the stream is excessive and only drops occasionally approximately to the amount to be expected in an unpolluted stream. The water above Warren in October is about the only sample which is satisfactory in respect to its free ammonia. The albuminoid ammonia follows closely the oxygen requirement, as was the case in the other streams, and increases to excessive figures in July, owing to the heavy storms preceding the sampling. The nitrates and nitrites appear in quantity only during the wet weather of July and November, and are practically absent during the dry weather. It is to be noticed that the sewage of Youngstown in no case causes the reduction of the nitrates as does the sewage of Columbus on the Scioto. In all cases the amount of nitrates and nitrites below Youngstown are in excess of that found above the city. The percentage increase in the amount of nitrites in the month of October is especially noticeable. The population per square mile of drainage area above the station below Columbus on the Scioto was about 170, while that above the Haselton station was about 155, and of this population only 46% were immediately above the points of sampling, while in the case of Columbus nearly 60% was immediately above the point of sampling. Further, it will be seen on consulting the water table that while the average rainfall on the Scioto water-shed for the months of August, September and October was 2.21, 0.74, 0.68 inches respectively, the rainfall on the Mahoning water-shed for the same months was 5.41, 1.23, 0.96 respectively; and the total rainfall on the Mahoning water-shed for the three months was 7.60 against 3.63 on the Scioto, accounting for the much smaller proportionate volume of water receiving the sewage of Columbus than that receiving the sewage of Youngstown. The chlorine determinations on the Mahoning river are influenced by the presence of saline springs which enter it in the vicinity of Niles, and which prevent accurate conclusions being drawn from the chlorine figures in regard to sewage pollution. The influence of these streams seemed particularly evident in the dry months; however, the chlorine increase at Alliance and at Youngstown obviously coincides with sewage pollution. The permanent and temporary hardness call for no particular comment. The water is softer in the lower portion of the stream. There is shown an increase in sulphates with a corresponding drop in carbonates between Niles and Youngstown during the dry months of September and October. It is possible that this may be due to the running in of acid-bearing waters from coal mines or similar sources. The total solids in the water show a general tendency to diminish towards the lower part of the stream, but the fluctuations are irregular. The high results at Youngstown and below obtained in September and October correspond with the saline additions as shown by the chlorine, but the results are too few to establish any definite conclusions.

GENERAL CONCLUSIONS.

Having reviewed the analytical results in detail it remains to consider what general conclusions can be drawn from them concerning the character of the water in the three rivers examined. The Scioto river drains an area in which the surface rocks are largely composed of limestone and dolomite, consequently the water is high in mineral constituents, particularly of carbonates of lime and magnesia, and the sulphate of lime. The average of all the results obtained on the samples drawn above the junction of the Olentangy, that is, those representing the Scioto river from Kenton to Sandusky St. Bridge, gives the following figures for the mean composition of the water for the six months covered by the examination.

Total Solids	56.5
Volatile Solids	10.2
Non-volatile Solids	46.3
Permanent Hardness	12.9
Temporary Hardness	18.0

It will be noticed that the sum of the temporary and permanent hardness falls considerably short of the amount of non-volatile solids.

This is explained by the fact that the sulphate of lime and carbonate of magnesia are both estimated as carbonate of lime having a lower proportionate weight. The undetermined alkaline salts, suspended matters, and silicates also increase the amount. The average composition of the Olentangy river is as follows:

Total Solids	52.1
Volatile Solids	9.2
Non-volatile Solids	42.9
Permanent Hardness	7.8
Temporary Hardness	20.2

The water of this river is slightly softer and slightly lower in sulphates than the water of the Scioto.

The average composition of the Mahoning river is also given:

Total Solids	27.8
Volatile Solids	4.9
Non-volatile Solids	22.9
Permanent Hardness	4.2
Temporary Hardness	9.8

It will be seen that this river is much softer than either of the others. These general averages are largely departed from at different points in the stream, as is readily seen by consulting the table of analyses. It may be noticed that the Scioto appears to be somewhat more uniform in composition at the different stations than the others.

The effect of population and sewage on the stream can be best investigated through the organic ingredients, the nitrates, and the chlorine. It is evident from the table of drainage areas and populations that the rivers drain comparatively thickly populated areas. In order to discuss the effects of this population on the analytical character of the stream it is first necessary to establish, as a base of computation, the constitution of sewage. The composition of city sewage varies so greatly with the amount of water used per capita and other conditions that it is extremely difficult to fix a standard for comparison, in order to answer the question, how much sewage does a stream receive? The average analysis of the Alliance sewage for the six months covered by the experiment was:

Free Ammonia	0.3721
Albuminoid Ammonia	0.1512
Total Solids	49.4
Chlorine	2.11

This result is considerably below the figures shown by the sewage of other cities. The composition of the sewage of the city of Columbus as determined by a series of twelve analyses just completed is as follows:

TESTS OF COLUMBUS SEWAGE.

(FROM INTERCEPTING SEWER AT SCHILLER STREET.)

Date. 1898.	Free Ammonia.	Albuminoid Ammonia.	Chlorine.
Feb. 21......	.6600	.4100	3.00
" 22......	.4640	.2980	2.80
" 23......	1.6880	4.6280	3.20
" 24......	0.4780	0.2800	3.00
" 25......	0.3620	0.2040	2.80
" 26......	0.3620	0.3360	2.60
" 28......	0.5140	0.4800	3.20
March 1......	0.4840	0.2260	3.00
" 2......	0.6400	0.4780	3.20
" 3......	0.5180	0.4960	3.60
" 4......	0.6720	0.5320	8.80
" 5......	0.5980	0.5500	3.80
Average	0.6200	0.7422	3.59

The compositions of the sewages of London, England; Lawrence, Massachusetts and Worcester, Massachusetts are given as follows:

	Free Ammonia.	Albuminoid Ammonia.	Chlorine.
London	4.5160	0.5471	15.00
Lawrence, Mass.	1.8202	0.5302	5.25
Worcester, Mass.	1.8760	0.3160	4.17

From the figures for these three latter cities Mr. Stearns, in the report of the Massachusetts Board of Health for 1890, has calculated the composition of sewage corresponding to different amounts of water per capita, and gives the following as the composition where one hundred and twenty gallons of water are supplied for each inhabitant. Free ammonia 1.5000, albuminoid ammonia 0.3000, chlorine 4.20. The per capita amount of each ingredient in the sewage has also been calculated, and is given by Mr. Stearns as: free ammonia .015 pounds or 6.8 grammes; albuminoid ammonia .003 pounds or 1.4 grammes; chlorine .042 pounds or 19.1 grammes. Mr. Hazen informs me that the data which he has collected correspond more nearly to twelve grammes of organic nitrogen and thirty grammes of chlorine for each person connected with the sewers. This would be equivalent to about 7.3 grammes of free ammonia, 3.6 grammes of albuminoid ammonia, and 30 grammes of chlorine per inhabitant. If the Alliance sewage be assumed to consist of the water above Alliance plus the additions made by the town, the change in composition would correspond to the following average analysis: free ammonia .362, albuminoid ammonia .133, chlorine 1.90. Assuming Mr. Hazen's figures for the amount of free ammonia per inhabitant as correct, and it will be noticed that these correspond very closely with those given by Mr. Stearns, we may calculate the corresponding amounts of the other elements in the Alliance sewage by a simple proportion. This would give for the amounts added to the Alliance sewage by each inhabitant, free ammonia 7.3 grammes, albuminoid ammonia 2.3, chlorine 38.3. From the analyses of the Columbus sewage the amounts may be calculated in the same way. The ratio of the other ingredients to the free ammonia for the average of these analyses give 7.3 grammes free ammonia, 8.7 grammes of albuminoid, and 53. grammes chlorine per inhabitant. In view of the various results above shown it is obviously impossible to fix a composition which may be considered as representing sewage accurately; but for purposes of comparison Mr. Hazen's figures for the chlorine, albuminoid ammonia and free ammonia per inhabitant will be taken, and also a sewage corresponding in dilution to 4.2 parts of chlorine per 100,000 parts, such a sewage being about 17% more saturated than that of the city of Columbus as shown by the tests made in February. The chlorine is not destroyed by any subsequent change which the sewage may undergo; it is not absorbed by the soil through which the water may percolate. It may be considered as a certain index of the sewage pollution of the stream provided it is not introduced into the river from mineral sources. A calculation of the relation between the population on the drainage area and the chlorine in the streams should show whether the streams received chlorine from underground sources in addition to that furnished by the inhabitants on its banks. The gaugings of the stream are necessary to make this calculation. Gaugings were made by Professor Brown at a few points. Below Kenton the average of the measurements made on August 17th and 27th, show an average flow of about three million gallons, equal to about 11,355,000 kilogrammes. The population of the drainage basin above Kenton is estimated at 6,685, which will correspond to about 200 kilogrammes of chlorine daily. If all this drained into the stream it would bring chlorine up to 1.8 instead of 0.25 actually found. From this it is evident that only a small portion of the rural drainage can get into the stream in dry weather, and that no mineral source is required to account for the amount of chlorine found. The gauging at Jones' dam, August 5th, showed 62.6 million gallons, or about 237 million kilogrammes. The population above this point is shown by the table to be 72,221, which should furnish 2166.6 kilogrammes of chlorine. If all this chlorine went into the stream it would make the amount 0.91 parts per hundred thousand instead of the 0.41 found on August 23d, again showing that the chlorine in the stream is more than accounted for by the population on its water-shed. The gauging at Dublin Bridge, August 5th, was twenty-five million gallons, or 132,-000,000 kilos. The population on the Olentangy drainage area above this point was about 40,000, corresponding to 1200 kilos of chlorine. If all this went into the river, the chlorine contents would be 0.91 as against 0.54 found on August 23d. The gaugings on the Mahoning river were reported as not very satisfactory. The average cf the results at Youngstown for August, September and October gives about forty-four million gallons or 166,000,000 kilogrammes. Population above this point is 80,000, which would be equivalent to 2,400 kilos of chlorine, which would correspond to 1.44 chlorine in the water, the average chlorine for the three months being 1.09. This figure is so much nearer the calculated value than those shown by the Scioto and Olentangy that it suggests some mineral source of chlorine in the river.

If we assume the chlorine in the water of the river to be derived from sewage and not from mineral sources, the distribution of the sewage in the stream is easily calculated. Taking as a basis of calculation a sewage in which the chlorine is 4.2 the per cent. of sewage at any point in the stream would be shown by the simple formula,

$$\frac{100(a-b)}{4.2-a}$$

in which "a" stands for the chlorine in the unpolluted water of the stream, and "b" for the chlorine in the water at the point tested. The following table was calculated for each of the three rivers. The first column gives the percentage of sewage water indicated by the average chlorine of the six months; the second, the percentage of sewage represented by the chlorine found in the October samples. It is to be understood that this sewage may have been thoroughly oxidized until all organic impurity has been destroyed. The figures stand merely for the percentage of the water which entered the stream directly or indirectly as sewage of the strength assumed. The sewage below the towns is probably largely in the condition of fresh sewage. On the Scioto river the water above the city of Kenton has been assumed as sewage free, and its average chlorine contents of 0.23 taken as that present in an unpolluted water. This chlorine is probably due to the scattered population of the upper water-shed, and thus really stands for remote sewage pollution, so that the actual figures given in the table for the lower stream represent percentages of sewage water in excess of that present in the water above Kenton, which stands for the drainage from the thinly settled rural districts.

Percentages of Sewage Derived Water in the Streams Calculated from Chlorine Excess.

SCIOTO RIVER.

Drainage area, square miles.		Average for 6 months.	October.
153.	Kenton, above	0.	4.
	Kenton, below	14.	39.
109.	Marion, above	7.	16.
	Marion, below	35.	43.
962.	Girls' Ind. Home	...	18.
	Girls' Ind. Home, below	...	22.
1023.	Wyandotte	7.	13.
1038.	Jones' Dam	6.	12.
1053.	Sandusky St. Bridge	12.	18.
1565.	Frank Road Bridge	51.	98.
1650.	Shadeville	42.	75.
3160.	Circleville	10.	22.

OLENTANGY RIVER.

		Average.	October.
29.	Galion, above	15.	23.
	Galion, below	121.	164.
422.	Delaware, above	0.5	1.8
	Delaware, below	30.0	125.
488.	Olentangy Park	8.5	13.
512.	Dublin Bridge, Columbus	8.0	15.5

MAHONING RIVER.

		Average.	October.
82.	Alliance, above	0.	2.7
	Alliance, below	10.	33.2
596.	Warren, above	1.7	4.0
	Warren, below	4.2	10.2
815.	Niles	8.0	...
967.	Youngstown, above	12	35.
	Youngstown, below	21.	58.

The calculations for the Olentangy river are made on the assumption that the normal chlorine is the same as that above Kenton. The evidence of marked sewage pollution above Galion is fully supported by the high free ammonia per cent. in this water. The figures for the Mahoning river have but little absolute value for Niles and the points below that town, owing to the known presence of sources of mineral salt. For this reason the figure for October is omitted as the chlorine results were probably due to the presence of mineral salt in considerable amount. The relative amounts of sewage shown by this calculation above and below Youngstown probably stand as an approximate measure of the increase in sewage. These tables show clearly that the stream received sewage at many points on its course. It would seem that the amount of sewage as shown by the chlorine contents is in excess of that draining into the river from the larger towns. Thus, in the case of the Scioto river, the average percentage of sewage as shown by the chlorine is 14% just below Kenton, 35% below Marion, and 7% at Wyandotte Grove. The drainage area above Kenton is 153 square miles, above Marion, 109 square miles, and at Wyandotte 1023 square miles. Assuming that the increase in volume of the stream is proportional to the drainage area, the sewage at Kenton should constitute 2.3% of the stream at Wyandotte, and the sewage of Marion 3.5% of the stream at Wyandotte, giving a total of 5.8%; while the amount found is 7%. This suggests the addition of sewage at other points along the stream in excess of that found in the normal drainage of the rural districts. The source of this is obviously the smaller towns and hamlets along the banks of the river. In the month of October the sewage below Kenton is 39%, below Marion 43%. At the Girls' Industrial Home the percentage of sewage due from the towns of Kenton and Marion would be about 11%, the dilution being assumed proportional to the drainage area. The water at that point is shown by the October samples to contain 18% of sewage water, or a gain of 7% due to other sources of pollution. If the highest amounts of chlorine found at Marion on September 23d be taken as a base of the calculation, it still leaves a deficiency at the Girls' Industrial Home of nearly 15% of the total sewage in the stream. Of course the number of results is too small to base anything like certain conclusions upon, but they strongly indicate the continuous pollution of the stream along its course to this point. The increase of sewage below the Girls' Industrial Home is an illustration of what is probably taking place at numerous points on the stream. There is a curious anomaly in the relation between the results at Jones' Dam and the Girls' Industrial Home. The great falling off of chlorine and the sewage which it stands for, at the lower points shows a possibility of considerable additions of pure water between these points. Too few results were obtained at the upper point to justify positive conclusions with regard to this. If established as a persistent difference, it would point to numerous springs along this portion of the river. The gain in sewage as the Scioto river approaches Columbus is marked, both for the average of the six months and for the maximum drought in October. Below Columbus the dropping off in the percentage of sewage is more rapid than the increase of drainage area would seem to warrant, apparently indicating a greater proportionate flow into the stream from the lower drainage basin than from the upper. The Olentangy river also shows marked departures from what would be expected if dilution were proportionate to the area drained. The fact of the almost entire disappearance of the Galion sewage at Delaware is somewhat remarkable. The drainage area above Galion is only twenty-nine square miles, above Delaware four hundred and twenty-two. Simple dilution should have reduced the Galion sewage to not over 6% of the river; that it should be so much below this figure speaks well for the stream as being largely supplied with water from unpolluted sources. The very heavy increase in chlorides at Delaware has been previously referred to. The amount of fresh sewage entering the stream at this point is small, but the soil drainage must be loaded with the salts of the oxidized and clarified sewage water of the town. A deep seated or mineral source of this chlorine at Delaware is hardly probable. An analysis of a deep well water from Delaware was made for Dr. Orton, and is given in his report on the underground waters. This deep well water only contained 0.22 of chlorine, corresponding to a sewage pollution of zero on the scale adopted. The rapid reduction in the sewage contents below Delaware as indicated by the chlorine may be due to dilution by spring water, and indicates that during the dry weather it is possible that the water of the Olentangy which reaches Columbus is largely derived from springs emptying into the river below Delaware. In the Mahoning river down to Niles the sewage shows dilution corresponding to the drainage area, being nothing above Alliance, 10.5 below, and falls to 1.7 above Warren. Dilution proportionate to the drainage area would give 1.3% at this point. This would indicate comparative freedom from local pollution along the stream. This seems to correspond to the low free ammonia at that point, the lowest on the river. Below Warren the sewage as shown by the chlorine increases more rapidly than the population and the drainage area would warrant, being three times as much above Youngstown as below Warren, while the population drained is not doubled and the drainage area increases nearly 50%. The local increase below Youngstown can be charged to the pollution of that city, and shows an increase of 8% due to the sewage. This is for the average of the six months.

How far is this sewage pollution a matter of danger if the stream is to be used as a water supply? This question is of course the vital one. If the figures in the foregoing tables represented fresh sewage, the question would answer itself. It has been shown by the Massachusetts State Board of Health that water receiving 10% of fresh sewage is made offensive thereby; that, leaving aside all question of fitness to drink, four per cent. of sewage is all that a river can receive and remain certainly free from bad odors and nuisance. Of course any fresh sewage at all unfits the water for drinking purposes. The above figures are given as showing that the percentages of sewage in the stream, if in a fresh or unoxidized state, would make themselves evident at once by the odors of the water. Thus, on the Mahoning river below Alliance the water has a distinct odor, becoming offensive in October. Below Warren the odor is faint except in October, when the sewage comes up to ten per cent., and the odor is slightly offensive. At Youngstown, where the increase of sewage is eight per cent., the odor is slight, excepting in the dry months, when there is an increase of thirty-seven per cent., and the river becomes distinctly offensive. In these cases the odor indicates the freshness and active character of the sewage pollution. The Olentangy shows the offensive odors due to the unoxidized sewage below Galion, but not below Delaware, on account of the filtered condition of the drainage from that town. On the Scioto the sewage declares its active character by this test below Kenton in October at the Sandusky St. Bridge above the city of Columbus, and at all points below that city as far as Shadeville. In all these cases the free ammonia is very high. Now if the free ammonia be accepted as a mark of fresh sewage, the question of the character of the sewage in the other parts of the stream will depend largely upon the amounts of this ingredient present. The chief difficulty here is that the presence of some free ammonia is to be expected in streams as highly charged with vegetable matter as these are shown to be by the large percentages of albuminoid ammonia and "oxygen required" found at the points above possible sewage pollution. The free ammonia in the Scioto river is least at Wyandotte Grove. In July it drops to 0.0028, but during the months of August and September it goes up to .0098, over three times this, and averages for the six months more than twice the minimum with practically no change in the albuminoid ammonia during the same period. The water above Kenton is loaded with vegetable matter. Its average free ammonia is higher than at Wyandotte Grove, but the high average is apparently associated with the wash of the November rains, bringing great impurity into the stream. If we consider the figures for the dry months only, we have for August, September and October a free ammonia contents of only 0.0047, which is associated with an oxygen requirement of 0.60. Now this water is above sources of sewage pollution, and may be assumed as containing the amount of ammonia to be expected in the Scioto river when free from sewage, even when containing considerable organic matter of a vegetable character. For the same dry months the ammonia contents of the river at Wyandotte only once goes down to this figure, while it averages 0.0081. At Jones' Dam it averages 0.0087 for the same time. In both of these cases there is a lower oxygen requirement than is found above Kenton. This points to the conclusion that some unoxidized sewage remains in the stream at this point. As further evidence, it may be noticed that while nitrites and nitrates are entirely absent from the water above Kenton for these three months, only once do they disappear at Jones' Dam, and in no case at Wyandotte. These substances being associated with the destruction of sewage, and the nitrites showing the process to be incomplete, it appears to me that the conclusions from the ammonia determinations have here additional confirmation. While it would be going too far to claim that the river at this point is sewage contaminated, it certainly must be admitted that its purity is questionable. Of course these tests were made at a stage of very low water, and when the sewage of Columbus went as far as Circleville practically unoxidized; but low water conditions are always those associated with danger, and are liable to occur every summer. The other points in the stream show by their higher ammonias evidence of sewage in an unoxidized state. The Olentangy river shows a minimum of free ammonia just above Delaware, where its contents approximate closely that of the Scioto at Jones' Dam and Wyandotte; though here in October it sinks to 0.0040, much lower than at any other point on the stream. The Mahoning river shows its lowest figure for free ammonia just above Warren, which again corresponds to the minimum at Jones' Dam and at Wyandotte in the Scioto. At all other points it is far above this minimum, and indicates almost certainly active sewage pollution. At certain times the evidence of sewage pollution at the points which on the average represent the minimum danger from this source becomes more positive, the free ammonia running much above the average at the station.

In concluding, the results of the discussion of the chemical analysis may be summed up as follows: the streams examined all show evidence of sewage pollution, not only by the drainage of the larger cities, but also at minor points along the streams; that this sewage is in excess of that which can be duly oxidized by the water; that the purification of the water during its flow is not a sufficient guarantee of the safety of the stream as a source of public supply; that the cities of Alliance and Youngstown on the Mahoning, Galion on the Olentangy, Kenton, Marion, and Columbus on the Scioto are so overloading the streams with sewage as to cause the water to be not only worthless as a source of domestic supply to the towns below them, but to make it a nuisance and offense for miles below the point of infection; that the sewage of Delaware is so far purified by natural filtration as to effect but little the appearance and odor of the stream, but that it is not so far purified as to leave the stream receiving it free from danger when used as a drinking water.

REPORT ON THE

Bacteriological Examination of the Waters

of the

Scioto, Olentangy and Mahoning Rivers.

By A. M. BLEILE.

This work was undertaken for the purpose of determining the bacteriological conditions of the rivers with a view to their source as a supply of potable water, and also to fix the amount of pollution added by the various cities situated on their banks. The latter point determined the selection of sites in places other than those which might have been selected if some points considered incidentally in the work had been the main object. It is to be regretted that the bacteriological examination of water, like the chemical one, has the defect of not at once and definitely indicating either the positive harmfulness on the one hand or on the other its safety as a potable water, and that either method will only indicate a greater or lesser degree of pollution due to organic matter, with a probability that this is of animal origin, without directly revealing the presence of germs or other bodies capable of producing disease or disturbance in the human body. The ideal method for water examination would be a bacteriological one by which not only the number, but also the kind of bacteria, could be surely and rapidly determined, and thus the safety or dangerous character of the water at once fixed on definite points. Present methods of bacteriology are too imperfect to allow of this in practice, and therefore we only, by the bacteriological method, as with other methods, *infer* that which should be a positive demonstration. All that can be practically carried out with present methods and means is to determine the number of bacteria in a given sample and from their greater or lesser number conclude the greater or lesser degree of the purity of the water, and we can also infer to a certain extent that an increase in bacteriological numbers is due to contamination by animal products, especially if such an increase at a given point occurs suddenly and to a marked extent; for it is well known that the addition of vegetable debris, while it may raise the ammonias and other constituents of the water, will not to nearly so marked a degree raise the number of bacteria, and a sudden fluctuation in the number of bacteria would therefore point to the contamination of such water by human or animal waste products. When we take into consideration, however, that the number will vary directly with the amount of pollution and that the disease-producing power stands in relation, though perhaps not a direct one, to the given number of germs, we have in this purely quantitative examination of water a valuable and indispensable adjunct to other methods; and when it is further borne in mind that a pollution in itself would manifest itself constantly by an arithmetical increase in the quantities used for its determination, whereas the bacteria would be affected in a geometric increase, the value of the method will be apparent.

Two other considerations help to fix the importance of a bacteriological survey of waters. In a flowing stream the degree of purification can be estimated by the variations which occur in the numbers of bacteria; and further, not only are the direct producers of specific diseases, as typhoid and cholera, to be feared, but it is known that other forms, as the ordinary putrefactive bacteria, when present in large numbers, may produce gastric and intestinal disturbances which, by undermining the general tone of the individual, produce a greater susceptibility to zymotic diseases apart from the severity of these disturbances themselves. Not only is the water containing these bacteria capable of producing such effects directly, but when it is used in the preparation of foods taken in the raw state, as in the washing of some vegetables, or when it is used in the rinsing of vessels that contain milk, where the contained bacteria find a fit medium for their future growth and propagation, is it capable of spreading disease.

METHODS.

The culture medium used was the beef peptone agar, as usually prepared. The medium was rendered just alkaline, phenol-phthalein being used as an indicator. Agar was preferred to gelatine, because in similar work done on the Ohio river some years ago it was found that occasionally our Ohio summers bring a temperature high enough to melt the gelatine and thus cause loss of results. Then, too, liquefaction of the plated culture, which so frequently occurs with water bacteria on gelatine, could be obviated by the use of the agar medium. It is to be borne in mind that with this medium as with any other, we do not get a development of all of the bacteria contained in the water, as it is not possible to construct a medium which would offer the best condition for all species of bacteria, and of course no reckoning is made in the ordinary methods of plating for the anærobic forms or their spores which may be present occasionally in such waters. However, as more stress is laid on comparative results than on the absolute number obtained, the method fulfills all requirements. The statement made sometimes that a gelatine medium will give larger numbers than the agar medium, does not rest on a sufficient number of experiments, nor are the numerical differences observed in many of the results given great enough to be counted against the agar medium. The medium was always plated in Petri dishes 10 c. c. in diameter. No attempt was made to keep the plates at a constant or uniform temperature, since the exigencies of the work necessitated the carrying of the plates over the route for two and sometimes for three days. All plates were made at once at the river side where the sample was taken, so that there was no delay with its consequent increase of bacteria between collection of the water and plating of the same. During the warmer months, *id est* June, July, August and September, three days were given for growth on the plates before the count was made. In the last two cooler months the count was made after five days of growth. As it would be found to be inconvenient to always count at the lapse of the time set, experiments were made looking to a stopping of the growth and preservation of the plates for some days longer. A simple and effective method was adopted, after proper tests had been made. A round filter paper, slightly smaller than the inside of the cover of the Petri dish, was fastened by a few drops of mucilage to the under side of the cover. The paper was then flooded with formalin and the cover again placed on the dish. Cultures treated in this way have further growth of the colonies completely inhibited, and the medium remains fresh for days, or as observations made later for control show, fully as long as two weeks. The same object can also be obtained by simply flooding the culture with a thin layer of formalin, but here one is apt to dislodge and so lose some colonies, and if kept for a longer time the para-formaldehyde which forms on the evaporation of the water will be deposited in spots and streaks on the culture medium, and may interfere with the subsequent counting.

Duplicate plates were made at each station and the numbers given are the averages of the two plates. In most cases the agreement of the numbers from the duplicates was quite close, though in a few instances there were marked discrepancies. The wider differences might be due to a different bacterial content in the smaller proportion of water taken for each plate from the sample, or what seems to me more likely, in consideration of all the circumstances, that the preparation showing the smaller number of bacteria held zooglea masses which were not thoroughly broken up. The amount of water used for each plate was one c. c. Where larger numbers of bacteria were to be looked for, the original water was diluted forty, one hundred, two hundred and fifty, or two thousand times, as occasion required. In many instances all of the colonies on the plate were counted. This of course was not possible where the highest numbers were encountered, and here bacteria were counted in ten or fifteen smaller squares and the number on the whole surface calculated from the average so obtained. The Petri dishes used for plating were sterilized in the laboratory and then carried in cardboard boxes made for the purpose, each of which held a pair of dishes, and of such size as to give a snug fit. They were made square, however, instead of round, as the empty space given in the corners facilitated the removal of the dishes. In the first trip some plates were lost by a slipping of the culture medium occurring during transportation. Later, however, the dishes were most carefully cleansed by boiling in dilute ammonia before the final washing and sterilization, and no farther trouble was experienced as the film of agar now adhered tightly, even if the dishes were subjected to somewhat rough handling. The pipettes for measuring the water were carried in brass tubes a little larger than themselves and plugged at either end with cotton and so sterilized.

The results are given first in a numerical table, with the stations given in their order as they occurred on the river; next, in curves for each month where the distance between stations is marked on the abscissa. These latter tables give the logarithms on the vertical line instead of the actual numbers, as the use of these would have unduly extended the size of the table.

OLENTANGY RIVER.

		June.	July.	Aug.	Sept.	Oct.	Nov.
0	Galion, above	*	318	247	131	563	982
2	Galion, below	*	2,701	18,446	31,600	111,900	81,100
43	Delaware, above	608	1,352	866	261	883	2,210
46	Delaware, below	890	1,038	519	420	1,622	2,373
64	Olentangy Park	*	680	701	394	275	1,797
69	Dublin Bridge, Cols.	1,152	1,636	2,073	773	520	4,017

LITTLE SCIOTO RIVER.

0	Marion, above	868	866	1,375	1,169	430	2,755
1	Marion, below	1,156	4,306	16,783	12,520	7,100	15,320

SCIOTO RIVER.

0	Kenton, above	1,308	476	433	268	393	1,859
2	Kenton, below	*	5,774	2,436	4,200	17,220	13,900
49	Girls' Indust. Home, above	*	*	*	628	1,265	2,781
50	Girls' Indust. Home, below	*	*	*	658	$\frac{484}{1980}$	2,446
58	Wyandotte Grove, Cols.	731	914	289	302	199	2,015
61	Jones' Dam, Cols.	816	394	588	354	705	2,223
66	Sandusky St. Bridge, Cols.	1,472	1,028	4,541	10,800	1,150	10,170
70	Frank Road Bridge, Cols.	8,856	63,650	195,100	246,100	183,400	135,000
77	Shadeville	*	708	885	3,234	13,160	18.140
91	Circleville, above	118	14,428	610	503	756	3,451

MAHONING RIVER.

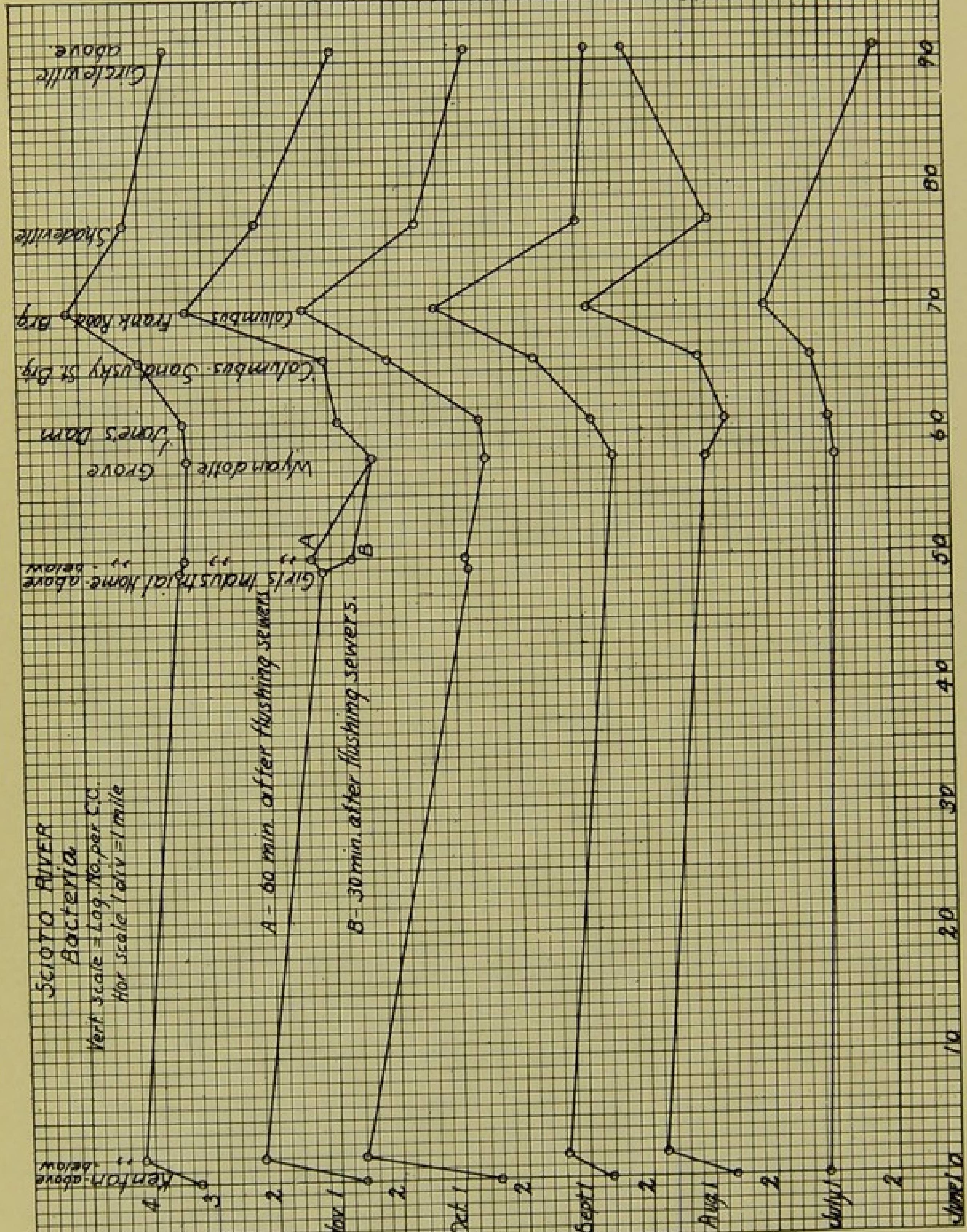
		June.	July.	Aug.	Sept.	Oct.	Nov.
0	Alliance, above	1,623	1,768	263	410	742	20,215
2	Alliance, below	1,914	7,032	5,594	9,910	20,370	57,250
39	Warren, above	816	5,974	155	163	540	5,720
42	Warren, below	1,455	14,820	1,238	7,700	7,140	14,920
45	Niles	*	3,812	443	303	599	7,857
48	Girard, above	1,012	*	*	*	*	*
53	Youngstown, above	2,250	14,178	576	1,160	2,630	5,523
55	Youngstown, below	2,395	12,428	5,164	6,350	30,460	13,150

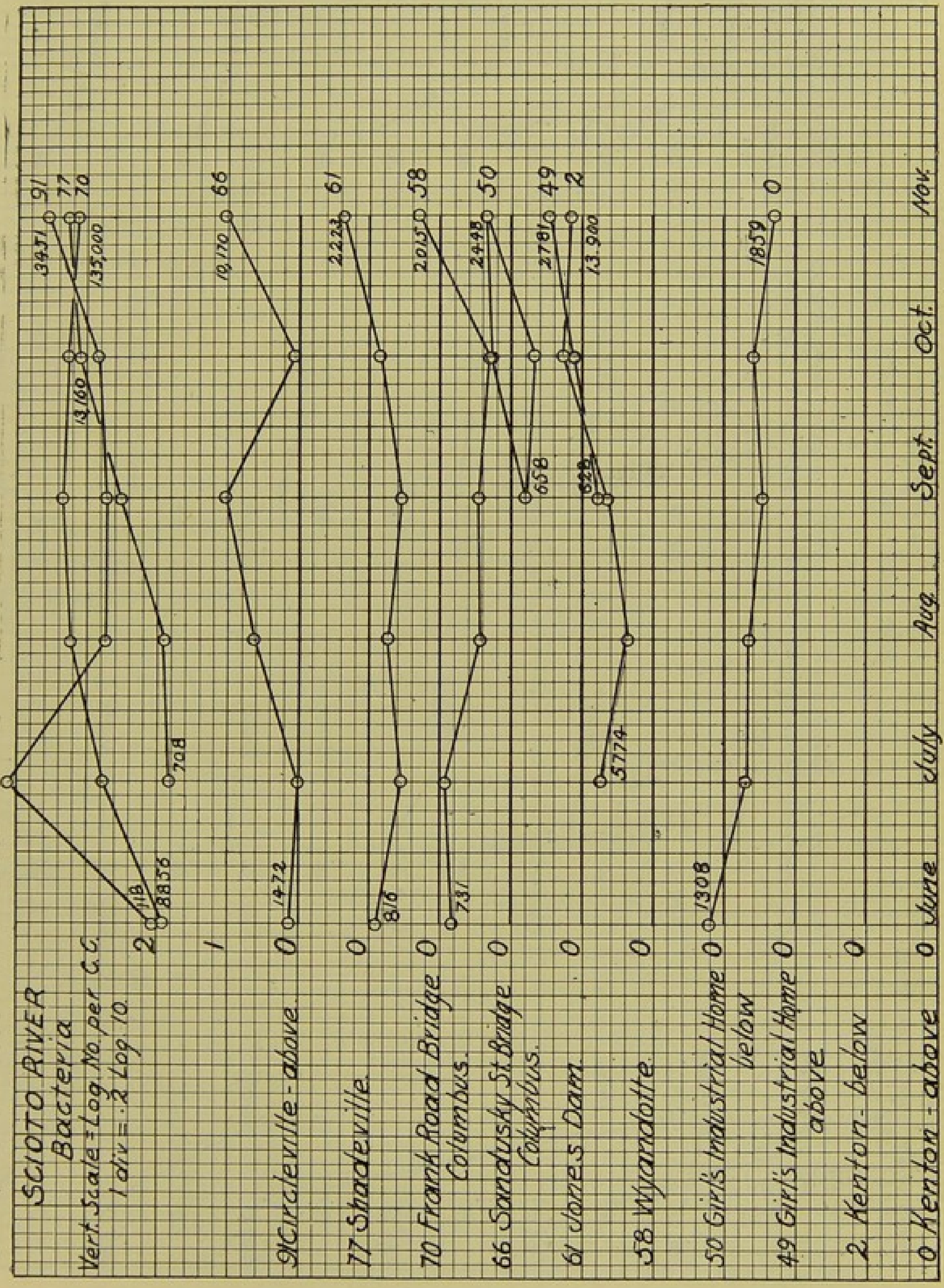
* No examination.

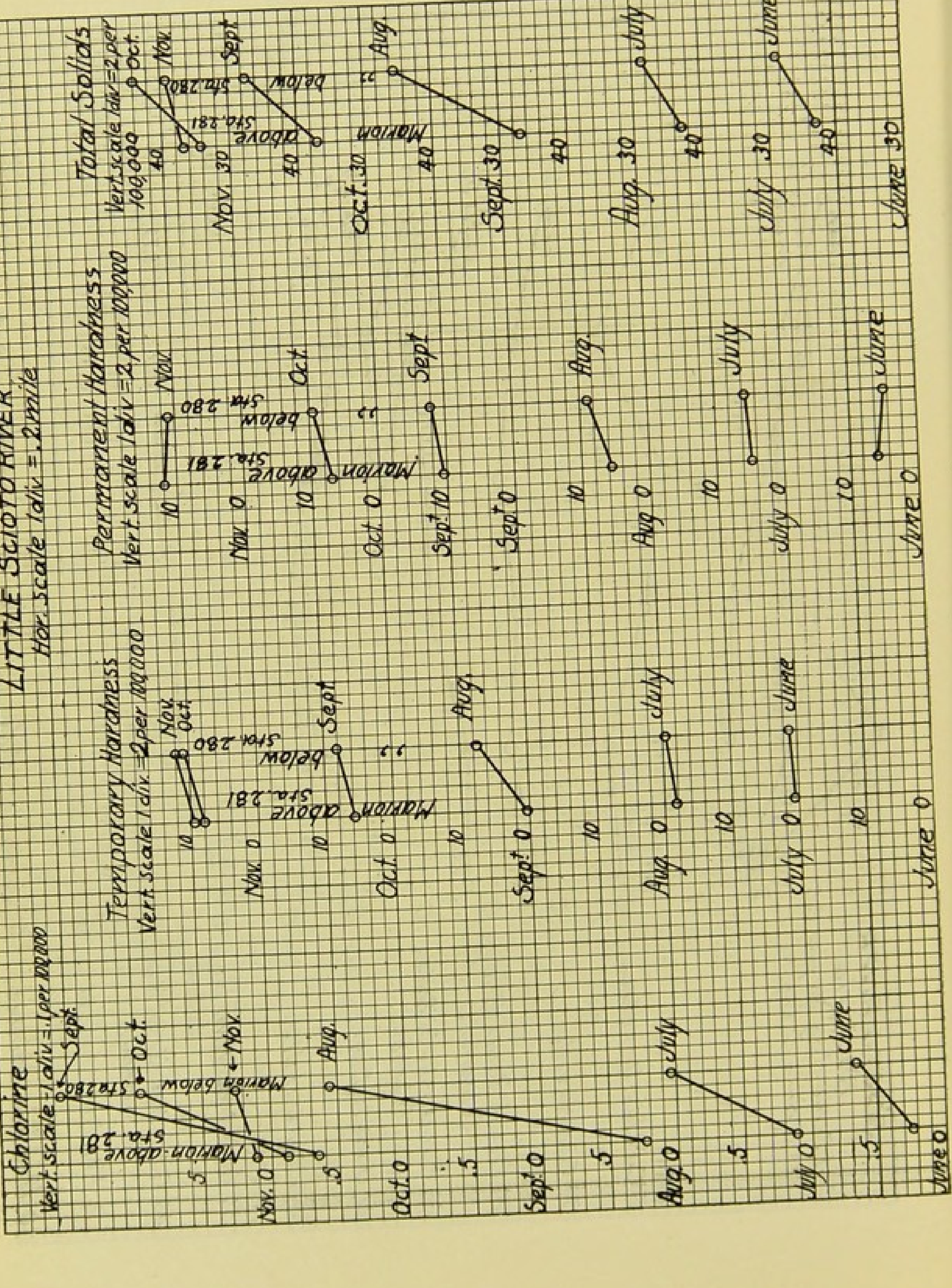
SPECIAL EXAMINATIONS.

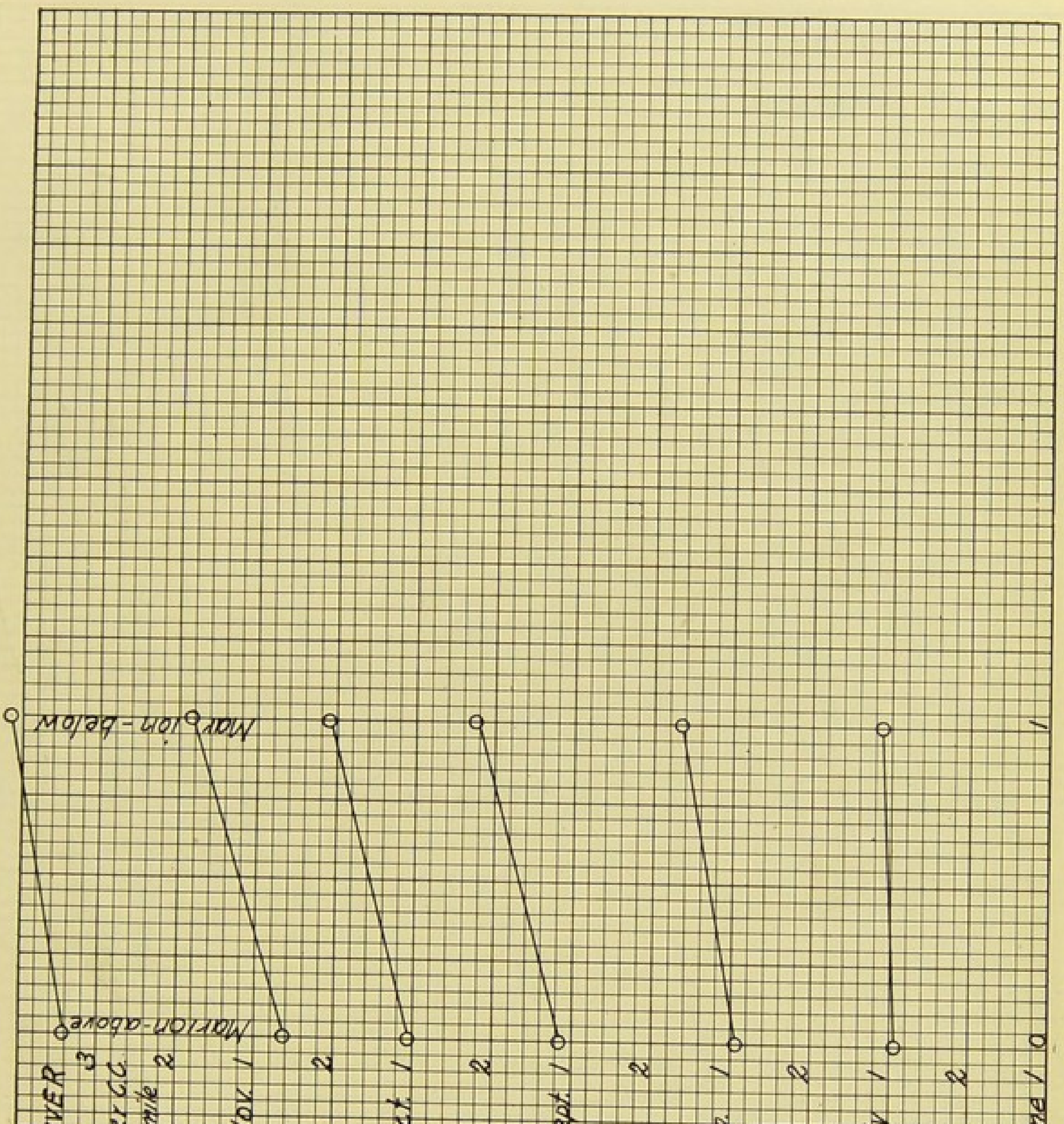
Warren, filtered water	538	1,968	50	....	330	875
†Alliance, sewage	196,200	105,600	80,800	152,900	146,200	......
Alliance, effluent	7,360	459,680	561,400	611,000	1,111,500	......

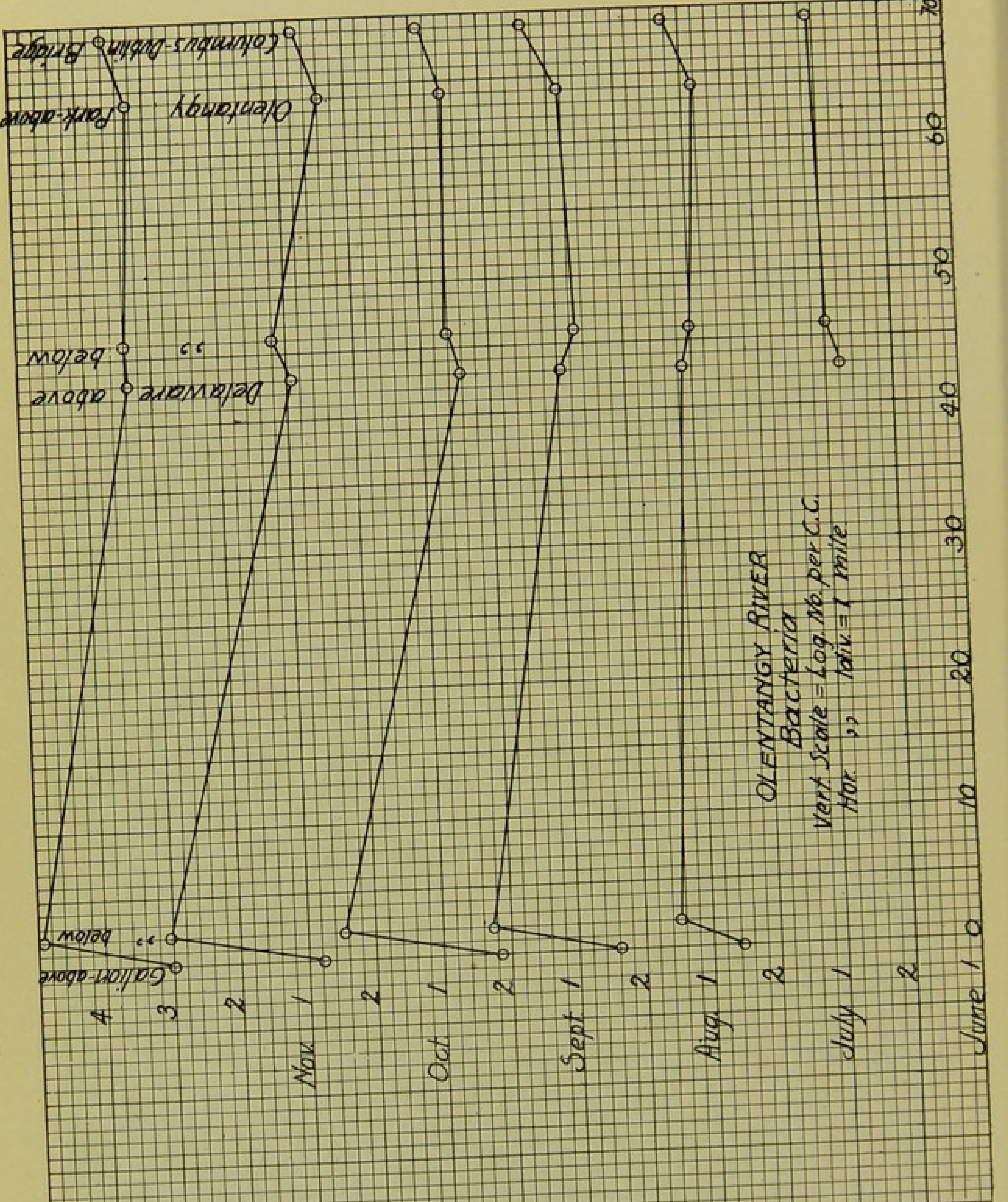
† During June, July and August, no note was taken of amount of alum used. On September 30th and October 7th composite samples were taken representing the average of 24 hours sewage flow. For the first of these there was 300 lbs. of lime used for 277,540 gallons of sewage; for the second, 320 lbs. of lime and 40 lbs. of alum for 304,793 gallons.

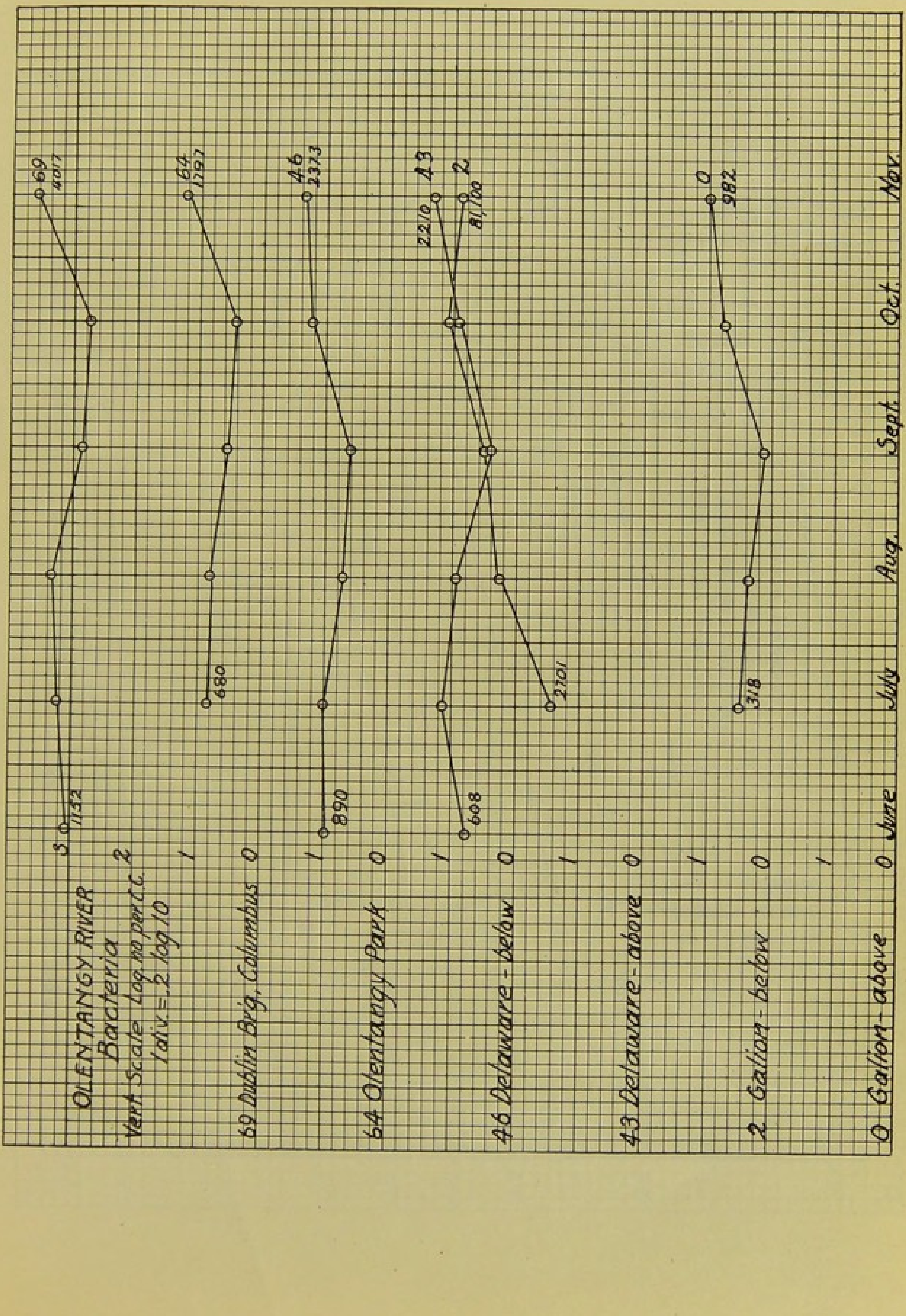

SCIOTO RIVER
Bacteria
Vert. Scale = Log. No. per C.C.
Hor. scale 1 div = 1 mile
A - 60 min. after flushing sewers
B - 30 min. after flushing sewers.
Kenton-above
'' -below
Girls Industrial Home-above
'' -below
Grove
Wyandotte
Jone's Dam
Columbus-Sandusky St. Brg.
Frank Road Brg.
Columbus
Shadeville
Circleville above.
A
B
June 1
July 1
Aug. 1
Sept. 1
Oct. 1
Nov. 1
0
10
20
30
40
50
60
70
80
90

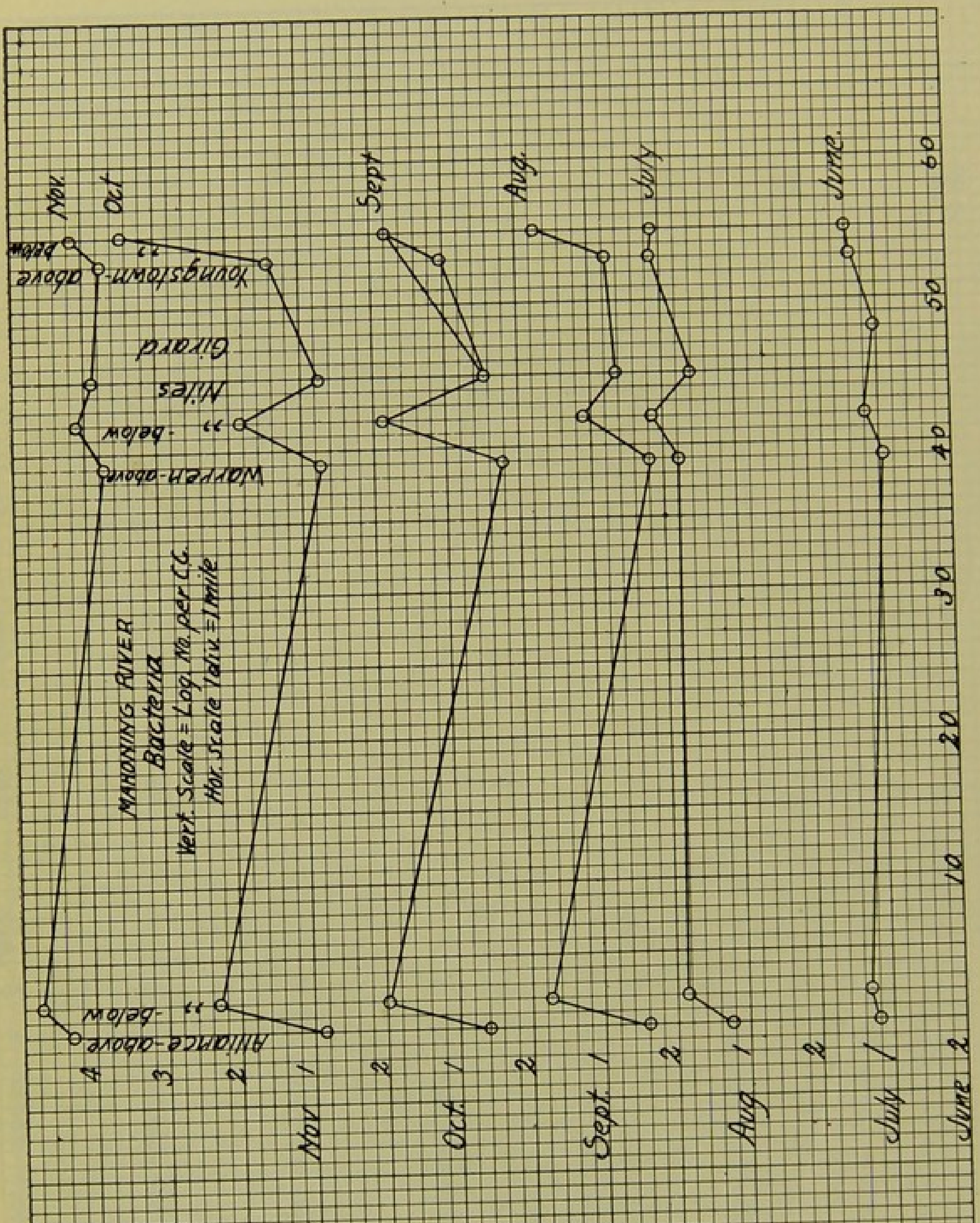

SCIOTO RIVER
Bacteria
Vert. Scale = Log. No. per C.C.
1 div = .2 Log 10
91 Circleville - above
77 Shadeville
70 Frank Road Bridge Columbus
66 Sandusky St. Bridge Columbus
61 Jones Dam
58 Wyandotte
50 Girl's Industrial Home below
49 Girl's Industrial Home above
2 Kenton - below
0 Kenton - above
June
July
Aug.
Sept.
Oct.
Nov.

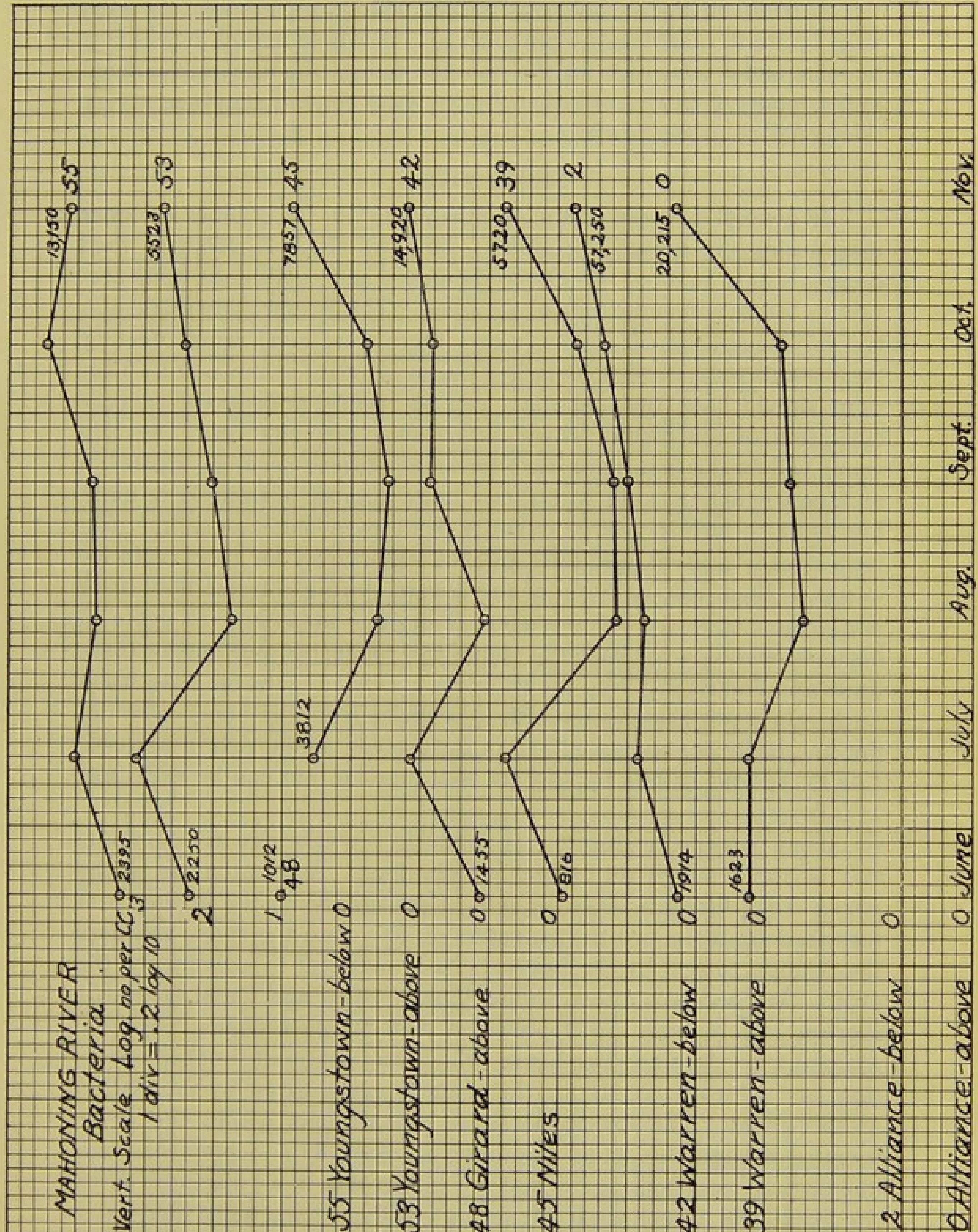

LITTLE SCIOTO RIVER
Hor. Scale 1 div. = .2 mile
Chlorine
Vert. scale 1 div. = .1 per 100,000
Temporary Hardness
Vert. scale 1 div. = 2 per 100,000
Permanent Hardness
Vert. scale 1 div. = 2 per 100,000
Total Solids
Vert. scale 1 div. = 2 per 100,000
Marion above Sta. 281
Marion below Sta. 280


LITTLE SCIOTO RIVER
Bacteria
Vert. scale = Log. No. per C.C.
Hor. scale 1 div = 1/20 mile
Marion - above
Marion - below
3
2
Nov. 1
2
Oct. 1
2
Sept. 1
2
Aug. 1
2
July 1
2
June 1 0
1


OLENTANGY RIVER
Bacteria
Vert. Scale = Log. No. per C.C.
Hor. " 1 div. = 1 mile
Galion-above
below
Delaware above
below
Olentangy
Park-above
Columbus-Dublin Bridge
Nov. 1
Oct. 1
Sept. 1
Aug. 1
July 1
June 1
0
10
20
30
40
50
60
70


OLENTANGY RIVER
Bacteria
Vert. Scale Log. no. per c.c.
1 div. = .2 log 10
69 Dublin Brg, Columbus
64 Olentangy Park
46 Delaware - below
43 Delaware - above
2 Galion - below
0 Galion - above
June
July
Aug.
Sept.
Oct.
Nov.
1132
4017
680
1297
890
2373
608
2210
2101
81,100
318
982


MAHONING RIVER
Bacteria
Vert. Scale = Log. No. per C.C.
Hor. Scale 1 div. = 1 mile
Alliance-above
" -below
Warren-above
" -below
Niles
Girard
Youngstown-above
" below
Nov.
Oct.
Sept.
Aug.
July
June.
Nov
Oct.
Sept.
Aug
July
June
10
20
30
40
50
60


MAHONING RIVER
Bacteria
Vert. Scale Log no per CC 3
1 div = .2 log 10
55 Youngstown-below
53 Youngstown-above
48 Girard-above
45 Niles
42 Warren-below
39 Warren-above
2 Alliance-below
0 Alliance-above
June
July
Aug.
Sept.
Oct.
Nov.

CONCLUSIONS.

A study of these plates and tables will be undertaken for each river by itself. Taking the numbers for the whole period, it will first be seen, and I refer here for the weather data to the figures contained in the report of Prof. Lord, that the bacterial content stands in a very close relation to the rainfall.

SCIOTO RIVER.

In general it is seen that in months with rains the number is higher than during the subsequent months, until we reach November, when there is a most marked rise due to the heavy and continuous rains prevailing before and at the time of sampling. This is especially marked in the July sample at Circleville, where there were local rains affecting these points only, causing a marked rise in the river at this point. That rains should have such an effect can be readily understood on consideration of the results which follow such precipitation. The rain water will in the first place wash from the surface decaying matter of all kinds, which not only furnishes a large number of bacteria in itself, but will also furnish a large quantity of nutrient material for the bacteria already present, and thus give an opportunity for their rapid increase. Then, too, in many of the sewers, during a lesser flow there is a greater or lesser sedimentation of organic material, rich again in bacteria and food for bacteria, which will be flushed out during these times and find its way into the tributary and finally into the river itself. Such rain water also carries with it particles from the upper layers of the soil, badly contaminated and in themselves, again, rich in bacteria. The exceptions to this finding are well marked, but can be explained as follows:

They occur below Kenton; at Sandusky street bridge in Columbus; and at the Frank Road bridge in Columbus. At Kenton and at the Frank Road bridge a large amount of sewage, being the greater part furnished by these two towns, enters directly into the river, and here the dilution caused by the heavy rains is sufficient to account for the drop. At Sandusky street bridge, Columbus, it was found later that there is also a more direct pollution than at other points, from the drain of a nearby slaughter house, which was not at all times in operation, and which accounts for the peculiar curve given by the station at this point. The lowest bacterial content falls within the dryer months, though the actual minimum is reached in September, with one or two exceptions again, and not in October in all instances when the Scioto was at its lowest. It seems startling at first sight that water at a low stage of the river should, when viewed in the light of bacteriological examination, be purer, that is, more wholesome, than water taken from a higher stage of the river. But here again consideration of the factors at work will show that this must be true. The direct pollution occurring immediately after a rainfall has already been alluded to, and with a cessation of those conditions mentioned there must of necessity be a drop in the number of bacteria. Then at these times the subsoil water, feeding into the river, will come from lower levels of the ground not so badly contaminated, will flow at a slower rate and will therefore reach the rivers more purified by processes of natural filtration. Finally, with the lower stages of the streams, the water will be exposed to the sun in thinner sheets, the riffles will be marked in their effect of exposing and aerating the water, all of which must contribute to a lessening of the number of bacteria or a purification of the stream. As stated, not all places reached their minimum during September. There is a rise at Kenton below town, a slight one at Wyandotte which may, however, easily fall within the errors of experimentation, a decided rise at the Sandusky street bridge and at the Frank road bridge, and some rise at Shadeville, including then the points which we found exceptions as to the rise in November, and also Shadeville. That is, points where the sewage is emptied directly into the river close to the station, are the ones affected here again, and this we explained by noting that the sewage, which is itself not much diminished in amount, is received into a smaller amount of water than before, not so much diluted, and giving us therefore even a marked rise at Shadeville, eight miles below the emptying of the large Columbus sewer. It is evident that the rise here has been caused by the accession of the Columbus sewage into this small volume of water, and that it could not be taken care of in this stretch of flow.

Taking the river from station to station it will be seen that there is a marked difference in every case between the bacterial content of the water above and below the cities. This in some cases is simply enormous, and corresponds to the amount of pollution, in a general way, which is known to exist between these stations.

An exception to this general deduction seems to exist at the stations above and below the Girls' Industrial Home, where there is a population of 450. Here it will be seen that the rise for two months is slight, and for the third month there is an absolute fall. The conditions at this point are somewhat peculiar. A small sewer is constantly discharging into the river, but the mass of sewage is retained in the vaults of the out houses, which are flushed once a day, and our samples were taken about three thousand feet below the sewer from thirty minutes to one hour after such flushing. A large spring of sulphur water discharges into the river at this point. Its volume is not thought sufficient, however, for a dilution of the water enough to explain the discrepancies in the bacterial count. It was thought that since sulphuretted hydrogen itself, when passed into a nutrient solution containing bacteria, will inhibit, or on longer exposure, destroy the bacteria, the sulphuretted hydrogen in the spring water might have caused a similar destruction of the bacteria in the river water. To test this point, plates were made of the river water itself, and of this water after the addition of one per cent., two per cent., five per cent., ten per cent., twenty per cent., and fifty per cent., respectively, of the sulphur spring water, but the counts of the plates so prepared agreed so closely with the count of the undiluted river water that no inimical effect could be made out.

There is not, however, a progressive increase in the number of bacteria straight down stream. In other words, it is apparent that the large number of bacteria which gain access to the river are lost in some way, that is, that the water purifies itself as it is carried on through the stream bed. This can best be seen if we compare the figures shown by a station below town with the figures obtained at the station below, above the next town. Just how much purification takes place in a running stream and how this purification or destruction of bacteria is effected, are moot questions. Several causes are here invoked. It is known that exposure to sun light will kill off many forms, and it is further known that aeration, while it will at first increase the number of bacteria, will eventually lead to destruction of a large number of them. Then, sedimentation may be a factor of some moment, though that this should be very great in the rivers here in consideration, does not seem probable. True, Rafter has made observations in which he found greater numbers of bacteria at greater depths of water, but observations made by Russell in another place do not show any marked differences in depth. In our shallower streams, especially during low water, broken by irregularity of contour and many riffles, conditions for rapid sedimentation are not most favorable. Then it is to be borne in mind that our bacteria must be of a low specific gravity, not much different from that of water, and that they therefore would not tend to settle rapidly. Further, many forms are endowed to a high degree with the power of motility, and there is no reason to assume that they would seek the bottom of a stream rather than the higher portions of the water. It is true that the sediment of a river may be found higher in bacteria than the water, but this would follow from the fact that this sediment contains large quantities of organic matter, food for the bacteria, and that they would increase enormously in this habitat. This purification goes on to a marked extent, even in the course of a few miles, as witness, for example, the numbers for August below Columbus, 195,100, and at Shadeville at the same time, seven miles below, where the number drops to 885.

In a general way the bacteriological fluctuations in this river correspond to the fluctuations given for the free and albuminoid ammonia in the chemical analysis. There is, however, not a complete parallelism between these determinations, nor is it to be expected, because, while vegetable impurities washed into the river would show in the ammonias, especially the albuminoid, their effect upon the bacteriological numbers, as already stated, would not be nearly so marked as after the addition of organic matter of animal derivation.

LITTLE SCIOTO RIVER.

The only points taken on this branch were at Marion above the outlet of a large sewer and below this outlet some few thousand feet. At this point the pollution produces a very marked increase in the number of bacteria at the lower station, and it will be noted that the figures for the two stations vary in the same direction throughout. The lowest point for the station above was reached, however, in October, which corresponds to the lowest stage of the river, and since this drop is so decided it would also account for the somewhat low point reached at the station below in this month. It was noted that at the time of sampling during this month the river was slightly higher than a month previous, though no rains had fallen in the immediate vicinity of the stations.

OLENTANGY RIVER.

In general the deductions made in regard to the Scioto river will apply to findings made on the Olentangy. Here we find the minimum number of bacteria reached in September in three cases, the maximum reached in all cases except at below Galion, at the Olentangy Park, and at the Dublin bridge at Columbus in November, the time of heavy rains. At the station below Galion, the river receives again a large amount of sewage and this amount, as in places on the Scioto, discharged into a small stream would raise the bacterial count in proportion to the lessening of the water in the stream itself. The dilution of the sewage by the November rains and a consequent fall in the number is again nicely shown at this point. The October decrease below, except at Olentangy park and at Dublin bridge, may be accounted for by the fact that at Olentangy park there is a permanent dam, and that the slack water this month reached up to the station. Below the Dublin bridge station a temporary dam had been thrown across by the water works people, giving us slack water here, and sedimentation may have brought about the lesser differences noted in this month on this river at these points. The stations above and below Delaware, again, present an anomaly from the general rule that there is an increase of bacteria below each town. It will be seen from the table and charts that in several instances the count below Delaware was less than that above, being twice positively lower, and once so little higher that it may be considered as practically the same number as that found above. The station for the first four months above was just at a ford, and it was thought that the stirring up of the river bottom which occurred during the passage of vehicles might unduly raise the count here. The next three months the station was moved about seventeen hundred feet further up stream, but here the same condition was presented in the month of November as at the Girls' Industrial Home on the Scioto. We again have several large sulphur springs pouring their water into the river between the stations, but this feature has been discussed above. It would be fair to conclude from the figures that the sewage of Delaware, which is not provided with a regular sewer system, to a large extent takes care of itself so far as bacteria are concerned, on its way through the soil to the river.

MAHONING RIVER.

An inspection of the tables and charts made out for the bacterial numbers at the stations on this stream will reveal the same general conditions found on the rivers already discussed. We have here again a rise below each city, which in some cases, as at Alliance, is very considerable, and here again the periods of lower bacterial count correspond in a general way to lower stages of the water in the rivers, whereas the higher bacterial counts come at periods preceded by rains, which have caused greater or lesser rise in the river. In general, however, the lowest point in the count has, at the various stations, been reached in the month of August instead of September, as in the other rivers. It will be noted that there is a very large difference in the numbers as obtained above Alliance and at the station below Alliance. At this town there is in operation sewage disposal works, which take care of the sewage by chemical precipitation; examinations made at the works themselves showed that so far from this method destroying bacteria or lessening the number, the effluent from the works which discharged into the river was many times richer in bacteria than the original sewage, though the curve in general runs parallel with the curve obtained above the station. In this river, too, the effect of this lessening of the numbers of bacteria in the flowing stream is very well marked. A striking case is presented by the station at Warren below, and at the next station at Niles, only three miles distant, and yet we have such an enormous drop as from 14,820 down to 3,812, or, as in another month, from 7,140 down to 599. The only anomaly presented by the curves on this river is the drop which occurs at Youngstown below in the month of November, whereas all other stations show a rise for this month, due, as already stated, to the excessive rains and rise in the river. As a matter of fact, the river here showed nearly the same number as it did during the month of July. At this point the river has doubtless received a large quantity of sewage, and possibly dilution of this mass by the increased influx of water would partly account for the figures; possibly the refuse from tin and other mills in which acid is used, and which finds its way into the river, has caused destruction of the bacteria. The sources of pollution on this stream are admirably given in the report of Prof. Brown.

In support of some of the statements made above, a few authorities may be cited, though it is not the purpose of this report to present anything approaching a treatise on water examinations. Our finding that the low stages of the river correspond to low bacterial counts, is in general accord with findings of other workers, and I think is substantiated with reasons given above in connection with presentation of these figures. Frankland finds the same facts in an examination of the rivers Thames and Lee, extending over almost a whole year, and Miguel (quoted by Frankland), working on the Seine, the Marn and the Orequec, had similar results. That exposure of water to light and air causes a diminution of bacteria, has been substantiated by the observations of many workers. With regard to sedimentation, the belief was expressed above, and reasons given for same, that this did not play a considerable role in the purification of our streams. It is possible that such sedimentation should take place in waters which flow in a quieter way through deeper channels, less broken than our rivers present, and the results of Rafter, who found greater number of bacteria at greater depths of water, are not questioned; but, on the other hand, Russell (quoted by Frankland) found in sea water at a hundred meters, one time 260 bacteria, at another 20, at another 5, per cubic centimeter; and in another table which he gives, he found more bacteria at fifty meters than at any greater depths at which he examined. In fact, there can be made out no constant relation in these places between the number of bacteria and between the depths.

Frankland, examining the reservoir used for one of the London supplies, found a considerable diminution in the number of bacteria in a large reservoir, but here all of the water had been in the reservoir at least one month and much of it as long as six months; and while there is an unusual length of time given here for sedimentation, still others factors, as exhaustion of the water as a culture medium, together with its exposure to air and sunlight, might be invoked as having assisted in the diminution of bacteria.

To sum up the results: it is found from the tables presented that every town, with the possible exception of Delaware, adds very materially to the contamination of the river as it is received by such town, and that at a few stations only is the water of such bacterial purity as would let it be considered a safe potable water, and this occurs at any of the stations only at certain times. At all of them the bacterial count is occasionally, during periods of heavy rainfall, raised to such an extent as to make them suspicious and in most of the cases to allow of their being called positively dangerous for use. At the head waters of the streams were encountered, during the dryer months, or even in months including only moderate rainfall, fair conditions, as measured by the bacterial content. But notwithstanding the purification which occurs in the streams in flowing, the subsequent pollution is sufficient to keep the water above what might be taken as the normal limit for the number of bacteria in a safe water. This condition is reached on the Scioto river at a few stations only, as at Wyandotte Grove during the months of August, September and October, and at Jones' Dam. On the Olentangy river we have this reached practically once only, in the month of September, at Delaware above town. On the Mahoning river a safe figure is reached twice only, and this at Warren above town during the months of August and September, and possibly once at Niles in September.

In fixing a number which should be taken as a normal for these streams, that is a number which would represent the water in a high degree of purity, some difficulty is encountered, because the standard so taken must of necessity be more or less arbitrary. It has been attempted to fix a number which should form such a basis for waters in general, and any variation above this number would then mean a contamination injurious in its effects on the health of persons using such polluted waters; but obviously what would be a fair standard for any one locality might be too high or too low for another locality where it is known that the bacteria present in the water come from ordinary sources and are not injurious, as from air and from the varying amounts of innocuous vegetable matter which will reach such streams. In the cases presented here, however, a standard may be set up by considering the samples at the head waters during the dryer months when they were at their best. Considering in this way the Olentangy river, we find that in August, which may be taken as a fairly representative month so far as general conditions go, the bacterial count did not exceed 250 per cubic centimeter, and this was in fact improved upon in September, and this figure of 250 should therefore not be exceeded at any place in the river if the water is purifying itself as rapidly as it is being contaminated; a condition, however, which is not found anywhere below, except that it is closely approximated once at Delaware. For the Little Scioto, no data about the head waters are available. On the Scioto river one may take the station above Kenton as a point for fixing our standard, although on account of the vicinity of some houses here, all sources of pollution are not certainly excluded, and taking the numbers presented by our dryer months, 300 bacteria per c. c. would be fixing a not too severe standard; and on this river, again, we find that all along its course the pollution is so much greater than can be disposed of by the agencies acting in this direction that only at one station do we find a return to the normal degree of purity. In attempting to fix a standard for the Mahoning river we had the station at Alliance above town, and as appears from the report of Prof. Brown, the water here is not above suspicion of pollution, and that there is such pollution is shown by the enormous accession of bacteria caused by the rains. Taking here, however, as our standard the least number of bacteria found in the month of August, when they reached 250 per c. c., a fair requirement for this stream would be not to exceed 275 per c. c. The water should then be found not richer in bacteria than this number, and notwithstanding the marked effect of purification in this stream by ordinary causes, a purification which may be assisted by the numerous dams which may be found in its course, which are opened frequently to let out the stored water, we here find again that at only one station, and then only twice during August and September, at Warren, has the original purity of the water been regained, and in these instances even surpassed. At other points, except twice at Niles, the river is far in excess of the standard in bacteria, and it is shown here, as in the other rivers, that the sewage pollution is traceable and manifest throughout the course of the stream as far as examined.

REPORT ON

Stream Gaugings and Sources of Pollution

of the

Scioto, Olentangy and Mahoning Rivers.

By C. N. BROWN.

The object of the summer's work was to find the minimum flow or discharge of water in the Scioto, Olentangy and the Mahoning rivers at several points along their course, usually at or near some considerable sized city or town. This information is a part of that necessary to determine whether or not a stream may be utilized as a source of potable water or as a receiver of sewage.

The season has been very favorable for securing very small flow in the streams on account of the prolonged period of drouth that extended over the entire State during the latter part of the summer and the fall. But the observations of a single season should not be accepted as giving the extreme minimum until the observations have been carried over several years.

The following is submitted as the final report of the gaugings of the flow of water in the Scioto, Olentangy and the Mahoning rivers during the months of August, September and October of 1897:

SCIOTO RIVER.

Kenton. Station Scioto, 302.5. Drainage area=153 sq. mi.

		Cu. Ft. per sec. per sq. mile of basin.
Aug. 17	2.52 million gallons per day=	.025
Aug. 27	3.54 " " " " =	.036
Sept. 18	1.43 " " " " =	.014
Oct. 3	1.47 " " " " =	.015
Oct. 30	1.71 " " " " =	.017

Marion. Station Little Scioto, 280.5. Drainage area=109 sq. mi.

		Cu. Ft. per sec. per sq. mile of basin.
Aug. 13	1.45 million gallons per day=	.0206
Aug. 27	1.15 " " " " =	.0164
Sept. 18	.61 " " " " =	.0085
Oct. 2	1.08 " " " " =	.0153
Oct. 30	2.81 " " " "	(Thrown out.)

Columbus. Station Scioto, 240. Drainage area=1,070 sq. mi.

		Cu. Ft. per sec. per sq. mi. of drainage area.
Aug. 5	62.66 million gallons per day=	.091
Sept. 17	2.91 " " " " =	.0042

It was learned some days later that Jones' dam had been opened and the water drawn out, so as to repair the dam, and again closed very shortly before this gauging was made. It is therefore less than the normal flow of the river at this time.

Oct. 1	1.31 million gallons per day (A)=	.0019
Oct. 1	3.12 " " " " (B)=	.0045

Note.—Gauging "A" was made just above the waterworks intake and all of the water was going into the intake. Gauging "B" was made just above the slack water above the Fishinger dam, not far above the Wyandotte grove. The difference is due to the dams between the two points.

On October 1st, and for some weeks after, the bed of the Scioto was perfectly dry in many places below the waterworks intake. There was no surface flow, but water stood in pools, and there was no doubt a sub-surface flow through the gravel. The flow of the stream was not at all uniform, on account of the very irregular way in which the water was discharged from the numerous mill dams in the twenty miles of river above Columbus. I would estimate the minimum flow to be near three million gallons per day, or .0043 cubic feet per second per square mile of drainage area.

Shadeville. Station Scioto, 227.5. Drainage area=1,670 sq. mi.

		Cu. Ft per sec. per sq. mile of basin.
Aug. 6	152.13 million gallons per day=	.141
Sept. 16	20.00 " " " " =	.0185
Sept. 30	24.44 " " " " =	.0227

The September 16th gauging is probably too low because of the large amount of floating material in the water catching on the meter vanes and therefore causing it to indicate a lower velocity than existed. The September 30th gauging was not troubled with the floating material and is of more value. Daily readings were taken to the surface of the water and the fluctuations are shown on the diagrams. The lowest flow was on October 30th, but no gauging was obtained on that date. It probably went as low as 16 million gallons per day, or .015 cubic feet per second per square mile of drainage area.

OLENTANGY RIVER.

Galion. Station Olentangy, 306. Drainage area=29 sq. mi.

		Cu. Ft. per sec. per sq. mile of basin.
Aug. 10	131,000 gallons per day=	.0135
Aug. 31	124,000 " " " =	.0128
Sept. 18	11,000 " " " =	.0011
Oct. 4	47,000 " " " =	.0048
Oct. 30	29,000 " " " =	.0030

At the last three gaugings the entire flow was sewage only, as the stream was entirely dry above the mouth of the sewer, which was about one hundred and fifty yards above the gauging station.

Columbus. Station Olentangy, 238.5. Drainage area=523 sq. mi.

		Cu. Ft. per sec. per sq. mile of basin.
Aug. 5	35. million gallons per day=	.104
Sept. 17	7. " " " " =	.0207
Sept. 30	4.77 " " " " =	.0141

The dam at Olentangy Park, Columbus, was emptied for repairs and then closed, during the month of October, therefore no gauging was made in that month.

MAHONING RIVER.

Alliance. Station Mahoning, 531.5. Drainage area=82 sq mi.

		Cu. Ft. per sec. per sq. mile of basin.
Aug. 18	9.47 million gallons per day=	.201
Sept. 26	1.58 " " " " =	.0336
Oct. 10	1.55 " " " " =	.0320

Warren. Station Mahoning, 496. (Also at Stations 500 and 504). Drainage area=596 sq mi.

Aug. 20	95.09 million gallons per day (Sta. 496)=	.247
Sept. 25	67.24 " " " " (Sta. 496)=	.174
Sept. 26	60.68 " " " " (Sta. 500)=	.157
Oct. 9	13.68 " " " " (Sta. 504)=	.036

The gaugings at Warren are very misleading and unsatisfactory because of the many mill dams on the river above the town.

The gauging of Aug. 20 is, probably, not far wrong, but may be somewhat too large.

Those of Sept. 25 and 26 are both very much too large.

The Sept. 25 gauging was made in Warren at the same point as that of Aug. 20, but it was found after the measurement had been made that a large flouring mill, run by water power, was situated some distance above the gauging station, and that the flow obtained on that day was only the water used by the mill in running its water wheels, and that no water was running over the mill dam. On the next day, Sept. 26, another measurement was made at a point four miles up the river and above the mill and the Warren water works with the expectation that a normal flow would be obtained. But on the next trip, Oct. 9, it was learned that the mill dam at Leavittsburg, which is above the gauging station of Sept. 26, had been opened on the afternoon of Sept. 25 for the purpose of draining the pool above the dam so as to repair the dam, and that nearly five days were required to empty the pool. Therefore, the large flow obtained on Sept. 26 was the surplus water from the Leavittsburg dam and does not in any way represent the normal flow.

The Oct. 9th gauging was taken above the Leavittsburg dam, which was then closed, and above the mouth of a large tributary, Eagle creek, which comes in from the north and below the mill dam at the town of Newton. Both the main stream and Eagle creek were gauged and the result given is the sum of the two. This is also too large because the mill at Newton was running and was using more water than the average flow, the miller having stated that the pool behind the dam was being drawn down quite rapidly.

It has been impossible to secure any gaugings at Warren which would themselves represent the normal minimum flow of the stream.

Taking all the conditions into consideration an approximate estimate of 6 million gallons per day may be given as an outside figure of the actual minimum flow for this season, or .017 cubic feet per second per square mile of drainage area.

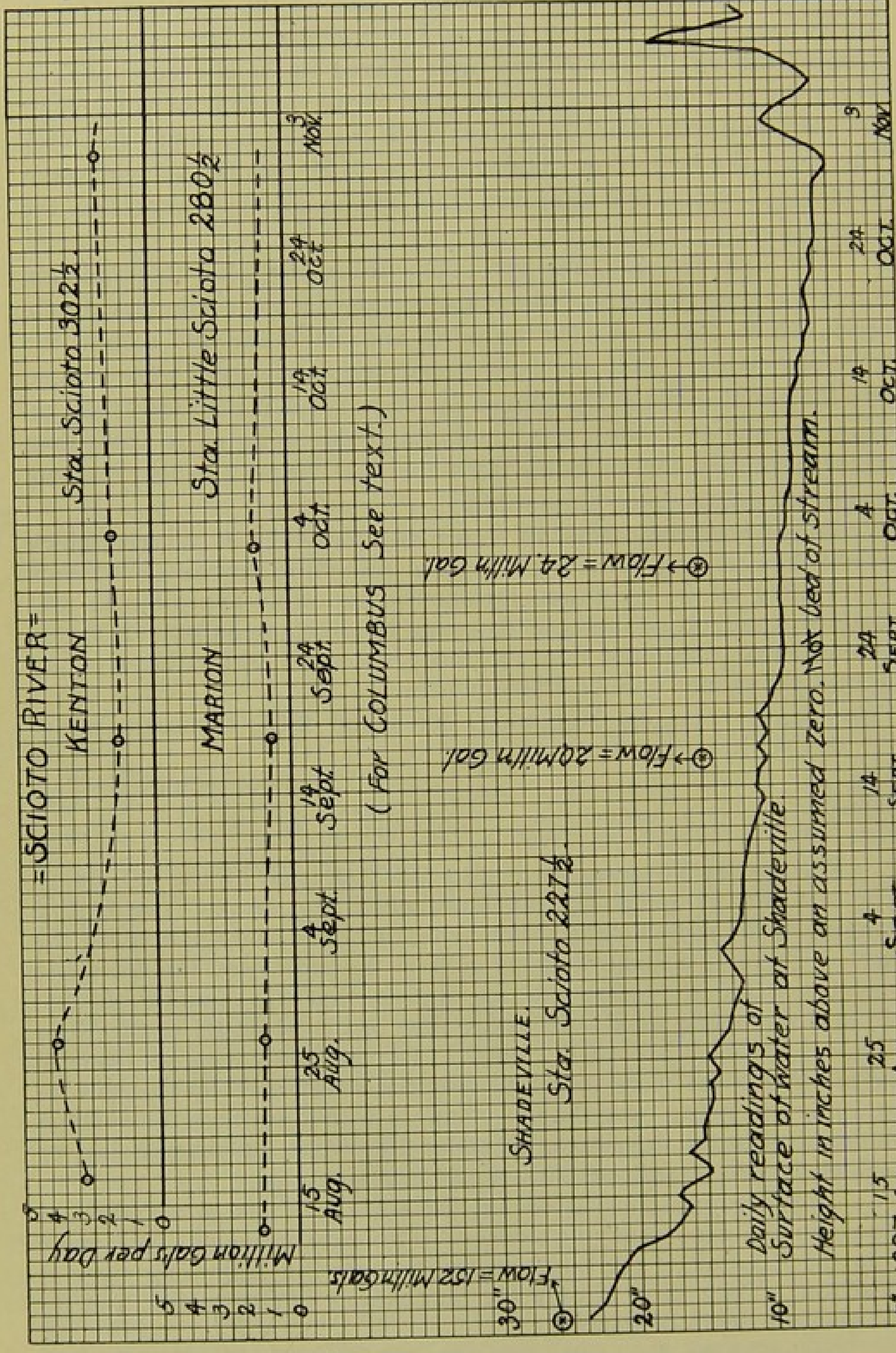
Youngstown. Stations Mahoning, 408.5 and 480. Drainage area= 967 sq. mi.

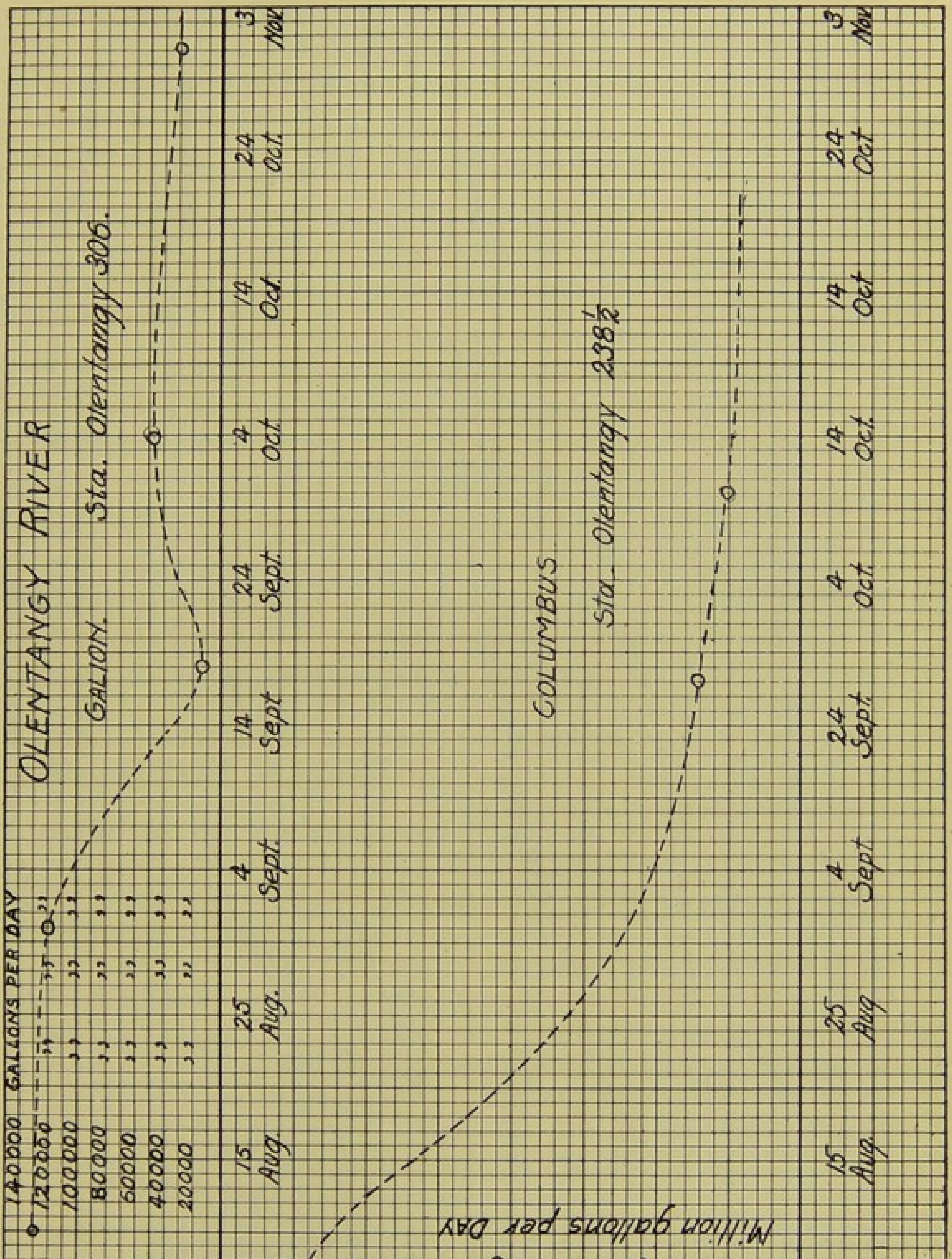
Aug. 26	91.	million gallons per day.
Sept. 25	22.9	" " " "
Oct. 9	17.9	" " " "

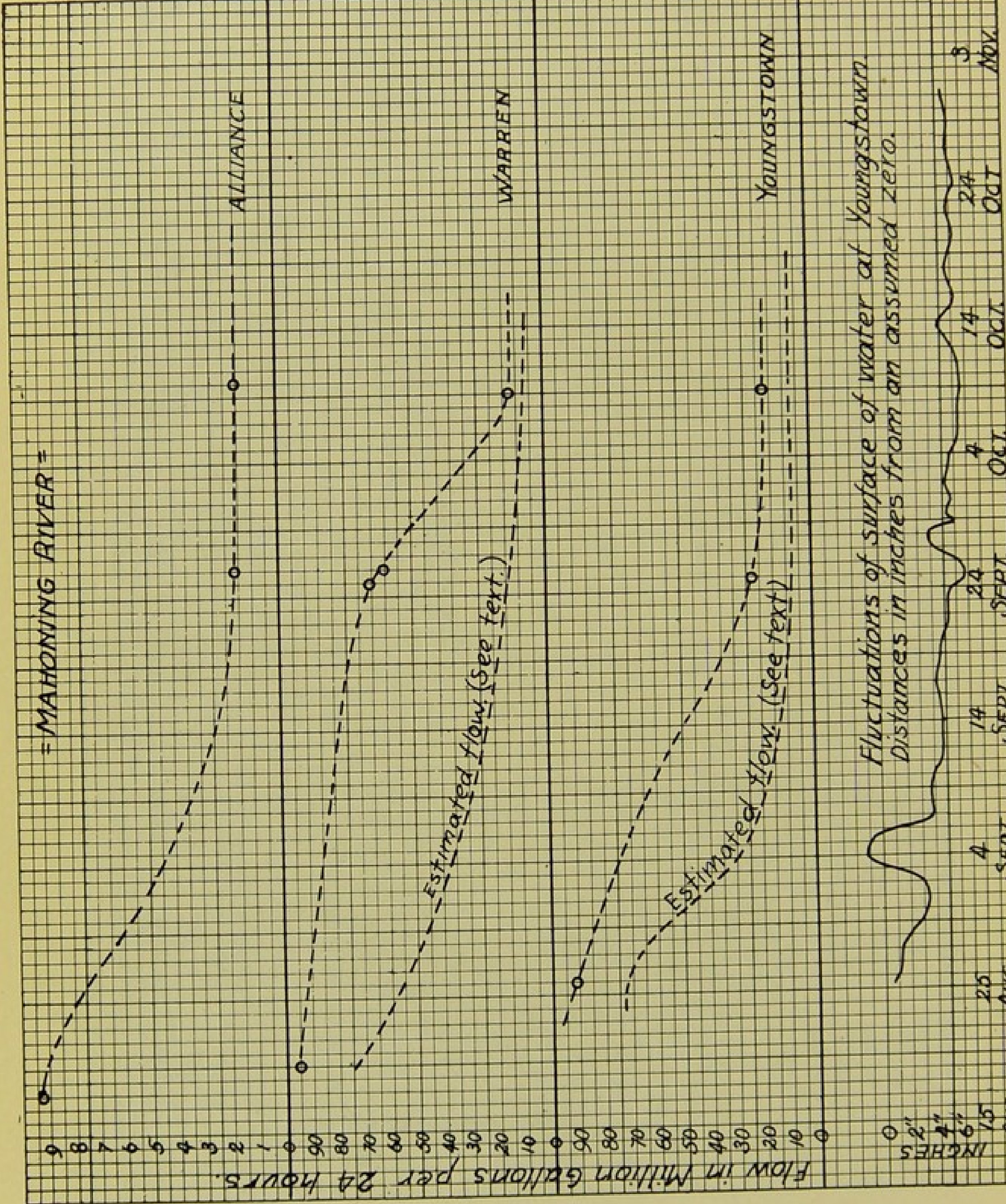
The flow at Youngstown is also much affected by the mill dams. The last two gaugings are no doubt much too large. The Oct. 9 gauging is probably nearly, if not quite, twice the average flow for the day. There is a large flouring mill in Youngstown, run by water power, situated above the gauging station, that was running on Oct. 9th and was using nearly the entire flow of the 24 hours in the 10 or 12 hours in which it used the water. The gaugings were all made in the afternoon and were therefore only the water used by the mill, as no water was going over the mill dam. I would estimate the average minimum flow for this season at about 10 million gallons per day, or .026 cu. ft. per second, per sq. mile of drainage area.

Daily readings were taken of the surface of the water and are shown in the accompanying curves. The measurements were made from the handrail of the highway bridge over the Mahoning river at Haselton. They show simply the fluctuations of the surface and do not give the depth of water.

The following diagrams or curves giving a graphic representation of the quantity of water flowing, are plotted from the above tables and are self-explanatory:


=SCIOTO RIVER=
KENTON
Sta. Scioto 302½.
MARION
Sta. Little Scioto 280½
(For COLUMBUS See text.)
SHADEVILLE.
Sta. Scioto 227½.
Million Gals per Day
Flow = 152 Mill'n Gals.
Flow = 20 Mill'n Gal.
Flow = 24. Mill'n Gal.
Daily readings of
Surface of water at Shadeville.
Height in inches above an assumed zero. Not bed of stream.
30"
20"
10"
5"
1897 Aug 15
25 Aug
4 Sept.
14 Sept.
24 Sept
4 Oct.
14 Oct.
24 Oct.
3 Nov


OLENTANGY RIVER
GALION. Sta. Olentangy 306.
COLUMBUS Sta. Olentangy 238½
140000 GALLONS PER DAY
120000
100000
80000
60000
40000
20000
Million gallons per day
30
20
10
0
15 Aug.
25 Aug.
4 Sept.
14 Sept.
24 Sept.
4 Oct.
14 Oct.
24 Oct.
3 Nov.


= MAHONING RIVER =
ALLIANCE
WARREN
YOUNGSTOWN
Estimated flow (See text.)
Estimated flow. (See text.)
Fluctuations of surface of water at Youngstown.
Distances in inches from an assumed zero.
Flow in Million Gallons per 24 hours.
INCHES
15 AUG.
25 AUG.
4 SEPT.
14 SEPT.
24 SEPT.
4 OCT.
14 OCT.
24 OCT.
3 NOV.

The maps transmitted with this report show the location of the points where gaugings were made, samples of water gathered, the location of sewer outlets, water works, intakes, etc., etc.

Following is a description of the methods used in gauging, and other points that may be of interest or value to the Board or to others that may undertake this or similar work.

THE METHODS USED IN DOING THE WORK.

The best natural cross section on a straight portion of the stream at or near the point where the gauging was desired was selected. At some points it was found necessary to change the gauging station from that first chosen because of the change of shape of the cross section and the reduction of the velocities due to a decrease of the amount of water flowing. This was done on the Scioto at Shadeville and Columbus, on the Olentangy at Columbus, and at Youngstown and Warren on the Mahoning.

Daily readings of the level of the water surface were taken at two points only, viz.: at Shadeville on the Scioto and at Youngstown on the Mahoning. Unless much work is done in dressing up the channels of the streams the daily readings are of little value for determining the volume of the very small flow of large streams, and in this work very little was done in the way of dressing the beds and banks of the streams or in the building of permanent works to make measurements from.

All of the gaugings, except those at Galion on the Olentangy, were made by using a Buff & Berger No. V current meter for measuring the velocities of the water in a measured cross section of the stream.

The meter was rated three times during the progress of the work and the rate found to change slightly with use. The rating was done in an open reservoir of still water, on a specially prepared car and track, 150 feet long, belonging to the department of Civil Engineering of the Ohio State University. The meter would record a minimum velocity of .06 feet per second. The meter worked very satisfactorily in clean water, but not so well in the filthy water filled with solid sewage matter and grass blades or small floating water plants that were found at several of the gauging stations, because the construction of the instrument is such that these floating matters caught and held on the vanes of the meter wheel and retarded or stopped it. I do not know of any other meter of equal sensitiveness that is any better designed in this respect.

Several methods of reaching the various points of the cross section where the velocities were desired were tried and are briefly described below.

Row boats were used at Shadeville twice and at Youngstown once. At Shadeville the boat was held steady by two assistants standing in the water at the stern of the boat while the observer worked over the bow of the boat and the recorder was on shore. The boat was held very steady and the plan was satisfactory for this work in water not more than four and one-half feet deep.

At Youngstown the boat was held by a rope about 100 feet long and attached to an anchor in the center of the stream above the gauging station, and by an assistant in the stern of the boat with two pike poles, the observer working over the bow and the recorder being on the shore. In both cases where a boat was used a tape line was swung across the stream above the water for the purpose of measuring the width and for locating the soundings and the points where the velocities were taken. The Youngstown method of using a boat was not satisfactory as the boat could not be held steady enough and it was not again used.

At Warren a light uncovered spring wagon, drawn by one horse, was tried once with very satisfactory results at that place. It could not be used at many places on account of steep banks. The wagon was driven alongside of a tape line swung across the stream and the observer worked from the back of the wagon.

At Marion a rough foot bridge was built across the stream and all measurements were made from it. It stood all summer and was most satisfactory.

At Kenton the stream was so narrow that a single heavy plank was used as a foot bridge and answered the purpose well all summer.

At Alliance a temporary foot bridge on movable trestles was used once with good satisfaction.

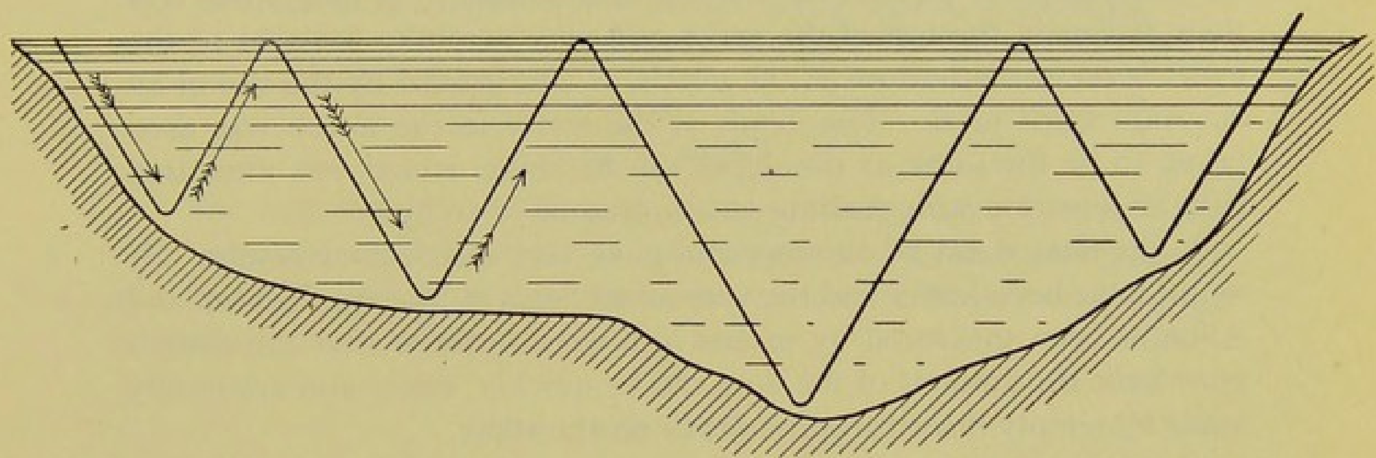
During the latter part of the summer the boats, wagon and temporary foot bridge were abandoned and the observer waded the stream, using high rubber boots, to make the measurements of velocity and depths.

This is by far the quickest and cheapest method when the water is not too deep, but in all cases the permanent foot bridge is very much the best method and should be used when circumstances will permit. It will not often happen that highway or railway bridges will be so situated as to be used for the minimum flow work, but they can usually be found so located as to be available if the maximum flow should ever be desired.

In every case a tape line was stretched across the stream for the purpose of locating the soundings and the points at which the velocities were observed. In the wide streams soundings and velocities were taken at five foot intervals and in the small streams they were taken at one or two foot intervals. Depths were measured with a two-foot rule or were read on the handle of the meter, which was graduated to tenths of a foot. In large streams the depths were read to tenths of a foot and in small streams to one quarter of an inch.

After a number of experiments it was determined that a period of two minutes was sufficient for a run of the meter at a point to determine the velocity, and this was usually used. The readings were duplicated at each point and when not checking were reduplicated. The time period was determined by a stop watch, reading to fifths of a second, in the hands of the recorder. The observer gave a signal when starting the recording mechanism of the meter and the recorder started the watch, then at the end of the chosen period the recorder signaled and the observer threw the recording mechanism of the meter out of gear, thus obtaining the number of turns of the meter wheel in a given time.

The average velocity at each point was determined by "integration," that is by moving the meter slowly and uniformly along a vertical line from the surface to the bottom and back to the surface several times during the period it was recording. The attempt was made to "integrate" the entire cross section by moving the meter at a slow uniform rate along a zig-zag line in a vertical plane, as shown in the figure. But satisfactory results could not be obtained in this way and the method was not used.



The area of the cross section was calculated by dividing it into triangles and trapezoides. The velocities averaged for each portion and the flow through each portion thus obtained. The total flow was the sum of these parts. The flow was calculated in cubic feet per second and then reduced to millions of gallons per day by multiplying by the decimal 0.646.

At Galion on the Olentangy the stream was so small that it could not be gauged by the above method, so a dam with a notch was built and the flow of the stream determined by the weir formula.

The formula used was taken from Trautwine's Engineer's Pocket Book, and is as follows:

$$Q=3.33\ L\ H^{\frac{3}{2}}.$$

Where

Q=Cubic feet per second.

L=Length of weir in feet.

H=Head or depth of water on weir in feet.

The above formula is given for the condition of no end contractions and requires that the length (L) be reduced by one-fifth ($\frac{1}{5}$) of the head (H) when there are two end contractions, as existed at this place. The formula modified to suit the conditions as existing at the Galion weir would then become,

$$Q=3.33(L-\tfrac{1}{5}H)H^{\frac{3}{2}}$$

Where

Q, L and H have the same values as given above.

The dam was built of tongued and grooved flooring plank driven in the bed of the stream with the tops resting against a 2 in. by 4 in. wale piece reaching from bank to bank and strengthened by heavy stakes and props on the lower side. No trouble was experienced in making the dam water tight. The bed of the stream was protected from the overflow by brush held in place with stakes and stones.

The notch was rectangular and was $7\frac{1}{16}$ inches long, equal to 0.588 feet. The notch was cut in a sheet of iron about $\frac{1}{8}$ inch thick which was bolted to the planks forming the dam. A strong stake was driven in the bed of the stream about five feet above the dam and cut off just below the level of the bottom of the notch. A long spike was then driven in the top of the stake and very carefully brought to the exact level of the bottom of the notch, as determined by the use of an accurate spirit level. The depth of the water in the notch was then taken to be the same as the depth on the stake, which was measured with an accurate scale reading to hundredths of an inch.

The dam stood all summer and gave very satisfactory results. It might have been better had the very small flows at Marion, Kenton and Alliance been measured by means of a weir, because after the dam is once built the amount of the flow can be quickly, easily and accurately made by simply measuring the depth on the stake.

INFLUENCE OF MILL DAMS.

When the streams became very low in the month of September, very marked irregularity was noted in the flow of the Mahoning river, although there had been no rain. Investigation showed that this was due to the numerous mill dams on the river and its tributaries.

The irregularities were due to two causes connected with the dams.

First.—The mills using the water stored behind the dam did not run continuously. While running they would use more water than the normal average flow and thus lower the level of the pool until it was much below the crest of the dam. When stopping for the night, or sometimes for several days to permit the pool to fill, the flow just below a dam would almost disappear.

Second.—Some of the dams needed repairs and the owners took advantage of the low water to make them. The pool behind the dam would then be drained and send quite a wave down the stream. The dam at Leavittsburg required nearly five days to empty and the wave is well marked in the readings taken to the surface of the water at Haselton, see Sept. 28 on curve. When the repairs were completed and the dam closed so as to fill the pool again the flow below the dam would be practically destroyed. Although by going down stream below other dams in use a flow would be found, it consisted only of the water used by the mills at the lower dams and was drawn from the supply stored in the pools behind them.

The influence of the dams makes the gaugings at Warren and Youngstown on the Mahoning and at Columbus on the Scioto very unsatisfactory and misleading because they do not show the average flow of the streams at those points. An effort has been made to estimate the flow at these places and the figures are given above.

As far as known there are no dams above Kenton, Marion, Alliance or Galion, and the gaugings there may be taken as showing the normal conditions for this season.

Sources of Pollution of the Scioto, Little Scioto, Olentangy and Mahoning Rivers.

SCIOTO RIVER.

The examination of this part of the drainage area of the Scioto river was undertaken largely for the purpose of noting the amounts and kinds of pollution that would be of special importance to the Columbus water supply.

THE AREA EXAMINED.

The area includes a part of the north-west quarter of Franklin county, the central two-thirds of Union county, a small part of the eastern quarter of Logan county, the western quarter of Delaware county and a small corner of Marion county, and has an area of about 502 square miles.

The Scioto river runs in a southerly direction through the eastern edge of the district considered, and no streams worthy of note enter from the east, while several of considerable size enter from the west.

The area is a fine farming region and is under a high grade of cultivation. In parts special attention is given to cattle raising, and in parts of Union county hay is the principal crop.

The entire district is covered with a complete network of fine turn-pikes, which can always be taken as an indication of a prosperous and progressive people.

Cities and Towns.—There are no large cities or towns in the area under consideration. The largest are given below with their approximate population.

Marysville, Union county	Population	about	3200
Richwood, Union county	"	"	1500
Magnetic Springs, Union county	"	"	300
Broadway, Union county	"	"	400
Hilliards, Franklin county	"	"	500
Dublin, Franklin county	"	"	350
West Mansfield, Logan county	"	"	500
Ostrander, Delaware county	"	"	400
Prospect, Marion county	"	"	1100

There are a number of the usual small country cross-road villages with populations ranging from 25 to 100, scattered over the district, there being one or two in each township.

Mills and Factories.—There are no manufacturing establishments of any size in the area and those that are found are mostly grist and saw mills, planing mills, tile works and such like that make no objectionable refuse. No tanneries were heard of, and only a few slaughter-houses, which will be mentioned in detail below.

Public Institutions.—The principal public institution is the State Hospital for the Insane, in Columbus. This large institution is a constant menace to the purity of the Columbus water supply.

The Girls' Industrial Home in the south-west corner of Delaware county, and about 18 miles above Columbus, is directly on the banks of the river and turns all its sewage into the stream.

The Union county infirmary and the Union county Childrens' Home both drain sewage into Mill creek, which is a tributary of the Scioto river. Both of these institutions are small.

Salt Springs.—Inquiries were made for salt springs or wells but none were located. In two or three places deep wells have been bored hunting salt, but no flowing salt wells could be heard of. Several flowing wells were found but none of them were saline.

Population.—The population of the district has been estimated from the 1890 census as 27,700, or as 55 per square mile. The density of population for the entire state, (1890) including all cities was 90.1 persons per square mile. If all cities of 1000 and over be excluded the rural population was about 50 persons per square mile. Inasmuch as there are only three towns over 1000 (Marysville 3200, Richwood 1500 and Prospect 1100) in this district, and the people are mostly farmers or in some way directly dependent upon farming, the population is now probably very nearly the same as in 1890. About 33% of the population is gathered into towns and villages. Only one of these towns, Marysville, has a public water supply and none of them has a system of sewers.

Following is a detailed description of places examined:

Dry Run.—Starting from Columbus and proceeding up the river the first tributary is Dry run entering the river through the western part of the city. This small stream empties into the river at a point about one mile above the water works intake. It drains an area of six or seven square miles, which includes a small part of the sparsely settled portions of Columbus and the grounds of the State Hospital for the Insane. The greater part of the basin is flat farm lands. The only objectionable point in the basin outside of the city is a small slaughter-house on the head of one of the small branches and located in the north-east corner of Prairie township, Franklin county. It is about five and one-half miles from the mouth of the run.

State Hospital for the Insane.—This large state institution has Dry run passing through its grounds, makes use of it as a carrier of most of its surface drainage and may at times send its sewage to the same channel.

The drainage from the hospital comes from the following several sources:

1. General surface drainage of lawns and roads.
2. Surface drainage and wash from hog-pens and slaughter houses.
3. Drainage from gas works.
4. Wash water from laundries.
5. Sewage from baths, water-closets, kitchens, etc.

1. The general surface drainage from lawns, roads, etc., is divided between Dry run and Broad street. There is of course no objection to this drainage.

2. The surface drainage and wash from the hog-pen and the slaughter-house all goes directly into Dry run and must be objectionable. At the time of my visit, May, 1898, there were about 150 hogs confined in the pens and fed on the garbage from the hospital and on the refuse from the slaughter-house, which stands inside the pens and on ground that has a steep slope into the run. The slaughter-house is used twice each week during the summer, but three or four times each week during the winter, from September to March.

3. The drainage from the gas works is emptied directly into the run, but is of course small in amount.

4. The wash water from the large laundries is drained directly into Dry run through a large sewer pipe. The water noticed was quite foul looking and a considerable mass of filth had accumulated about the mouth of the drain. It was strongly stated, by some, that no sewage was permitted to enter this drain, while others stated that under certain conditions sewage would be and had been discharged through this drain.

5. The true sewage is supposed to be pumped to the Scioto river

at the Mound street bridge, in the lower part of the city of Columbus.

The sewage is gathered from the buildings into a main sewer about 20 inches in diameter, which empties into a large catch-basin not far from, and just east of, the north end of the main building, or just at top of the bluff and on the north side of a road that leads down to the pure water pumping plant. From the bottom of this catch-basin another pipe leads to the sewage pumping station on the grounds of the Institution for Feeble Minded, on the south side of Broad street. From there, together with the sewage from the Institution for Feeble Minded, it is pumped to the Mound street bridge. It was stated that this sewage pumping station and pipe line had never been clogged or disabled since its establishment, many years ago. In the catch-basin mentioned above there is a coarse screen over the mouth of the outlet pipe. This screen intercepts any large solid matters that might clog or injure the sewage pump. The principal objects caught are large pieces of paper, rags and at times entire garments and other articles that the patients of the hospital may dispose of or destroy by throwing them into the closets or sinks. This screen is supposed to be cleaned about three times per day by the engineer of the pure water pumping station. If the screen is neglected it will soon become entirely clogged and water tight, and will hold the sewage in the basin. It was stated that when the sewage reached a certain height in the catch-basin it would back up the sewer and then overflow into the drain from the laundries to Dry run. It was also stated that a former engineer had neglected the screen, and had been reported several times by the Columbus sanitary police for permitting the sewage to empty into Dry run; but that the present engineer had never permitted this to occur.

It seems to be true that the faithfulness of this engineer in attending to a difficult and disagreeable piece of work determines whether the hospital sewage enters the Scioto river through Dry run above the city or through the pump main at the Mound street bridge below the city.

Arlington.—About four miles above the junction of the Olentangy river with the Scioto river is the suburban village of Arlington on the east side of the river. The village is small but all the houses are fitted with all modern conveniences, and each has a water supply from wind-pumps. Four or five houses have built a sewer to carry their drainage to the river, while others drain into cesspools.

The club-house and the inn have cesspools.

The Quarries.—The large limestone quarries extend from Arlington up to Jones' Dam, a distance of nearly one and one-half miles. All the largest are on the east side of the river, although some good sized ones are being opened on the west side.

They employ a variable number of men, depending altogether upon the demand for stone for buildings, streets, etc. At times fully 300 men are employed, when all the quarries are working full.

The workmen are largely from a floating population and are housed in numerous small houses about the quarries. These houses are usually provided with out-houses with shallow or no vaults. A dashing rain washes much filth into the river. During times of low water in the summer there is doubtless great pollution of the banks of the river by the workmen, unless the river is thoroughly policed.

Hilliards.—Hilliards is a small country village with a population of about 500 and situated on the divide between the Scioto river and Big Darby creek. It is in the north-west quarter of Norwich township, Franklin county, and about four miles to the west of the Scioto river.

There are no factories or mills, and but one small creamery. It is probable that the drainage of this village would not seriously affect the river.

Dublin.—Dublin is a small country village with a population of 350, situated on the west bank of the Scioto river in Washington township, Franklin county, and about 13 miles by the river from the mouth of the Olentangy.

The village is a neat, clean-looking place, and the dwellings seem to be provided with out-houses with vaults. A street runs along the top of the river bank so that there are no houses or other buildings overhanging the river.

The ground on which the village stands slopes rapidly into the river so that all surface drainage goes quickly into the river.

There are no mills or factories except a water-power grist mill.

Farm Land in Franklin County.—The portion of the area under consideration east of the river and in Franklin county is rolling farm land drained by small streams with a rapid fall to the river. There are a few small dairies that furnish milk to Columbus, and a small amount of truck farming. The portion on the west of the river is devoted to stock raising and general farming. Along Hayden's run, which empties into the river about two miles below Dublin, are a number of large hog-pens, used for fattening hogs, immediately on the stream.

Between Dublin and Columbus 22 barn-yards were noted on the immediate banks of the river. Some of these are small but many are large and not very well kept.

Jerome.—This small country village of about 75 people is in the eastern edge of Union county, on a small stream that flows into the Scioto river. It has no factories or other special filth producer and would not seriously affect the river.

Girls' Industrial Home.—This school has at present, May, 1898, a population of 388, including inmates and officers.

It is beautifully situated on the west bank of the river and has ten large buildings thoroughly equipped for the proper care and instruction of its 360 girls.

A complete system of water supply and sewage is provided for all the buildings and grounds. All the sewage is emptied directly into the river. The school is about 18 miles, by river, above Columbus. Samples of water were taken from the river above and below the Home sewers during the latter part of last summer for examination, and reference is here made to the reports of Dr. Bleile and Prof. Lord for the influence of this sewage upon the river.

The Home pumps the river water for laundry, bath, sprinkling and fire protection, but use the water of a large spring for drinking and cooking.

Mill Creek and Blues Creek.—Mill creek is the largest tributary entering the Scioto river within the area under consideration. Mill creek has its source in the eastern part of Logan county, flows south of east across the entire width of Union county and reaches the river in Delaware county. It has one large branch on the north, Blues creek, which heads in central Union county and joins it near its mouth in Delaware county. These two streams drain a rather flat or very gently rolling farming district in central Union county. The following villages and towns are situated on these streams :

On Mill creek—	Approximate Population.
North Greenfield, Logan county	75
Newton, Union county	200
Peoria, Union county	125
Marysville, Union county	3200
New Dover, Union county	100
Watkins, Union county	75
Belle Point, Delaware county	100

On Blues creek—	Approximate Population.
Broadway, Union county	400
Ostrander, Delaware county	400

None of these villages or towns are worthy of special mention except Marysville, which will be referred to below. The villages are all without public water supply or sewers or manufacturing establishments other than small saw mills or drain-tile works. The inhabitants are either farmers or follow some calling dependent upon farming.

Marysville.—This handsome country town is the county seat of Union county; it is the largest town in Union county, and also the largest in the area considered in this report.

It is the only town that has a public water supply. This supply is obtained from a group of small drilled wells. The town has at present no system of sewers but has the adoption of a system under consideration.

There are a number of drains for surface water from the streets and a few private sewers may be connected with them. There are a few private sewers leading directly to Mill creek, such as from the county court house and jail, from the principal hotel, and a few of the best residences. Most of the residences that have baths, water-closets, etc., drain the sewage into cesspools.

There is a flouring mill and two or three saw and planing mills in the town, but no other manufacturing plants of any size.

There are three small slaughter-houses near the town and two of them are near the creek below the town.

Marysville is about 18 miles by creek, from the Scioto river, or the mouth of Mill creek, or about 40 miles by water above Columbus.

No definite information was obtained on the subject but it is probable that Mill creek is almost, if not quite, dry during the dry summer weather.

County Infirmary.—The Union County Infirmary is about two miles north of Marysville, on a small creek that empties into Mill creek below Marysville.

The capacity of the infirmary is 150 persons, but it has never had over 80 at one time. The building has a water supply under pressure, and has baths, water-closets and laundries. The sewage first goes into cesspools and then into Crosses run, which empties into Mill creek.

Children's Home.—The home is located about one and one-half miles east of Marysville, on the south side of and near Mill creek. The home has a capacity for 44 children and has been full. It has no water supply under pressure. The drainage goes into a small run which empties into Mill creek about two miles from the home.

White Sulphur and Millville.—These are very small country villages on the west bank of the river above the mouth of Mill creek. There is nothing worthy of mention at either of them. The population of both is not over 150 or 200.

Bokes Creek.—Bokes creek is nearly as large as Mill creek, and, like it, heads in Logan county, flows easterly across Union county and enters the Scioto river in Delaware county, Thompson township.

The villages along Bokes creek are:	Approximate Population.
West Mansfield, Logan county	500
York, Union county	75
Sommersville, Union county	75
Pharisburg, Union county	75
Magnetic Springs, Union county	300

The character of the villages on, and the area drained by Bokes creek, is practically the same as Mill creek, and does not call for further mention.

Richwood.—Richwood ranks next to Marysville in size and importance. It has a population of about 1500 and is growing. It has no water supply or sewers but is considering the building of both. There are a few wood-working factories, but no large plants. The town is on the divide between the waters of three tributaries of the Scioto, viz.: Fulton, Rush and Ottawa creeks. By the shortest route by water it is at least eight miles from the Scioto river. It is not probable that its drainage at present seriously affects the river.

Radnor.—This small village of about 250 people is on the head of a small run that empties into the Scioto from the east. By the run, Radnor is about six miles from the river. There is nothing worthy of special mention.

Prospect.—This prosperous little town, of about 1100 population, lies on the east bank of the river. It has neither water works nor sewers. It has two flouring mills, two saw mills, a planing mill, tile works and bicycle works. None of these plants are large. There is one small slaughter-house.

The town is growing and will probably put in water works and sewers before many years. The surface drainage goes directly to the river. Prospect is about 44 miles, by water, from Columbus.

This is the last point that adds any notable pollution to the Scioto river until we reach the mouth of the Little Scioto.

LITTLE SCIOTO RIVER.

The Little Scioto river is one of the largest tributaries of the upper part of the Scioto river.

This stream drains an area of about 132 square miles lying in the central part of Marion county and in the south-west corner of Crawford county. The drainage area has for its northern boundary the main "divide" of the state, that dividing the waters of the lake from those of the Ohio basin. Small branches of the Little Scioto have their source within one or two miles of the Sandusky river, which drains into Lake Erie.

The basin of the Little Scioto is very flat and the streams have little fall and a sluggish current.

The basin is intersected in all directions by systems of county and township ditches, many of them very large.

The farmers use much tile underdraining and it will not be many years before the entire basin is most thoroughly drained by open and underground drains. The effects of this extensive draining are beginning to be felt and will become more pronounced as the drains are extended; the winter floods being higher, but of short duration, and the streams being nearly or quite dry in the summer and fall.

The area has but one city and one village, worth the name, within its boundaries. These are the city of Marion with a population in 1890 of 8,327 and now of between 9,000 and 10,000, and the village of Greencamp at the mouth of the Little Scioto, with a population of 290 in 1890, and of, perhaps, 350 or 400 now.

The total population of the area in 1890 is estimated at 12,060, or 91 per square mile. If Marion be excluded the rural population is about 3,730, or 28 per square mile. The average for the entire state, including all cities, was 90.1 per square mile; while if all cities and towns of 1,000 or more be excluded the rural population was 50 per square mile. It is to be noted, therefore, that the rural population of this basin is very small, and that nearly three-fourths of the entire population of the basin is gathered into a single well sewered city.

There are no manufacturing plants to be found except those in the city of Marion.

The only source of pollution to the Little Scioto river is then the city of Marion and the works in its immediate vicinity.

The mouth of the Marion sewer is about three and one-half miles above the mouth of the Little Scioto river. Samples of water were taken from the Little Scioto river above and below the mouth of the Marion sewer during the past summer, and reference is here made to the reports of Dr. Bleile and Prof. Lord, as to the effect of the Marion sewage upon the purity of the river water. From a personal inspection of the river at this point during the dry weather, I may say that if the polluted water be judged by the senses of sight and smell alone it was extremely foul.

During the past summer (1897) the flow of the river just below the mouth of the Marion sewer was at one time as low as 610,000 gallons per 24 hours, and for some weeks was only about 1,000,000 gallons per day.

A city official of Marion, who has every opportunity of knowing, stated that the outfall sewer was 18 inches in diameter and with a fall of a little less than 1 in 1,000, and that the average flow of sewage was one-fourth full. This would give a discharge of about 330,000 gallons per 24 hours. Therefore in dry weather the flow of the Little Scioto below Marion is from one-half to one-third condensed raw sewage.

Marion.—In 1890 Marion had a population of 8,327 but is growing and now has probably nearly 10,000 people.

There are several large manufacturing plants employing from 100 to 400 employees each, and there are extensive stone quarries just outside the city limits that employ a large force of men.

The city has several miles of brick and asphalt paved streets, and has a well planned system of separate sewers and storm water drains. There are at present between 14 and 15 miles of separate sewers in the city. The number of connections could not now be given but it is estimated that about 25% of the houses along the sewers were connected with the sewers and more are being connected all the time.

The system has 27 flush tanks, but all are not used except in the very dry weather; at present, May, 1898, only four are in use.

There are four fair sized slaughter-houses just outside the city limits that drain all their wastes into a large ditch that empties into the river just above the mouth of the sewer and below where the up stream samples were taken during the summer of 1897.

The city is supplied with water by a private water company. In the last report they had 15 miles of water mains and 800 taps. The average consumption was 450,000 gallons per day, with a maximum of 600,000 gallons per day. The water is obtained from shallow wells in a gravel bed near the river bank and about two and one-half miles from the city.

Bucyrus.—Bucyrus, the county seat of Crawford county, is on the Sandusky river, but has a small branch of the Little Scioto draining a portion of the south end of the city.

It was stated that a tile underdrain 12 or 15 inches in diameter drained a small part of the southern part of Bucyrus into the Little Scioto. It was stated that a few cellar drains emptied into this drain, but that no true sewage was allowed to go into it, that all the sewage went into the Sandusky river.

Greencamp.—Greencamp is a neat clean country village at the junction of the Little Scioto with the Big Scioto, and has a population of about 350. It contributes the surface wash from a few barn-yards and out-houses, but has neither sewers, water works nor manufactories making objectionable wastes.

THE MAHONING RIVER.

The Mahoning river is one of the largest and most important streams in Eastern Ohio. It drains a basin of about 1,000 square miles, rich in mineral and agricultural wealth, which are being developed by a busy and rather dense population.

The Mahoning valley is also one of the most important manufacturing centers of the state, having many large establishments producing iron and clay articles from the abundant raw materials of the region. It is also well supplied with transportation facilities, being near the Great Lakes and the Ohio river, and is also well provided with railroads.

The very favorable conditions have gathered along the lower part of the stream numerous large manufacturing plants, which have in turn drawn a dense population of work people about them. As the population has grown and the towns increased in size and number a public supply of water for domestic uses and fire protection has become necessary at several points. The people have turned naturally to the river that lay at their doors for this supply, and have made use of it at several points; but the large manufacturing establishments, as well as the towns along the banks, have thrown their sewage, manufacturing refuse and other filth into the stream until, on the lower part of its course, it is entirely unfit for domestic use, unless thoroughly purified.

It is the object of this report to locate and describe the various sources of pollution of the Mahoning river from its source to a point below the city of Youngstown.

A short general description of the stream will be given first in order to locate the principle towns and the general lay of the river.

The Mahoning river has its source in the hills of western Columbiana county, and then flows in a north-westerly direction, passing the city of Alliance at the corner of Columbiana, Mahoning and Stark counties, and near the south-east corner of Portage county.

Alliance is the first town of any size on the stream, and is the first to make use of it as a source of water supply and as a receptacle for sewage. The sewage is treated by chemical precipitation before being turned into the river.

From Alliance the stream flows a little east of north, passing through the corner of Portage county, the western edge of Mahoning county and entering the south-west corner of Trumbull county to Warren, the county seat of Trumbull county. Between Alliance and Warren it receives numerous tributaries, mostly from the west, which bring to it the drainage of about one-third of Portage county and portions of Stark, Mahoning and Trumbull counties.

The area drained is mostly rolling farm land, although some parts of the west and north are rather flat. There are no large towns in this area, except Alliance, but there are many small country villages scattered over the basin. The river, in the stretch between Alliance and Warren, about 46 miles, has six mill dams in it and furnishes power to as many small country flour mills and saw mills.

At Warren the river is used, after filtration through a mechanical filter, for a domestic water supply. This city has many sewers emptying directly into the river.

From Warren the river runs south-easterly through Trumbull county, passing the flourishing manufacturing towns of Niles and Girard at the county line.

At Niles a public water supply is obtained from shallow (60′ to 70′) wells along the bank of the stream. Some sewage and much manufacturing waste is turned into the river at this point.

At Niles two large tributaries are received, one from the gently rolling and flat country to the north, and the other, from the rather hilly country to the south.

Mosquito creek, the north tributary, is about 30 miles long and reaches well up into Ashtabula county.

After leaving Niles and Trumbull county, the stream, continuing on its southeasterly course, again enters Mahoning county, and after passing through the manufacturing city of Youngstown, and a few small towns below, crosses the state line into Pennsylvania, and finally reaches the Ohio river through the Beaver river.

Below Niles, the Mahoning receives many tributaries from both sides, which complete the drainage of a large part of Trumbull and Mahoning counties.

Youngstown uses the raw river water for a domestic supply and then adds its sewage to the polluted stream.

Mahoning River Above Alliance.—The area of the water-shed above the Alliance water works is 73 square miles. The population on the water-shed, not counting Alliance, is about 4,130 (1890 census), or 56.6 per square mile. The density for the entire state, including all cities, is 90.1, but if all cities of 1,000 and over be excluded, the rural population is about 50 per square mile. About 20% of the population of the area under consideration is gathered in small country villages, no one of which numbers over 300 persons.

The minimum flow of the river at Alliance during the summer of 1897 was 1.55 million gallons per 24 hours, or 2.4 cu. ft. per second, or .03 cu. ft. per second per square mile of water-shed.

The country drained is devoted almost entirely to agriculture and dairying, their being only a few small country coal banks in the district. There are no mills or manufacturing plants, unless the small cheese factories and creameries should be classed as such, located on the water-shed.

Some of the creameries and cheese factories were inspected and found to be kept in excellent order as to cleanliness. All the waste products are removed by the farmers in small quantities and fed to stock. I do not think that they could be considered as causing any special pollution of the stream.

There are six small country villages, none over 250 or 300 population, located on the water-shed. A few of these may be worthy of a short notice.

North Georgetown.—Population between 250 and 300. The village is near the river and steep ravines drain from it into the stream. Many outhouses, without vaults, were noticed on the banks of the ravines, and the filth from them, as well as the drainage of pig-pens and slops, would be washed into the river by a dashing rain.

There is a low dam across the river at this place for the purpose of forming a pond for fishing and pleasure boating. A small summer resort hotel stands on the banks of this pond and is frequented by picnics, excursions and summer boarders from Alliance and other cities of this part of the state. It was entirely closed at the time of my visit and nothing could be learned of its sewage disposal, etc. This point is only eight miles by the river from Alliance, and might, under improper conditions, furnish disease germs for its water supply.

Damascus.—Population about 250 to 300. The village has no special sources of pollution and is nearly one-half mile from the small stream which drains into the main river. It is not likely to affect the stream.

The other villages are all very small and quite a distance from the stream, some of them being on hilltops. Much of the surface drainage from them would pass over meadows or cultivated fields before reaching the small streams. All of these country villages have many outhouses without vaults, and so placed that much, or all, of the filth can be washed away by heavy rains.

Fairmount Children's Home.—This large children's home is about two miles due south of Alliance, and is situated on a small run that empties into the river above the city. There are about 200 persons at the home most of the time. They have a system of underground irrigation sewage disposal which has been working very well for about two years. The overflow outlet, to be used in case of a stoppage of the regular system, empties into the small run mentioned above. This overflow is very seldom used, but when it is used, it taints the Alliance water.

Alliance and East Alliance.—The city of Alliance lies along the west side of the county line, between Stark and Mahoning counties. Along the east side of the same line, in Mahoning county, is the village of East Alliance. This village has no water supply except very shallow wells, many of them flowing, and no drainage except a few open ditches. The ground upon which it stands is flat and boggy. The ditches empty into a small run in the eastern part of Alliance, which in turn reaches the river above the water works intake.

If the information given me about this run is true I would consider it a continual and very dangerous menace to the health of Alliance. I verified many of the statements, but the most important could not be checked because the work was under ground, or in, or under buildings. I saw that this run received the surface drainage of East Alliance and of a portion of Alliance, including several manufacturing and business streets.

It is reported that several private sewers, built before the present general sewer system was adopted, empty into it. Among these is the sewer from a large school-house in the eastern side of the city. The run passes through the grounds of two large manufacturing plants, employing about 1000 men. It here receives all the surface drainage, some manufacturing wastes, and it was reported that the closets of these two works were connected directly with the run.

It was also reported that a private sewer from the hotel at the railroad station brought all the hotel sewage into the run. I saw the run at a point below the factories and the hotel drain, and the appearance of the water justified the statements made above. Fragments of food and kitchen refuse showed that the kitchen slops at least came from the hotel to the run. The water was foul, black, greasy and had every appearance of ordinary sewage.

A sewer connecting with the disposal works is built along a part of the run, but there are now no connections between sewer and run, so I was told, and I saw none.

I presume that it is the intention to have the sewage go to the disposal works, but even if this is done, connections should be made to take the dry flow, at least, of the stream.

The effluent from the sewage disposal works enters the river below the water works intake.

The slaughter-houses are small and near the river below Alliance.

Summary.—The river as it comes to Alliance is, probably, free from continuous, dangerous contamination, with the exception of the small run at Alliance, and this can be remedied with little trouble or expense.

There are two other points which may at times become dangerous, viz: the Children's Home and the summer resort at North Georgetown. The population per square mile is a little greater than the average of the state, as 56.6 is to 50, but is not likely to increase. None of the country villages are growing, they are rather decreasing in number.

Mahoning River Above Warren.—The flourishing and beautiful little city of Warren, county seat of Trumbull county, is situated on both sides of the Mahoning river, and is, by the river, about 46 miles below Alliance, 6 miles above Niles, and 16 miles above the Youngstown water works.

The area of the water-shed above Warren is given by Mr. Allen Hazen as 596 square miles. The population is, from 1890 census, including all towns above Warren, but not Warren, 33,300, or 56.0 per square mile. If we exclude Alliance, the only town over 1,000, the density of the rural population is 43.2, as compared with 50, the average of the entire state on the same basis.

About 36 per cent. of the population of this district is gathered in towns, as follows:

Alliance		7,600
North Georgetown Damascus Leavittsburg	From 250 to 300 each; say	800
Newton Falls		700
37 small country villages, estimated separately and then combined		2,900
Total		12,000

The minimum flow of the river during the summer of 1897 was not well determined, but was estimated from the measurements made and the conditions existing to be about 6 million gallons per 24 hours, or 9.3 cu. ft. per second, or .015 cu. ft. per second per square mile of water-shed. (See report on flow of streams.)

The country drained is devoted almost entirely to agriculture and dairying, the only mines being those above Alliance.

The area drained can be best described by taking it in detail, as follows:

Alliance.—Alliance is a thriving and growing manufacturing town and railroad center with a population of 7,607 in 1890. It now probably numbers between 8,000 and 9,000. It has a public water supply, owned by a private company with a capacity of 4.5 million gallons per day.

The city treats its sewage by chemical precipitation before turning it into the river. This has been in operation since July, 1896, and has given very fair satisfaction. There are at present 175 connections made to the sewers and 12 flush tanks, and the flow is 300,000 gallons per day. It is claimed by the city engineer that there is a large amount of ground water leaking into the sewers. The pollution of the river by this treated sewage can be best determined from the results of the examinations made during the summer by Dr. Bleile and Professor Lord.

I may say, however, that the general appearance of the river below the sewage outlet was very good during the past summer. There was no offensive odor, no green scum or black slimy deposits on the bed or the banks of the stream. I saw small fish, said to be bass, caught in the stream at the lower edge of the town during the extreme low water.

The pollution by the small run in the eastern side of Alliance has been described above.

The Alliance slaughter-houses are few and small and not much used, but are near the river below the city.

Limaville.—At the small country village of Lexington, about three miles below Alliance, or 43 miles above Warren, the two good sized tributaries, Beach creek and Deer creek bring the drainage of the northeast part of Stark county into the main river.

The only village of any size in the basin of these streams is Lima or Limaville, about 3 miles above the mouth of Deer creek. It has a population of about 200, but has no factories, sewers, or water works.

The usual drainage from pig-pens, barn-yards, slops and outhouses without vaults, finds its way into Deer creek during heavy rains.

Newton Falls.—Going northerly, down the river, from the mouth of Deer creek we find but one village, Princetown or Milton, of about 50 persons, before reaching the little town of Newton Falls, at the junction of the west branch with the main river and about 16 miles, by river, from Warren.

The town of Newton Falls, with a population between 700 and 800, occupies a rather narrow strip of land lying between the two branches of the river. The surface is well drained into the stream. There is no public water supply (wells being used) or system of sewers. There are a few private drains from cellars and sinks, but it is claimed that no true sewage is carried away by them. Numerous outhouses without vaults, pig-pens and barn-yards were noticed on the banks of both streams, and so situated that the filth would be carried away with very little rain.

One small slaughter-house is located on the river bank and a second one stands back in fields quite a long distance from the river.

One fair-sized creamery, with pig-pens, stands immediately on the river bank just below Newton.

There is a small country grist and flour mill and dam for water-power located here. They cause no pollution worth mentioning. There are no factories or mills here.

West Fork of Mahoning River.—This large tributary enters the river from the west, at Newton Falls, and drains an area of nearly 100 square miles, lying mostly in the eastern part of Portage county. The basin does not contain a single town of 300 persons, the villages are small and scattered. The district is rolling and flat agricultural land.

No unusual sources of pollution were seen or heard of; only the usual conditions of a stream flowing through a moderately populated agricultural region were found to exist.

Eagle Creek.—Eagle creek is another large tributary from the west, which enters the river about 7.5 miles above Warren. It drains an area of 75 or 100 square miles, mostly in Portage county. The basin contains a number of small country villages, like that of West Fork, and is very much like that stream in every way. The basin may be somewhat flatter than that of West Fork. No special pollution was found.

Leavittsburg.—Leavittsburg is a country village with a population of about 300, and is situated on the banks of the river, at the mouth of Duck creek, and about 6 miles, by river, above Warren.

A grist and saw mill, with dam for water power, are situated here. There are no other mills or factories, creameries or cheese factories at this point. The village is mostly built along the high banks of the river and Duck creek, and the usual number of outhouses, pig-pens and barn-yards drain directly into the stream.

Many of the filth producing places are so near the water of the stream that a very light rain would wash much objectionable material into the river and creek. I would think the water supply of Warren might be very dangerously polluted by the surface drainage of this village.

Duck Creek.—Duck creek is about 8 miles long and empties into the river from the south at Leavittsburg. It is mentioned here because this is the stream into which a graveyard is underdrained. This graveyard is a small country burying place, of not over two or three acres extent, situated near the center of Sec. 25, Newton township, Trumbull county, or in the extreme southeast corner of Newton township. It is not near any town or village, being about 6 miles from Newton Falls.

An underdrain leads from the burying grounds into the head waters of Duck creek. This ground water would go down Duck creek about eight miles and then six miles further, or 14 miles in all to reach the Warren water works.

The graveyard is used very little indeed, and it seems to me that the little town of Leavittsburg is a source of greater danger to Warren than this burying ground could possibly become.

County Infirmary.—The Trumbull county infirmary is north of Warren, and is situated in the southeast part of Champion township, the buildings standing on the banks of a small creek known as Young's branch. The buildings are not over 1.5 miles above the mouth of the creek, which empties into the river just about 1.5 miles above the Warren water works, or the infirmary buildings are almost exactly three miles, by water, from the Warren water works.

There are two large buildings, one for men and the other for women; the combined capacity is 125 persons. The women's house is thoroughly equipped with baths, water closets, laundries and slop sinks. The sewage is led directly into Young's branch. The men's house has baths, water closets, etc., but the closets are used by invalids only. This sewage also goes directly into the small stream.

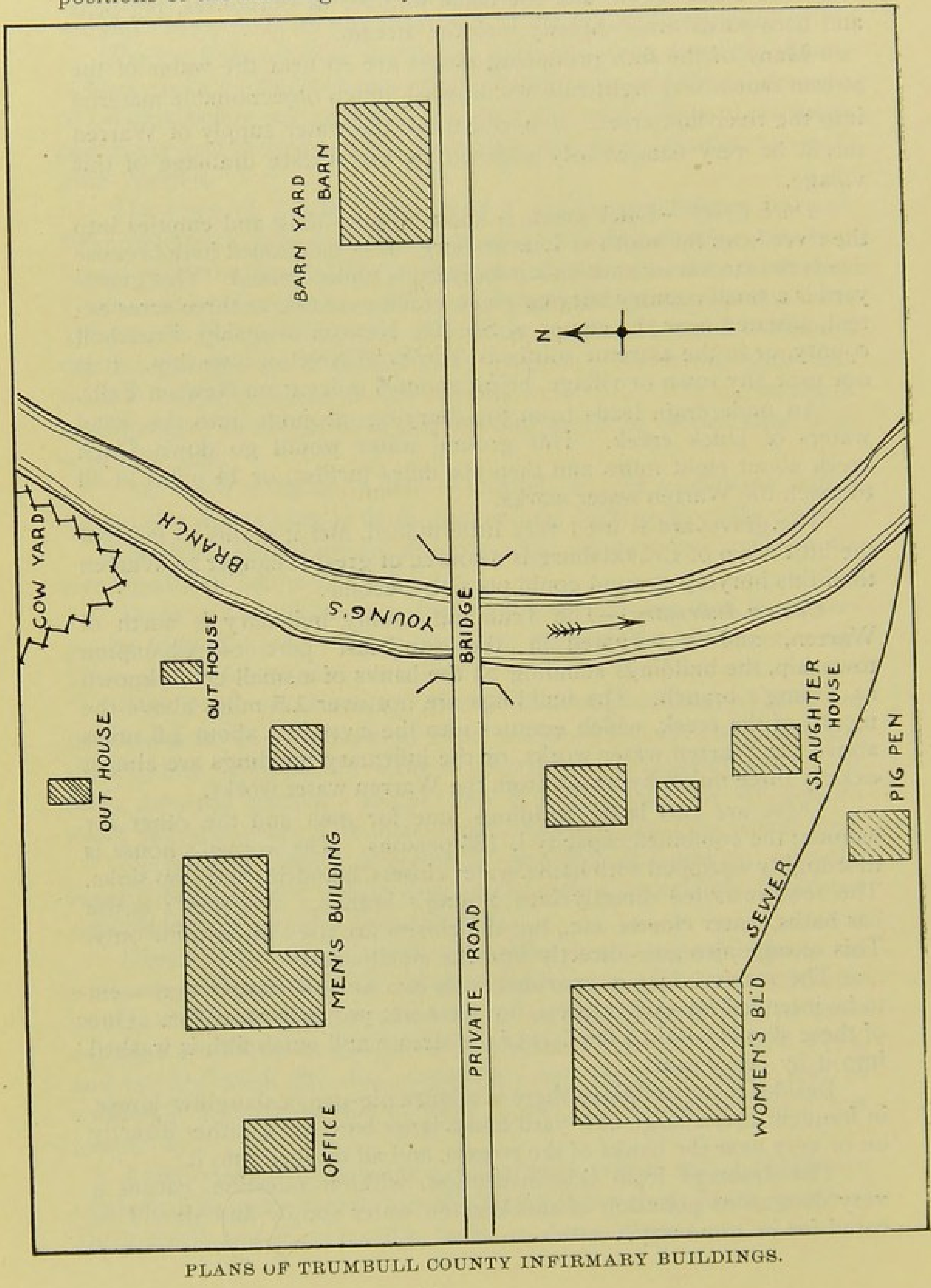
The men's house is provided with two outside closets that seem to be intended for earth closets, but were not properly cared for. One of these stands within a few feet of the stream and much filth is washed into it by every rain.

Besides these buildings there is a large pig-pen, a slaughter-house, in frequent use, a large cow-yard and a large barn-yard, either directly on or very near the banks of the stream, and all drained into it.

The drainage from this institution, without question, causes a very dangerous pollution of the Warren water supply and should be cared for in some way.

I learned indirectly that the County Commissioners have a sanitary engineer now studying the problem.

The accompanying rough free-hand sketch shows the relative positions of the buildings and yards.



PLANS OF TRUMBULL COUNTY INFIRMARY BUILDINGS.

Warren.—All of the sewers and drains from the city of Warren, except one, empty into the river below the water works intake.

There is one "storm-water" drain, or sewer, that drains the district north of the Erie railroad and east of the river, that empties into the slack water above the dam and only a few hundred feet above the dam and on the same side of the river as the intake. It was claimed that nothing but surface water entered this drain, but it was afterwards admitted that slops, stable drainage, etc., could get into it through sinks in private yards. This drain should be carried below the water works dam.

Summary.—The river, as it comes to Warren, drains an agricultural district, with only one town, Alliance, of any size within its water-shed, and it is 46 miles distant.

The points where dangerous pollution may be expected are as follows: Alliance, Newton Falls, Leavittsburg, Trumbull county infirmary, the Warren storm-water drain above the water works.

Mahoning River Above Youngstown.—The active manufacturing city of Youngstown, county seat of Mahoning county, and the center of all business of the Mahoning valley, lies on both sides of the Mahoning river, in the northeastern part of the county. The water works is about 62 miles below Alliance, 16 miles below Warren, 10 miles below Niles, and about 5 miles below Girard.

The city includes about 6.5 miles of the course of the river within its corporate limits. The city now includes the following formerly independent villages, viz: Haselton, Gibsonville, Riverview, West Youngstown, Brier Hill and Williamstown.

The water works intake is near the geographical center of the city, but somewhat above the center of population.

The area of the Mahoning basin above the Youngstown water works is about 900 square miles.

The population on the water-shed, including all towns above Youngstown, but not including any of Youngstown, is about (1890 census) 64,100, or 71.2 per square mile. A part of the city of Youngstown should be included in an estimate of the population above the water works; at least 10,000 should be added to the 64,100, making 74,100, and bringing the average density up to 82.3 per square mile, as compared with 90.1 for the entire state. Excluding all towns of 1000 and over, the rural population of this district is about 48 or slightly less than the average of the state.

About 52% of the population of the district is gathered into cities, towns and villages as follows, from 1890 census:—

Alliance	7,610	
Warren	5,970	
Niles	4,290	
Girard	1,500	
Columbiana	1,110	
Part of Youngstown, estimated	10,000	
		30,480
Canfield	700	
Newton Falls	700	
Cortland	700	
Mineral Ridge	850	
North Georgetown, Damascus, Leavittsburg, North Lima, estimated at	1,100	
54 small villages estimated separately and combined	4,130	
Total town and village population		38,660

This is equal to 52% of total population.

The minimum flow of the river during the summer of 1897 was not well determined at Youngstown, for the same reason as at Warren, the disturbing element being the numerous mill dams and water power mills on the stream. The flow at Haselton, at the lower edge of Youngstown, was estimated at 10 million gallons per day, or 15.5 cu. ft. per second.

The gauging station was below the Youngstown water works and two good sized tributaries entered the river between the two points, making the area of the water-shed above the gauging station about 930 square miles. This would make the average minimum flow of the stream at this point about .017 cu. ft. per square mile per second.

The country drained is largely agricultural, but also includes a considerable number of small coal mines in that part of the water-shed below Warren. None of these mines are now large railroad mines, but some of them do a considerable local trade.

The number of manufacturing plants has largely increased below Warren, and the drainage from them forms one of the large items in the pollution of the river.

The water-shed and sources of pollution are described in detail below.

Warren.—This prosperous little city had a population of 5,970 in 1890, and the city engineer now estimates it to have 10,000.

The city has a water supply and is well sewered. The use of water-closets, baths, etc., which require sewer connections is almost universal. The water works pumps 1.5 million gallons of water per day, and this may be taken as the quantity of sewage. To this must be added the sewage and waste water from several large manufacturing plants, which pump their own water.

The large manufacturing plants at Warren are a rolling mill, a tube works which has a galvanizing plant and turns a large quantity of waste acid into the river, a "sprinkler" works, a linseed oil mill, a paint works, an incandescent electric light works, and a large flour mill run by water power. These works employ from 100 to 400 persons each. There are quite a number of smaller works not mentioned.

The night soil of the city is carried to a depot, on high ground below the city, and mixed with lime, under cover, and then sold as a fertilizer. The slaughter-houses are few and small and not near the river.

De Forest.—De Forest is a small, new railroad village situated in the southwest part of Howland township and the northwest part of Weatherfield township, and about three miles southeast of Warren. It is on high ground and about one mile from the river. A very small run or ravine carries the surface drainage to the river. There are no sewers.

There is a good sized railroad hotel at the railroad junction, and small railroad repair shops. The population is between 150 and 200. The hotel gets water from the Warren water works, but the private houses use wells. There were quite a number of cases of typhoid fever, with a few deaths, in the village during the winter of 1896-97.

Niles.—The population in 1890 was 4,290. It is now estimated by the mayor as being between 7,000 and 7,500, he basing his estimate upon 1,500 votes cast at a recent election. The population is largely foreign working people who are employed in the many manufacturing plants of the city.

The city obtains a public water supply by pumping from a group of small wells, from 60 feet to 75 feet deep, driven in the gravel near the bank of the river, into a reservoir on top of an adjacent hill. I should think there would be great danger of getting the polluted ground water from under the city.

There is at present no complete system of sewers, there being but two in the city, the "new one" under the paved street with about 40 house connections and the "old one" built by private parties with five house connections. The house plumbing is drained into cesspools. There is a general desire to have a complete sewer system built, and as the city is growing rapidly such will probably be done in the near future.

There are several large iron works at Niles that are great sources of pollution. All of those directly on the banks of the river or Mosquito creek have their outhouses for their hundreds of employees hung over the edge of the stream so that the filth may be carried away at once by the stream. A large school house was also so provided.

There is a large tin-plate and also large galvanized iron works that discharge large quantities of chemicals into the river. These are mostly acids used in cleaning the iron plates before coating with tin or zinc.

During the low water of the summer of 1897 the river was discolored for several miles and large numbers of fish killed by these chemicals.

The two slaughter-houses are small and are situated on high ground to the northwest of the city.

The pollution from the two sewers, the outhouses of the mills and the wastes from the tin and zinc plate mills, is very great and is practically constant. This, taken with the fact that Niles is only about nine or ten miles above the Youngstown water works, would indicate a dangerous supply at the lower point .

Two large tributaries enter the river at Niles and may lessen the danger somewhat by dilution. The tributaries are Mosquito creek from the north and Meander creek from the south. These are described below.

Mosquito Creek.—This large tributary of the Mahoning river enters from the north at Niles, and is about 30 miles long and drains an area of about 125 square miles, about 20 of which are in Ashtabula county.

The basin is quite flat, at the north there being a number of extensive marshes or swamps. The southern part is gently rolling land. The entire basin is devoted to farming, stock raising and dairying.

The main creek is a clean nice looking stream and seems to have a good fall and current. It flows in a very straight line nearly due south through a broad beautiful valley.

There are several small country villages in the basin, but only one, Cortland, worthy of special note.

Cortland.—Cortland is a pleasant appearing country town, situated on a small branch of Mosquito creek, and with very little in the way of manufacturing. There is one saw mill and one grist mill and a small cheese factory that runs a part of the time. It was not in use at the time of my visit.

The usual drainage from outhouses, pig-pens, slops, etc., will go into Mosquito creek and then into the main river. Cortland is about 12 miles by water from Niles, and has a population of about 700.

Meander Creek.—Meander creek is a large tributary entering from the south opposite the mouth of the Mosquito creek. The greater part of the basin lies in the central part of Mahoning county and is about 15 miles long in a north and south direction, and has an area of about 90 square miles.

The water-shed is rolling or hilly with a broad flat valley along the stream. It is mostly used for farming and grazing land. In the neighborhood of Mineral Ridge there are a number of small coal mines. None of them are run in a large way or work many men. They furnish coal for local use only, none of them make use of a railroad market.

There are two towns worthy of note in the basin of this stream, viz.: Canfield and Mineral Ridge.

Mineral Ridge.—This village lies along the top of a high ridge and is about one mile east of Meander creek. It had a population of 850 in 1890, and has not grown since. It has neither a sewer system nor public water supply. The usual surface drainage of the country village exists, but much of it would flow over broad fields before reaching the creek. The village is about three miles due south of Niles and has an electric car line connecting the two places.

The coal mines at this place were at one time of considerable importance, but they are small affairs at present.

Canfield.—This country village has a population of about 800 and lies on the divide between Meander creek and Mill creek, another branch of the Mahoning river. It has no public water supply, sewer system or any manufacturing plants. The usual village surface drainage exists.

County Infirmary.—The Mahoning county infirmary is situated one and one-half miles northwest of Canfield, on one of the main branches of Meander creek. The buildings were burned in 1896 and new ones were nearing completion in December, 1897. The new buildings provide for the comfortable care of 300 inmates, and by a little crowding could accommodate 400. The old buildings have had 240 at one time.

The new building are provided with an abundant water supply, water-closets, baths, laundry and all modern improvements.

The sewer from the building is carried directly into the creek at a distance sufficient not to make a nuisance at the buildings.

Large pig-pens, barn-yards and small slaughter-houses also drain directly into the creek. The pollution of the stream will be greater than that at the Trumbull County Infirmary, but it is further to where the water is used, it being about 22 miles, by water, from the infirmary to Youngstown.

Salt Springs.—About one mile west of Niles, west of Meander creek and on the south side of the river, small salt springs were reported. The flow is very small and the salt solution very weak. At one time a sanitarium was built to make use of the springs for medicinal purposes, but has been abandoned.

These are the only salt springs or wells heard of in all the Mahoning Valley, and careful inquiry was made for them.

Squaw Creek.—Squaw creek is a small stream that enters the river from the east, and just above Girard. It drains much of Vienna and Liberty townships, that formerly had many fair sized coal mines. The mines have been mostly worked out and abandoned, and the population that always gathers about a mining center have gone elsewhere or turned farmers.

The main reason for mentioning Squaw creek is the park that has been recently opened near its mouth. The electric railway running from Youngstown, through Girard and Niles to Warren, opened this park for picnics, excursions, etc., from the towns along the railway. The attendance on Sundays, holidays and summer evenings amounts to many thousand persons. The sewage is thrown directly into the stream and finds its way into the river.

The park is about six miles, by water, from the Youngstown water works intake.

Girard.—Girard is a growing town of about 1,500 population, lying on the east bank of the river and about four or five miles above the Youngstown water works.

At the upper end of the town is a large slaughter and packing house that drains its waste into a ravine that empties into the river in about a quarter of a mile. Just below the slaughter-house is a large tannery, that also drains its spent liquors and wastes into the river.

Besides the above named places, there is a very large rolling mill and a large blast furnace situated directly on the river banks. The outhouses are hung over the river bank and the filth goes directly into the river. The banks are also horribly befouled by the workmen during low water in the river. Each of these works employs several hundred workmen.

The town is on hilly or very rolling ground and the private outhouses are not supplied with properly built cesspools or vaults, so that the surface drainage is very foul from the slops, laundry water, pig-pens and improperly constructed vaults.

Church Hill Creek.—This small stream enters the river just below Girard and drains the central portion of Liberty township. There were formerly many important coal mines and large villages of coal miners on the waters of this creek, but the mines are now exhausted and the villages gone, so that at present only the ordinary country drainage is found in it.

Mill Creek.—Mill creek is a large tributary from the south that enters the Mahoning river at Youngstown about one-half mile above the water works. The creek is about 20 miles long, heading in Columbiana county, and drains an area of about 80 square miles.

The town of Columbiana, Columbiana county, is on the head waters of this creek and had in 1890 a population of 1,112. It now has between 1,500 and 2,000.

At the time of my visit to the Mahoning Valley I had not noted that this town was on the water-shed above Youngstown and so did not visit it. I followed up Mill creek for nearly 15 miles, and finding only very small country villages, farming lands, no mines or manufacturing plants, I did not go to its head.

A small portion of the surface drainage of Canfield enters this stream, as has been noted in the description of that town.

North Lima.—This country village has a population of 250 or 300. There are no water works, sewers or manufacturing plants. The village is fully one and a half miles from Mill creek and the surface drainage would mostly pass over meadow lands to reach the creek.

Mill Creek Park.—The city of Youngstown has acquired a considerable strip of land on both sides of Mill creek from Idora or Lauterman Falls to a point very near its mouth, a distance of 2 or 3 miles. Drives, walks and bridges have been built along the steep sides of the ravine and across the stream and deep gullies.

The under brush is cleared out and otherwise improved. The park is well policed so that nuisances that would pollute the stream are entirely prohibited. This improvement has surely prevented a considerable addition to the pollution of the river.

Youngstown.—Youngstown lies on both sides of the Mahoning river and includes about seven miles of it in the city limits. The water works intake is about the middle of the seven miles, but the majority of the population is below the water works. The population in 1890 was 33,220, but must be well over 40,000 at the present time.

The city has a sewer system with an intercepting sewer carrying all sewage far below the water works. The sewer system yet lacks much before it will be completed and the area above the water works has very few sewers in it. The area above the water works is populated mostly by a foreign laboring class, who cannot afford to live in houses provided with modern plumbing conveniences, so there is small popular demand for sewers in the district.

The people live in small single or double houses crowded closely together on hilly ground. The slops and laundry water are thrown on the surface and drain rapidly to the river.

The health authorities realize the gravity and danger of the conditions existing and try to compel all vaults and cesspools to be built water-tight, by use of hydraulic cement, and then to be emptied at regular intervals. But a very superficial examination shows that many of the vaults are not properly constructed and cared for, while a number of outhouses on the steep slopes of the ravines have no vaults at all. I do not believe that it will be possible under the existing conditions of topography and population to prevent the surface drainage from this district being very foul sewage. It is difficult to estimate the population that contributes to this objectionable surface drainage, but I have placed the figure at 10,000 and I think it very conservative.

Above the water works intake there are four large iron and steel works, each employing several hundred men.

None of these have the outhouses over the river bank, and the Youngstown health officials assured me that they were all provided with large water-tight cesspools that were well cared for, and that they did not pollute the stream.

From all of these works I saw streams of dirty water flowing into the river; it had grease and oil floating on top and looked suspiciously like sewage, if it was not. The drainage from the large Ohio Steel Co. on the west bank of the river was especially bad, having a bad color and having in one place become stagnant and gave off very disagreeable and strong odors.

There is a flour mill run by water power a short distance below the water works, and the city water supply is drawn from the slack water above the mill dam.

Summary.—The most important and dangerous sources of pollution of the Youngstown water supply are as follows:

The upper part of the city of Youngstown. Girard: Surface drainage, tannery, slaughter and packing houses, manufactories. Niles: Surface drainage, sewers, manufactories' wastes and sewage. Warren: Sewage, manufactories' wastes. Alliance: Sewage, etc.

The smaller places have been described in detail and need not be repeated. Those named above are enough to condemn the unfiltered water for domestic use.

THE ROCK WATERS AND FLOWING WELLS OF OHIO.

BY EDWARD ORTON.

PART I. ROCK WATERS OF OHIO.

PART II. FLOWING WELLS OF OHIO.

The Rock Waters and Flowing Wells of Ohio.

By EDWARD ORTON.

In the present report the rock waters of Ohio that are derived from a considerable depth as compared with ordinary wells and also the flowing wells, or fountains, that are to be found in certain districts of the state are to be considered. Under the latter division, only those flowing wells that have a considerable head or pressure, and those that occur throughout districts embracing at least a few square miles of territory will be discussed. The number of wells, the waters of which rise to the surface or overflow feebly, is large, and there are many isolated examples of wells flowing with a considerable head, but the work of the Survey has not been conducted on a scale that will allow such cases to be treated here. The wells of the latter group are all drift wells and occur only where the drift deposits are found in thick sections, generally of 100 to 300 feet. The entire series of flowing wells, as above characterized and restricted, is confined to northwestern Ohio, and principally to the counties of Williams, Fulton, Henry, Defiance, Van Wert, Mercer and Auglaize.

PART I.

THE ROCK WATERS OF OHIO.

Our knowledge of the rock waters of Ohio as above limited has been almost wholly derived from wells drilled in the search for oil and gas, a search which has been prosecuted for the last few years with great zeal and energy through all sections of the state and particularly in northwestern Ohio. There is not a county in the state in which one or more wells have not been sunk in this interest during the last fifteen years, and in many counties such wells have been drilled by the score and the hundred.

Our knowledge of the water supply of the rocks penetrated by the drill is fragmentary and incomplete, despite the excellent opportunities to acquire it, for the reason that water was not included in the search that was in progress. Generally, it was a hindrance and obstruction to the explorations that were being carried forward, and in most cases all that we learn of it is by incidental reference. In a number of cases, however, the supplies discovered in the rock series have since been utilized and sometimes in the large way, and many wells have since been drilled, the sole object of which was to get control of the water that had been accidently demonstrated.

In order to understand and appreciate the facts that come in this division it is necessary to have a clear idea of the geological series of Ohio and of its distribution throughout the limits of the state.

SECTION I.

GEOLOGICAL COLUMN OF OHIO.

The geological series of the state consists of limestones, shales, sandstones and conglomerates. The several elements are associated in the order indicated below:

Coal Measures—

20. Upper Barren Measures.
19. Upper Productive Measures.
18. Lower Barren Measures.
17. Lower Productive Measures.

Conglomerate Coal Measures—

16. Homewood Sandstone.
15. Massillon Conglomerate.
14. Sharon Conglomerate.

Subcarboniferous (Waverly Group)—

13. Logan Group.
12. Cuyahoga Shale.
11. Berea Shale and Grit.
10. Bedford Shale and Sandstone.

Devonian Shale—

9. Ohio Shale, Great Black Shale.

Devonian Limestone—

8. Corniferous. Delaware Division.
   Columbus Division.

Silurian (Upper Silurian)—

7. Onondaga.
6. Niagara.
5. Clinton.
4. Medina.

Ordovician (Lower Silurian)—

3. Hudson River.
2. Utica.
1. Trenton.

Each of these subdivisions will be briefly characterized with reference to the inquiry before us. Before entering on this review, the reader is reminded that the water-bearing strata of this series are (1) sandstones and conglomerates, the purer and coarser, the better; (2) dolomitic limestone, when made porous by replacement; (3) soluble limestones, whether true or dolomitic, in which joints have been widened or channels have been dissolved under past or present conditions of drainage.

The strata of the Ohio section which are not water-bearing are (1) shales, the finer grained, the less productive; (2) impure sandstones in which shaly particles fill the spaces between the sand grains to a greater or less extent; (sandstones in which the cementing matter is carbonate of lime also belong in this list; (3) limestones when lying below natural drainage and dolomites in the same situation which have not resulted from the replacement of carbonate of lime by carbonate of magnesia.

The porous elements of our series are the more easily recognized from the fact that they are from time to time occupied with petroleum or natural gas. The reservoirs of these last substances are in all cases water-bearing rocks.

With these facts in mind, a brief review of the scale of the state will be made at this point. The several strata will be considered in ascending order.

1. THE TRENTON LIMESTONE.

Whether the Trenton limestone has any outcrop in Ohio, is a disputed question. S. A. Miller, of Cincinnati, first advanced the claim, in a paper read before the Cincinnati Society of Natural History, that the Point Pleasant quarries of the Ohio Valley belonged to this horizon. The late W. M. Linney of the Geological Survey of Kentucky, in a paper published in 1882, also held that the same mass of limestone belonged to the horizon above indicated. He based his belief on a series of closely connected sections which he had followed from undisputed outcrops of the Trenton in Central Kentucky to this point. On the other hand, the late Joseph F. James, in a paper that appeared a few years ago, held that on paleontological grounds, the Point Pleasant quarry rocks are indistinguishable from the Hudson river rocks of the Cincinnati section.

Following the series southward by the records of the drill from the Findlay gas and oil field, I concluded that the limestone of Point Pleasant could be best referred to the Trenton horizon. This opinion I still hold.

But however the facts in regard to the strata outcropping in the Ohio valley are construed, there is no room for doubt that the Trenton limestone underlies in characteristic and unmistakable form, and at a depth of from 1,000 to 2,000 feet, all of the northwestern quarter of the state; and also that it occurs at a still shallower depth in southwestern Ohio. In fact, every consideration makes it probable that the Trenton limestone is the universal floor of the entire state; but its presence has thus far been proved at but comparatively few points in the eastern half; but in every well drilled deep enough to reach its horizon, the formation never fails to reveal itself with unmistakable distinctness.

The Trenton limestone of southwestern Ohio and of the Kentucky outcrops, as well, is a gray or light blue limestone, occurring in somewhat heavy and fairly even-bedded courses. In composition, it is as a general thing found to be an impure limestone. This fact is well represented in the Point Pleasant limestones, which, whether or not they belong to the Kentucky Trenton, agree closely with the latter in both physical and chemical characteristics. Analysis of the Point Pleasant beds shows the following results. (Geol. of Ohio, Vol. I, p. 374).

Carbonate of lime	79.03
Carbonate of magnesia	0.91
Silicious matter	12.00
Alumina and iron	7.00

A composition substantially like this will cover most of the Trenton Limestone of Ohio. It is scarcely necessary to say that a rock like this, especially when below drainage, is never in any sense a porous rock, and consequently cannot be a reservoir of water, oil or gas.

There is, however, a phase of the Trenton limestone, as revealed in the underground geology of northwestern Ohio, and in adjacent portions of Indiana, which is porous to a high degree, and which has become, on this account, within the last few years one of the most famous strata of the country. In the districts named it is a prolific source of oil and gas. The same phase finds an outcrop in the Galena limestone of Illinois and Wisconsin, and in the Upper Division of the Trenton limestone of northern Michigan. I refer this phase to the second division of porous rocks as described on a preceding page, that, viz., in which a dolomite has resulted from a replacement of one-half of the carbonate of lime by carbonate of magnesia. That such replacement has taken place seems certain from the following facts, viz.: There are isolated areas of true carbonate of lime included in the dolomitic areas. Even in Findlay, which is a great center of Trenton dolomite, the limestone found in a single well proved to be true limestone instead of dolomite. This well was essentially unproductive. Again, in fragments brought up by the sand pump, a crinoidal limestone is often represented. Such a limestone was originally a true calcareous rock, and the change to its present dolomitic condition is the result of chemical action, subsequent to its formation.

By this change its porosity can be well explained. The atom of magnesian carbonate occupies less space than the corresponding atom of calcium carbonate which it displaces, while the entire volume of the rock is supposed to remain unchanged. Dr. T. Sterry Hunt estimated the porosity of Canadian dolomite to range from ten to thirteen per cent. Prof. J. D. Dana has calculated the porosity of Ohio dolomite and makes it from an eighth to a tenth of the volume of the rock. (Personal letter to the author). Dr. George S. Merrill makes the porosity of a pure dolomite on this theory of origin to be 12½ per cent. (Rocks, Rock Weathering and Soils, page 160).

It is only the uppermost beds of the Trenton limestone in Ohio that have suffered these transformations. Sometimes the change is confined to a very few feet; rarely it extends as far as 100 feet below the surface. The oil well driller readily distinguishes the dolomitic beds by the appearance of the drillings. The dolomite constitutes what he calls the "oil sand" or "gas sand," as the case may be.

This porous section of the Trenton limestone is not alone a reservoir of oil or gas, but is equally available as a reservoir of water. A strong brine generally occupies it where gas or oil is wanting. A peculiarity of this brine is that the chlorides of calcium and magnesium in it sometimes exceed in amount the chloride of sodium.

It is necessary to keep in mind what has already been stated, viz.: that the porous phase last described is quite local and limited in development, and that the great mass of the formation is essentially an impervious rock.

Though the Trenton limestone is the lowest stratum that has an outcrop in the state, we get in southwestern Ohio frequent evidences that a porous rock underlies it at a depth of 400 to 600 feet below its uppermost beds. In wells drilled to this level, flows of a brine rank with sulphuretted hydrogen rise to the surface. This brine is commonly known as "Blue Lick" water. The stratum which bears it can be called either an impure limestone or a calcareous standstone. It is generally referred to the St. Peter's sandstone of the Calciferous horizon. Sometimes it has happened that many weak flows of brine have been found as the drill descended to unusual depths. This experience was especially marked in Springfield and Dayton, where the drill was carried to a depth of twelve to sixteen hundred feet below the top of the Trenton limestone.

2. THE UTICA SHALE

The Utica shale is found in unequivocal and unmistakable characteristics in the deep wells of northwestern Ohio. It has the normal or typical features of the formation in New York in every respect, as color, grain, thickness and even in fossils. A few fragments of the shale brought up in the sand pump from the wells of Findlay, Bowling Green and other localities have yielded at least two of the most characteristic fossils of the formation, viz.: *Triarthrus Becki* and *Leptobolus lepis*. This stratum can be traced in all directions from Findlay, where the original identification of it was made, as a bed of dark brown or black shale, 250 to 300 feet in thickness, expanding to the eastward and thinning to the westward, and also to the southward. In the last named direction it is approaching the outcrop of the stratum in southern Ohio and northern Kentucky, and as it is followed southward, the black shale is found to gradually disappear, being replaced by blue or gray limestone, interstratified to some extent with shale of the same color, and indistinguishable from the underlying Trenton of the Kentucky scale. The limestone carries, however, some of the distinguishing fossils of the Utica, though not restricted to these, and has been positively identified as this formation on this ground alone. The lowermost fifty to one hundred feet of the Cincinnati section has been thus referred by some geologists.

The Utica shale, as its name would warrant us in expecting, is in the main an impervious stratum. It is not, however, as close-grained as many other shale formations, and pockets of gas and small reservoirs of salt water are frequently disclosed in it by the passage of the drill.

3. THE HUDSON RIVER FORMATION.

The Hudson river formation is both under cover and in outcrop in Ohio, a series of interstratified shales and limestones. Both elements are generally gray or blue in color, and both are fossiliferous to a high degree, especially in the outcrops of the formation. The series as shown in southwestern Ohio is 700 to 800 feet in thickness, and the average underground measure is not very far removed from these figures. But the volume of the stratum increases slowly from the center of the state eastward. Like the Utica, it grows thinner to the westward and the southward. The shale is very close and fine-grained and consequently it is as a rule almost entirely impervious; but in exceptional instances pockets of gas, sometimes under high pressure, are found in it, and whenever such occur, light veins of salt water are liable to be met with. On the whole, it is under cover a typical representative of a dry, or non-porous rock. In outcrop, it is one of the poorest of water bearers. Shallow wells that are dug in it sometimes obtain a precarious and scanty supply of water, highly charged with lime and other common minerals, the water seeping in from the beds that are traversed by the shaft, but there is not a formation of equal volume in the Ohio column that carries as little water as the Hudson river group.

4. THE MEDINA SHALE.

The Medina shale is found next in ascending order. It is the representative of a stratum of sandstone and shale that holds a very important and conspicuous place in the New York column. The sandstone, which is by far the more important element in this series, gives its name to the entire formation, which is accordingly known as the Medina sandstone. This stratum is made especially conspicuous by its color, which is prevailingly light red, though many beds of it are gray or white. The softer or shaly portions of the series are also red in color. The thin bed of red shale which occurs in southwestern Ohio, just at the junction of the lower and upper Silurian formations, was many years ago referred with some hesitation to the Medina horizon, on the basis of its position and color. (Geology of Ohio, Report of Progress, 1869, p. 148). This reference has been abundantly sustained by the results of the drill during the last fifteen years. The Medina has been followed in consecutive well records from northern Ohio, where it is unmistakably present, in a section normal as to thickness and color, to southern Ohio, where it is found in outcrop at the surface and the red rock of the deep wells of Hancock county, for example, and that of the outcrops in Warren county, are demonstrated to be one and the same. In the western half of Ohio, this formation is almost entirely represented by shale, but in the eastern half, sandstone courses, generally thin, are usually found. Sometimes even small pebbles occur in the Medina, both at the north and the south. Whether the white sandstone, which is the gas rock of the Lancaster, Thurston and Sugar Grove gas fields, belongs to the Medina horizon, or to the Clinton, to which the gas was at first referred, remains at present an open question. At any rate, the gas rock has not proved a prolific source of water at any point thus far. In New York and Ontario, however, it is a reservoir of gas and water on a very large scale.

5. THE CLINTON GROUP.

The Clinton series is one of the most distinctly marked elements in the geological scale of the country at large. Its outcrops are confined, as far as Ohio is concerned, to the southwestern portion of the state, and here its thickness seldom exceeds forty feet and sometimes falls to less than twenty. Under cover in central Ohio to the eastward, it seems to thicken to sixty or even to eighty feet in some sections.

It consists of limestones of various grades, some of which show remarkable purity. It is often made up of crinoidal fragments so loosely cemented as to make in outcrop a water-bearing stratum. It graduates into calcareous shales below and also bears at its upper limit a peculiar deposit of fine grained clay, bluish white in color, which proves impervious to percolating water. This layer does not often exceed one or two feet in thickness.

The Clinton is marked by high colors owing to the presence of iron in it, which gives rise to various shades of red, yellow and blue.

A characteristic iron ore also occurs in it, fragments of which have been brought up from 2,000 feet or more in drillings. Aside from the facts already reported, it is on the whole an impervious stratum, but one of the finest lines of springs of the state characterize the peculiar development above referred to. The water sinks through the crinoidal fragments of the formation until it reaches the Medina shales which underlie and at this point, which is the boundary between the Upper and Lower Silurian, the springs in question occur in fine development. These facts are well exhibited in Preble county.

6. THE NIAGARA SERIES.

The Niagara series that comes next above the Clinton, is a compound system, so far as its composition is concerned. Its lower portion is a fairly close-grained shale, while its uppermost division is mainly a dolomitic limestone of the type already described as due to replacement.

The shale has a maximum thickness in Ohio of 100 feet, which is reached only on the southern border of the state. The limestone element of the formation shows a maximum of 300 feet in thickness and this is also reached in southern Ohio. The shale is a characteristically impervious stratum; the limestone is water-bearing in some areas and in certain beds, but it is not to be counted water-bearing on a large scale like a homogeneous sandstone of the same thickness and extent.

The Niagara shale includes in southwestern Ohio lenticular beds of a well characterized limestone which is widely used and widely known as Dayton stone. This is impervious in itself, but is traversed by joints which often allow a fairly free descent of the water that reaches the surface of the limestone. The composition of the Dayton limestone is shown in the following figures:

Carbonate of lime	92.30
Carbonate of magnesia	1.10
Alumina and iron	0.53
Silicious matter	1.70

Like the Medina shale already described, the Niagara shale attests its impervious character by turning outward much of the water that sinks to its surface. Such springs, though generally lacking in strength, mark the horizon with great distinctness.

The limestone portion of the Niagara has proved a generous source of stored water in stations where it lies comparatively near the surface and has been exposed to atmospheric agencies in its preglacial history, by which its seams and joints have been opened on a considerable scale. In such cases the surface water descends bodily to the impervious bed and furnishes in many instances a large stock of water. The latter has generally been clarified in its descent, but little or nothing has been done towards its purification. Wells drilled into this stratum are sometimes found to be charged with grosser impurities than are to be found in almost any other formation in our column, but the next element above it, in like situations, shares the same characteristics. The composition of the best phases of the limestone is indicated by the following analyses:

	1.	2.	3.	4.	5.
Carbonate of lime........	54.25	53.77	53.50	53.48	55.59
Carbonate of magnesia....	43.23	44.76	45.79	42.25	43.76
Alumina and iron	1.80	0.39	0.39	0.40	0.42
Silicious matter	0.40	0.59	0.31	1.53	0.28

1. Hillsboro.
2. Springfield.
3. Fremont.
4. Bowling Green.
5. Genoa.

7. THE ONONDAGA SERIES.

The Onondaga system, known in our reports as the water-lime and perhaps including also beds of the Lower Helderberg series, is by far the most important limestone in the state so far as the areas occupied by it in outcrop are concerned and the thickness which it maintains, particularly in the northern and western portions of its area. Its maximum development in thickness is not far from 600 feet, but this measure is found only by the drill. In outcrop exposures it rarely reaches 25 feet and perhaps never exceeds fifty feet. From its fine exposures in southern Ohio it thickens to the northward and eastward. In Highland county an included section shows it to be but twenty feet in thickness, (Geological Survey of Ohio, Report of Progress, 1870, p. 283) while in the deep well drilled at Columbus, nearly 500 feet were referred to it on the satisfactory evidence of the drillings and the fragments that were brought to the surface. By far the most important areas of this stratum, so far as thickness is concerned, are covered with the deposits of the drift, which themselves are often very heavy. In composition the stratum can best be described as a dolomite. For large districts the exposed portion of the series are exceptionally pure, constituting an almost typical double carbonate of lime and magnesia. This is shown in the following analyses, viz., of the Greenfield stone from southern Ohio and of the Genoa stone from the northern section of the state.

1. Greenfield.
2. Rocky Ridge.

	1.	2.
Carbonate of lime..............................	53.67	54.10
Carbonate of magnesia.........................	42.42	44.27
Alumina and iron	1.30	0.29
Silicious matter	2.42	0.87

In other districts and notably in northwestern Ohio, while still dolomitic in general character, it is rendered impure to some extent by the presence of iron and alumina that are blended with it so that its character is gradually changed thereby. This type is most characteristically shown in Allen and Hardin counties. It is worked on a large scale in the quarries of Lima and Dunkirk for rough masonry and for railroad ballast. In color this phase is dark blue. It is a very tough and stubborn rock. It bears abundant and unmistakable evidence of shallow water origin in the shape of mud cracks which cover its surface. Ripple marks are not often found upon it. It is mainly made up of thin beds, two to four inches in thickness, but occasional layers are found six to eight inches in thickness. Fossiliferous beds occur here in better development than in most parts of its extent.

This type is not especially soluble and the joints consequently have not been greatly widened in the course of its history, but they have sufficed, after all, to allow the surface water to descend with a considerable measure of freedom, and the Onondaga series will be found to be the most important water-bearing stratum of the entire column of the state.

The second type of this stratum remains to be named. It is seen at its best in both northern and southern Ohio. At Greenfield it is remarkably even in its bedding, the courses usually ranging from four to twelve inches in thickness. The rock is a nearly pure dolomite, as the analysis already given shows, the principal foreign element being silica. It answers equally well for lime production as for building purposes. It is also used in the large way for curbing and crossings in city streets. It is not strong enough to answer the highest purpose for block pavements, though sometimes applied to this use.

Followed to the northward, it loses its evenness of bedding and the courses that compose it become thinner and more uneven. In this condition, while it often retains its purity of composition, its main use is in supplying a fine quality of magnesian lime, as can be seen from the analyses already quoted.

This phase of the limestone is very soluble and its joint planes are often open fissures, allowing a very free descent of surface water.

Underground caves and channels are often found in this formation. They are far more frequent than in any other of the limestones of the state. Some of the most famous springs of the state belong to the Onondaga series, as for example, Campbell's Spring in Pike county, and the Castalia Spring of Erie county, both of which will be described more at length on succeeding pages.

8. THE DEVONIAN LIMESTONE (CORNIFEROUS).

A limestone of Devonian age, which constitutes an important element in the scale of the state, comes next in review. There are two fairly distinct divisions of this series, established both on paleontological and lithological grounds. They are respectively known as the Columbus and Delaware divisions, but in the relations of the formation to water no such division is required. The upper, or Delaware portion of the series is distinctly less pure in composition, but no part of this series has in itself any storage qualities. Being a fairly pure limestone, its joints have been widened by solution where exposed to the atmosphere so as to allow a tolerably free descent of water from above, which does not, as a rule. descend into the earth to any considerable depth. A thin bed of shale or clay separates in many instances this limestone sheet from the stratum next below it, so that the formation now under consideration gives rise to numerous springs. The latter make many important contributions to the Scioto river in its course through Franklin county. Some of the springs furnish relatively large volumes of water and exemplify in their flow the general character of limestone springs, being evidently subterranean streams for a considerable distance back from their point of emergence. The famous Wyandotte Spring that enters the river five miles above Columbus is a good example of this mode of origin.

9. THE DEVONIAN SHALE.

This considerable and complex series represents a half dozen stratigraphical elements, more or less, of the New York column, but in its Ohio development it consists essentially of fine-grained and impervious materials from top to bottom. It is perhaps the poorest reservoir of water that the scale of the state affords. Yet even in this great mass of shales, some sandy zones occur which are occasionally found charged with gas, oil or salt water. It is also to be noticed that where important sections of the shale have been exposed to the weathering agencies of the atmosphere for a long time, a certain measure of permeability has been gained by them through the superficial enlargement of their joints, and the solution of some of their constituent minerals, especially by the decomposition of pyrites, which is generally abundant in the substance of the shale.

The Devonian shale ranges in thickness from 250 feet on its western outcrop to at least 2,500 feet in eastern Ohio.

The water that is supplied by exceptional localities in the shale is in all instances highly mineralized, carrying sulphuretted hydrogen, sulphate of alumina and sulphate of iron, as well as other compounds of this last named element. The presence of sulphuretted hydrogen is, in the popular judgment, generally sufficient to place such springs in the line of medicinal waters, and many of them not only in Ohio, but in other states as well, have acquired reputation in this line.

10. THE BEDFORD SHALE AND SANDSTONE.

The formation here named is in the large way a shale formation and consequently destitute of water, but a sandstone constitutes its upper member in some parts of the state, and this may possibly serve as a storage bed for water in limited instances. No cases of this sort have, however, been noted.

11. THE BEREA SANDSTONE AND SHALE.

The element now named is one of the most important of the reservoir rocks of our entire column, but for reasons that can easily be recognized, it produces fresh or potable water in but few and unimportant instances. It is essentially a driller's rock. Salt water, oil and gas are everywhere due in it and its bituminous contents are sometimes extraordinarily valuable. It is the most important of the earlier developed oil rocks of Ohio and commands great consideration also in West Virginia and Pennsylvania. It is a gas rock in some territory, and when the reader is reminded that it constitutes the famous Murrysville gas sand in western Pennsylvania he will see that no other stratum takes higher rank in this line.

It is found to be an oil rock as soon as it is followed under cover. At Mecca, Trumbull county, it has proved a valuable repository of oil; and here its only cover is 20 to 50 feet of boulder clay. In the Grafton oil field the Berea grit is less than 200 feet below the surface and yet a small oil production has been maintained here for forty years. At no greater depth, in many instances, salt water is found in this formation; but it is when the stratum has 750 to 1,000 feet of cover that it gives the best results as a source of brine. The recent discoveries of vast beds of rock salt in various parts of the country have made it economically impossible to work any longer these deep stocks of weak brine such as the Berea grit and other formations of our column so generally contain.

The thickness of the Berea grit ranges from 5 to 100 feet.

The Berea grit is everywhere directly overlaid by the Berea shale, a dark or black shale, 15 to 40 feet in thickness, which is not always easily separable from the next higher element in the series, namely, the Cuyahoga shale. It is a close-grained, but rather soft, deposit, which has yielded easily to glacial erosion, and that is therefore to a considerable extent wanting on the western outcrop of the grit, but its place is in such cases generally occupied by boulder clay which is as impervious as the natural cover would be. This fact accounts for the sparing occurrence of fresh water springs along the outcrops of the Berea sandstone, to which attention was called on a previous page.

12. THE CUYAHOGA SHALE.

The formation now to be reviewed is at the best but an indifferent and capricious water-bearer, but it is not as barren of water as the great Ohio shale (Number 9 of our Table). Though composed principally fine-grained mud rock, it also includes in some sections considerable bodies of sandstone, and no sections can be found of 200 feet or more in thickness that are altogether destitute of these sandy elements. Immersed, as these sandstones are, in shale, they very seldom furnish springs along their outcrops, or supply potable water to the drill. Such water as they contain is generally saline.

13. THE LOGAN GROUP.

This division of the Ohio scale is less definitely bounded and characterized than any of the elements that have been already passed in review. It consists of different elements in different sections of the state, or at least of elements the proportions of which vary in different sections to a great degree. Shales, sandstones and conglomerates enter into its composition everywhere, but in the southeastern quarter of Ohio, the dominant feature is a massive conglomerate that is found at its best in outcrop in Licking and Fairfield counties. It is in this element that the chief interest of this formation as a water-bearer lies. Under cover, this conglomerate had been found to be a famous source of salt water and occasionally of oil and gas. In its relation to the last named elements, it is known as the "Big Indian sandstone" of the Ohio Valley. Of course, it is only when comparatively near its outcrop that it is found as a reservoir of potable water. It is not certainly known to furnish a public water supply to any towns in the state at the present time. The conglomerate has a maximum thickness of 75 feet, but the entire formation measures not less than 300 feet in its full development.

14-15-16. THE CONGLOMERATE COAL MEASURES.

This division of our column is well nigh as important in its relations to water supply as it is in relation to other economic interests. In fact, its water production may be counted more important than even its coal production, looking to the future. In a few years the coal will all have been exhausted from the rocks of this age, but it will still remain for an indefinite future a source of good water supply. This division is characterized by three great sandstones, more or less conglomeritic, that are separated from each other by shales, coal seams, fire clays and even by thin beds of limestone and iron ore. The sandstones or conglomeritic elements are the three following, named in descending order:

Homewood sandstone.
Massillon sandstone or conglomerate.
Sharon conglomerate.

Each of these divisions reaches a thickness in some portion of its extent of 80 to 100 feet. They are composed almost exclusively of coarse and clear quartz sand, among which are irregularly distributed quartz pebbles. The sand is occasionally for small areas, fine grained and layers of shale occur in the same regions, but as a rule the sandstones are freely open to water and there seems nothing to interfere with a high degree of purity of the same.

17. THE LOWER COAL MEASURES.

This important division of the Ohio scale is as thoroughly known to us as any other portion of our column. We find in it the sandstones named below which are generally coarse in grain and of fair thickness, varying from 10 to 40 feet. All are water-bearing, though in many instances they have no fair chance to replenish their stocks when once reduced. The sandstones to be enumerated here are the following: (1) The Kittanning sandstone, between the Lower and Middle Kittanning coals; (2) the Lower Freeport sandstone, an important and persistent element of the scale, particularly in southern Ohio, where it often makes the roof of the Middle Kittanning coal; (3) the Upper Freeport sandstone, a less massive stratum that overlies the coal of the same name. It is poor in grain and springs occur but infrequently along its outcrops. All of these sandstones have faint conglomeritic phases.

18-19-20. LOWER BARREN MEASURES, UPPER PRODUCTIVE MEASURES, UPPER BARREN MEASURES.

The group of strata now to be considered constitute the three highest elements of the Ohio column. They are not, as a rule, as well known as those that have been already passed in review, but some elements of them are important in the present connection. The first seam to be named in the ascending order is one of the most important as a water-bearer in the entire list. It is the Mahoning sandstone, the lowest stratum of the Barren Measures. It is coarse or medium, never fine in grain, and has unusual steadiness for a coal measure sandstone. It has a considerable range in thickness, varying from 40 to 100 feet. It is feebly conglomeritic in places, especially in its uppermost portion.

There is a great deal of shale in the division which is not water-bearing. Limestones, some of them of considerable volume, also characterize this group. On the whole, these divisions must be counted poor in water. One of the highest elements in the series is the Pittsburgh sandstone, but its quality in respect to storage of water is indifferent.

With this brief characterization of the strata of the state in their relation to water supply, this review of our rock column will be concluded.

21. THE DRIFT.

The waters derived from the drift constitute by far the most important section of the state supply. But, aside from the few districts in which they appear in flowing wells from comparatively deep sources, they are not to be treated here. Mr. Frank Leverett's investigations, have been mainly restricted to the ordinary drift wells of Ohio.

SECTION II.

GENERAL CHARACTERISTICS OF WATER OF DIFFERENT DEPTHS.

Before taking up the water derived from each of these different sources, we must consider a few general principles that apply to all.

1. The subterranean waters from a comparatively shallow depth carry, as a rule, dissolved carbonates. Lime and magnesia are the leading bases, but potassium and sodium sometimes also occur in them in small quantities. Iron is unfailingly present and often in notable quantity. These wells are common sources of potable supply.

2. Water from a greater depth holds dissolved chlorides as well. Chloride of sodium is by far the most common, but chlorides of magnesium and calcium are often added. Such waters are generally called saline. The presence of chlorides is seldom shown in water at less than 100 feet in depth and in the cases where it occurs it is confined to a few formations of the Ohio column. It is very rare that the drill descends to 300 feet without encountering saline water, or water too highly mineralized with other elements to be acceptable for the highest uses. No water of the state is known that comes from more than 500 feet and still free enough from mineral solutions to warrant its use as potable.

3. Sulphates generally belong in the second class, but are sometimes found in the first division also. The most common compound is calcium sulphate, but sodium sulphate is not infrequent.

4. Sulphides, also, particularly sulphuretted hydrogen, though often rising to the surface in so-called sulphur springs, are especially characteristic of the water found in limestones, and nearly all the water of the great Ohio shale system is characterized in this way. Sulphides pass very promptly and by easily understood reactions into sulphates.

SECTION III.

DESCRIPTION OF WATERS FROM THE STRATA ABOVE NAMED.

The waters derived from the several formations above named will be next considered, and they will be taken up in the order of the preceding review. Only those cases will be treated at length in which conspicuous and important production is found in a stratum.

SUB-SECTION A.

THE TRENTON LIMESTONE.

1. All the water that we know from the Trenton limestone in Ohio is that derived from the deep drilling, or, in other words, from the oil and gas wells of northwestern Ohio. Our largest knowledge of it comes from the counties where the drill has been employed for the longest time and in the greatest number of wells. The counties are as follows: Lucas, Ottawa, Sandusky, Seneca, Hancock, Allen, Auglaize, Mercer and Van Wert. Other counties adjoining those already named make some additions to this list, but the most striking instances will be found in the list as above given.

The waters from this lower horizon, so far as examined, seem to have many features in common. They are all far removed from a potable character. All are highly mineralized and all have a strong bitter or saline taste. They contain large quantities of chlorides of sodium, magnesium and calcium. A marked peculiarity has been claimed for them in this respect that the two compounds last named frequently exceed the first or the chloride of sodium, and this is a somewhat unusual feature in underground waters. It does not appear in all of this deep water. They are also universally rank with sulphuretted hydrogen. Sulphates have not been reported in them thus far.

These waters are mostly artesian as is shown by the fact that they rise under considerable pressure, sometimes, though rarely, flowing from the well mouth, but generally stopping from 100 to 300 feet below the surface. In some of the best marked examples, noted at the time when drilling was most active, a dozen years ago, the water was found to rise in widely separated regions to approximately the same absolute height, viz., to about 600 feet above tide. Whether the wells flow, depends on the altitude of the surface. Where the surface is below the 600 foot line, the water, of course, escapes from the well mouth, but where the surface is higher the water falls as much below as the height of the surface exceeds that figure. Subsequent observations, though comparatively few in number, have substantiated the same conclusion. One of the latest examples is found in the recently developed oil field of Oregon township, Lucas county. In a well drilled there in 1896, an amazing flow of salt water was unlocked in the Trenton limestone. The height of the surface at this point is somewhat less than 600 feet above tide, and consequently the salt water flowed strongly from the well mouth. The owner of the well applied a pump to it to reduce the salt water, if possible. After vigorous and steady work for many days he succeeded to the extent of bringing in a considerable amount of oil from its higher level in the rock. But the oil production was maintained only while the pumping was continuous.

In a well drilled at Lindsay, Ottawa county, in 1886, the salt water rose very nearly to the surface. The water came from a depth of 70 feet in the Trenton limestone and reached an altitude of practically 600 feet above tide. In Hancock county cases have occurred by the score in which the salt water rose in great volume, whenever tested by the pump, to the same level named above, which would generally be reached within 100 to 300 feet of the surface. In Wood county a well on the Halsey farm produced for sometime a thousand barrels of salt water per day. With the water it also yielded 300 barrels of oil for the first few months of its life. The oil has since fallen away to less than 100 barrels, while the volume of water is maintained.

A careful study of the waters of the Trenton limestone was made by Dr. T. S. Hunt in his Chemical and Geological Essays. The results of his study are incorporated in an interesting paper in the volume referred to. The waters that he discussed are not, however, deep waters, but are such as occur in springs and shallow wells in this formation in Canada. The analyses given by him show the same general constitution that characterize the deep waters of Ohio when the rock is penetrated to the same horizon. I append a number of Dr. Hunt's analyses:

	Whitby.	St. Catherine.	Cledonia.	Lanoraie.
Sodium chloride	18.9158	29.8034	12.2500	11.1400
Magnesium chloride	9.5437	3.3977	1.0338	0.2790
Calcium chloride	17.5315	14.8544	0.2870	0.2420
Potassium chloride	......	....	0.0305	0.1460
Barium and strontium chlorides	......	....	....	0.0488
Sodium bromide	0.2482	......	0.0238	0.0283
Sodium iodide	0.0008	0.0042	0.0021	0.0052
Magnesium bromide	......	......	0.0238	0.0283
Magnesium iodide	......	......	0.0021	0.0052
Calcium sulphate	......	2.1923	......	......
Silica	......	......	0.0225	0.0552
Barium and strontium sulphate	......	......	......	......
Calcium carbonate	0.0411	......	0.1264	0.4520
Magnesium carbonate	0.0227	......	0.8632	0.4622
Barium and strontium carbonate	......	......	0.5555	0.0243
In 1000 parts	46.3038	50.6075	14.6893	12.8830

A deep water derived from some part of the Trenton limestone in a well drilled at Ripley, Brown county, Ohio, has been put into the market as a *Brom-Lithia* water. Analysis by Prof. Karl Langenbeck shows the following composition:

(Grains in an imperial gallon.)

Silica	2.0300
Alumina	0.0850
Ferrous sulphide	0.0520
Ammonium sulphide	0.7750
Calcium sulphide	18.6330
Magnesium sulphide	24.0890
Calcium hydrosulphide	3.2300
Calcium sulphate	1.8250
Magnesium bromide	0.6570
Sodium chloride	663.4530
Potassium chloride	18.9800
Lithium carbonate	11.0500

A single analysis of the deep brine of the Trenton limestone from northern Ohio is here introduced. The work was done for the State Board of Health by Prof. N. W. Lord. The results are calculated as grains to the United States gallon.

Potassium sulphate	4.66
Potassium chloride	56.24
Sodium chloride	2384.40
Calcium chloride	471.90
Calcium carbonate	25.83
Magnesium chloride	354.00
Iron oxide	0.08
Alumina	0.10
Silica and silicates	0.72
Total solids	3297.93

This water was taken from Well No. 8 on the Halsey farm, Plain township, Wood county, two miles west of the court house square in Bowling Green. The well has been a generous producer of salt water and oil from the beginning. The depth from which both products are raised is 1,256 feet. The salt water does not flow from the well mouth, but when left to itself rises to considerable height in the well. The constant pumping to which this and hundreds of other wells in the vicinity are subjected has had a greater or less influence on the salt water. At the first drilling of the well it yielded 300 barrels of oil per diem and continued this production for a number of months. At the same time it yielded as much as 1,000 barrels of salt water. The oil production of the well has latterly fallen to 100 barrels per diem, but the water still continues in large volume.

The character of the water is marked, as the figures above given show, but the chloride of sodium is in large excess over the other chlorides present. It will be remembered that in many examples of these deep waters from the old rocks the contrary has been claimed to be true. The claim has not been substantiated in Ohio.

A second analysis of the water is herewith given from the Hemmingray well at Newport, Ky. The water was found at a depth of 500 feet, or about 200 feet below the upper surface of the Trenton limestone. The analysis was made by Prof. N. W. Lord for the Ohio Geological Survey and is calculated in grains to the United States gallon.

Calcium sulphate	106.01
Sodium chloride	614.04
Magnesium chloride	54.17
Silica	00.41
Alumina and iron	trace
Sulphuretted hydrogen	*

*Undetermined, but in large amount.

This water was popularly called "Blue Lick Water" and was imagined by some persons to produce beneficial effects when taken into the human system. For bathing it would unquestionably prove advantageous in certain forms of disease.

SUB-SECTION B.

MEDINA AND CLINTON HORIZONS.

The geological elements indicated under the numbers 2 and 3 give no important or characteristic production of water anywhere in the state, for reasons that can be understood by reference to the description of these several elements as given in the preceding section. But at the junction of numbers 4 and 5 in southwestern Ohio, a remarkable line of springs occurs. These are all found on the outcrop of the Clinton limestone and largely on outcrops of outliers of this formation. In all such cases, the drift is generally thin. The horizon is well marked geologically, as it is very near the dividing line between Ordovician and Silurian time (Lower and Upper Silurian). It is also, in many instances, conspicuous by reason of color effects. The Medina series is generally high colored, a red band being its most striking element. As it is the only red stratum in the entire district, its presence is sure to be noted.

This line of springs led to the location of many farms in the original settlement of the country, and roadways connecting these tracts first occupied, have, in some instances, been maintained to the present day. There is also an abrupt change of level in many cases, as one passes from the Clinton to the Medina horizon. The former is apt to occur in a terrace-like outcrop. Moreover, there is often a well-marked change in soils, in passing from the higher to the lower levels. A belt of unusual productiveness characterizes the slope below the Clinton limestone, as a rule. It is probable that the escape of water at this level has something to do with this change in the character of the soil.

Since the buildings and improvements of farmers generally correspond to their success, the homes that are established along this boundary are more than usually attractive.

The water of these springs and from this horizon generally, has, so far as known, no peculiar qualities. Most of it has passed through the thin beds of drift that overlie the limestone, and afterward through 10 to 30 feet of Clinton limestone before reaching the impervious bed of Medina shale that turns it out to the surface. There are no conditions apparent that promise any unusual degree of purity through filtration or other means, but so far as known, these sources have given an acceptable and approved supply to many thousands of people during the lives of several generations. It is geologically the lowest potable rock water that is known in the state.

The counties in which this line of springs occurs are named herewith: Preble, Montgomery, Warren, Greene, Clinton. Excellent examples of the phenomena above described are to be found on the margin of Spring Hill in Warren and Clinton counties.

A considerable amount of water, but too highly mineralized for a potable supply, is found at this same horizon when it is reached in the deep wells of northwestern Ohio. The Medina shale is the one safe horizon in which to set the casings of gas and oil wells that are to be carried down to the Trenton horizon. In that part of the state, the Medina is usually a well marked red rock, and, as observed above, it is a landmark that never escapes notice in the well section. There is one higher horizon, viz.: the Niagara shale, where the casing can often be set successfully, keeping the well free from the invasion of deep rock water. It is never safe, however, to depend on this, but when the casing is set in the Medina shale, it has been found. in thousands of instances, to furnish sure protection to the well.

From these deep wells we get in many instances waters rank with sulphuretted hydrogen. Sometimes the water is more or less strongly impregnated with salt, and iron is often present in solution. No use has ever been made of these deep waters in any way, so far as I have been able to learn. The only obvious use is in medicinal baths.

The counties in which these deep wells of the Clinton are found are identical with the counties in which the Trenton limestone is petroliferous in the large way. The list will agree exactly with the list given under the deep wells of the Trenton limestone.

SUB-SECTION C

THE NIAGARA LIMESTONE.

The Niagara series consists of the Niagara shale and the Niagara limestone. The latter is also divisible into two or more elements, but they need not be distinguished here. The Niagara shale separates the Niagara limestone from the Trenton limestone. It is a close-grained and fairly impervious formation and, alike in outcrop and under cover, is a water-bearing horizon. The springs that are found on this line in the regions where it lies above drainage, are not as strong as those already described on the preceding page. But in Clarke, Greene and Highland counties, a good deal of water finds its way to the surface at this level, and many wells obtain water when drilled to this horizon. The latter statement applies especially to the districts about Springfield, Yellow Springs, Cedarville, Hillsboro, etc. Under deep cover the water is of very much the same character as that described in the preceding paragraph.

But by far the most important contribution that the Niagara limestone makes to the water supply of the state is found in regions where it was a surface rock in the ages that intervened between the establishment of Ohio as dry land and the epoch of the glacial drift. During this last period there were large areas of the limestone exposed to atmospheric agencies, protected only by the products of its own weathering. In such regions the joints of the limestone must have been widened and underground reservoirs and channels must have been established as parts of a general drainage system. Finally the drift came, covering and leveling up the entire surface of the country. The deposits which it brought sometimes allow the freest possible passage of water to the rock floor, and again, the boulder clay shuts out the surface water almost completely from considerable areas. By reason of this irregular distribution of the pervious cover, the rocky floor still takes an important part in the water circulation of the country. The first example of this condition is found in the experience of Sidney, Shelby county. The natural porosity of the Niagara dolomite also makes it a water-bearer in a few instances to be named.

(1) SIDNEY.

Some years since, the necessity of a public supply, especially for protection against fire, became evident to the people of the town, and water works were introduced at the public expense, with the Miami river which flows through the center of the corporation as the source. A reservoir was formed by damming the river above the town, but the quality of the water drawn from it was poor. In fact, it was used only for fire protection. It was justly considered unsatisfactory and unsafe for domestic use. In 1885, the excitement originating in the discovery of gas in Findlay in the previous year, led the enterprising people in Sidney to try their fortune with the drill in the home field. A deep well was accordingly drilled in the fall and winter of that year, and in the course of the descent a surprising flow of water was found in the upper limestone series, which is here about 200 feet thick. It consists altogether of Silurian elements. The series is as follows :

Niagara limestone	140 feet.
Niagara shale	40 "
Clinton limestone	20 "
Clinton and Medina shale	"

The water found in the limestone was highly sulphuretted, and although the flow was seen to be exceptionally vigorous, it attracted but little general attention at the time. The Trenton limestone, which was the goal of the driller, was found unproductive, but other companies were organized and other wells drilled, all of them showing the same general line of results, viz., neither gas nor oil in the Trenton, at least none of economic importance, but an abundant supply of water from the upper limestones. The water was under artesian pressure and rose with considerable force from the well.

One of the abandoned wells, viz., the one drilled on the Burkhardt property, was allowed to remain a flowing fountain, and has been sending out to the river a good sized stream ever since it was drilled. The water was struck in the Clinton series 217 feet below the surface.

Finally the demand for potable water for the town began to be more urgent and the deep supply in the upper limestones came to be considered in this connection. During the present year, 1897, the town has taken up the matter in earnest and has expended $80,000, in addition to half this amount previously spent in the establishment of the older plant.

Four wells have been drilled and the water found has been turned into the city pipes. The reservoir has been entirely abandoned. All the wells are located in the river valley and in the center of the corporation. The section found is as follows:

Gravel filled with water	30 feet.
Niagara limestone	90 "

The section shows that the wells obtain their supply from the Lower Niagara. If they had been carried deeper, they would undoubtedly have soon struck sulphur water, as was the case in all those that were drilled for gas. Water was found in the limestone all the way down. By its ascent in pipes connected with the wells, it shows an artesian head of 17 feet, and in one case in town, a head of 25 feet was reported. The flow from a six-inch pipe at the wells, rising three feet above the surface of the ground makes a splendid and imposing exhibition.

The supply for the town is ample for every purpose. The maximum production of the present year is 936,000 gallons in 24 hours;

the average is 400,000 gallons. The wells could without doubt maintain even the maximum for a long time.

A well, drilled into the limestone to the same depth as the city wells, at the brewery, a few hundred yards south of the water works secures the same artesian flow, but finds it affected by the pumps of the city plant. When these are taxed, the flow of the brewery well becomes intermittent.

The water is thoroughly acceptable for domestic use, but for steam boilers constant care and outlay are required. The sediment and crust deposited on boilers will make sometimes a deposit of an inch in two weeks' time.

The results of the analysis of the water recently made by Prof. C. C. Howard for the State Board of Health, shows the following composition. (Grains to the gallon.)

Calcium sulphate	23.85
Calcium carbonate	40.06
Magnesium carbonate	20.50
Sodium chloride	.09
Total solids,	84.50

The explanation of the high percentage of sulphate of lime is undoubtedly found in the fact that the water originally contained more or less sulphuretted hydrogen. By its oxidation, the sulphur appears in the form of sulphuric acid, and this takes the lime from a certain amount of carbonates in the water.

(2) CELINA.

Public water supply was established in this village in 1895 at an outlay of $50,000. Six wells have been drilled, the first three to a depth of 175 feet, the others to a depth of 300 feet. The wells are located 1¼ miles northwest of the court house. The drillers find 80 feet of drift, 120 feet of Niagara limestone and 60 feet of Niagara shale and Clinton limestone. They seem to have been drilled deeper than the water supply would require. Probably their entire stock is derived from 200 feet of the total depth. The supply is large and the capacity of the wells has never been reached by the pumps. The water rises to within 30 feet of the surface. The wells affect each other noticeably.

The quality of the water is not entirely satisfactory. It is too hard for many household uses and is particularly objectionable for steam-boilers. An analysis made by Prof. C. C. Howard in 1896 showed 146.5 grains of total solids to the gallon. Its constitution has been considerably changed in the interval between the analysis and the present time. Prof. N. W. Lord finds in it the following substances in an analysis recently completed. (Grains to gallon.)

Potassium sulphate	0.62
Sodium sulphate	15.90
Calcium sulphate	46.36
Magnesium sulphate	19.55
Magnesium carbonate	10.02
Sodium chloride	1.46
Iron and alumina	0.45
Silica and silicates	1.00
Total solids,	95.36

It is, of course, recognized that the notable percentage of common salt in this water does not imply its previous sewage contamination. It is distinctly a product of the rock strata from which the water is obtained.

(3) ST. MARY'S.

A public supply was introduced into this village in 1895. The drilling for oil and gas had been so extensive in this region that the underlying sources of potable water were well understood and no preliminary tests were needed in locating the public supply. Four wells were drilled in the year above named at a point conveniently located within the corporation limits, the first to a depth of 155 feet and the second to a depth of 265 feet. The first well did not produce as much water as had been expected and a torpedo was exploded in it to increase its flow, but no corresponding advantage was derived therefrom. It yields to the pump 200,000 gallons per diem, while the second produces 700,000 gallons per diem.

An analysis of the water made by Werner & Simonson of Cincinnati showed the qualities named below.

Temporary hardness (carbonates of lime and magnesia) . 31.50

Permanent hardness (sulphates of lime and magnesia) . . 5.00

The supply has been approved by the State Board of Health and is coming to be generally used by the people of the village.

This water is also derived from the Niagara limestone.

(4) FOUNTAIN PARK.

A few examples of excellent supplies of water derived from the porous or Guelph division of the Niagara limestone remain to be noted. The first occurs at Fountain Park, a station on the P., C., C., & St. L. Railway in the northeastern corner of Champaign county.

The discovery of this source of water was made about 16 years ago. A well was drilled in 1862 to a depth of 62 feet, about 20 feet of which was limestone, on the farm of A. J. Smith, Esq., and water flowed from the well mouth. It was forthwith observed that the water carried iron enough to leave a rusty stain on surfaces over which it flowed, which is by no means unusual. To this observation another was presently added, viz., that a knife blade held in the water became magnetic. The discovery was at once heralded that a new fountain of magnetic water had been found in this portion of the state. Others had been previously known there.

Just how the popular delusion in regard to certain waters being magnetic orginated, it is impossible to say. The earth is a magnet and iron rods and pipes set vertically in it take their part in magnetic phenomena. The steel drill with which all deep wells are sunk always become permanently magnetic and the iron castings of such wells becomes at least temporarily so. Similar phenomena can be found in every deep well without regard to the character of the water but just why one well or spring should be called magnetic rather than another is a matter of caprice or accident that cannot be explained. No water is ever called magnetic that does not flow through a vertical iron pipe, and all waters having this mode of egress have equal right to the name.

Presently it was determined that as the water flowed and was "magnetic" it must be utilized. A good hotel was forthwith built and equipped with bath-houses. It was designed especially for summer use. Other wells were drilled, including one deep well with a six-inch casing. This was sunk to a depth of 2,300 feet with the hope of reaching gas or oil. The territory has been pretty thoroughly tested with respect to flowing wells and fourteen in all have thus far been developed in the immediate neighborhood. They are all included within 150 acres. All the flowing water comes from the rock and in the deep well the main supply is derived from 114 feet. This fills the six-inch pipe and has a pressure head of 14 feet. In other wells on higher ground the head is reduced proportionately. These wells affect each other, but are not influenced by rainfall or the accidents of the seasons, so far as noted. The waters from different depths in the rock have distinctly different characters. The analysis of the water of the first well drilled was made by E. S. Wayne, of Cincinnati, and shows the following composition:

Chloride of sodium	13.64
Chloride of calcium	4.22
Chloride of magnesium	2.12
Sulphate of potash	2.61
Carbonate of lime	26.24
Carbonate of magnesia	11.41
Carbonate of iron	0.16
Silica	0.24
Organic matter	0.39
Total solids per gallon	61.03

This water is found to be laxative in its physiological effects, as its mineral constitution would lead us to expect.

Well No. 2, near the hotel, comes from a shallower depth and has more of the character of the drift water. Its composition as determined by Prof. H. A. Weber of the Ohio State University, is shown in the following table. This water is counted astringent, but it is hard to see how it can differ from the water of ordinary wells. A small amount of sulphuretted hydrogen is dissolved in it. The figures show grains to the United States gallon.

Carbonate of lime	15.293
Sulphate of lime	0.087
Carbonate of magnesia	1.367
Sulphate of magnesia	10.769
Carbonate of iron	0.160
Chloride of sodium	0.539
Sulphate of soda	1.186
Sulphate of potash	0.426
Silica	1.225
Organic matter	0.230
Total solids	31.282

The water from well No. 2 is largely sold in Columbus as a table water. It is counted satisfactory by those that use it.

The water of the deep well, Well No. 3 of the hotel property, comes as has been said from about 114 feet in depth. It has a flow of great volume, but actual measurements have not been made. If left to flow wide open from the six-inch casing, it reduces the head of all the surrounding wells.

Well No. 3, H. A. Weber.	Grains to U. S. gallon.
Carbonate of lime	14.242
Sulphate of lime	0.099
Carbonate of magnesia	1.457
Sulphate of magnesia	9.296
Carbonate of iron	1.457
Sulphate of magnesia	9.296
Carbonate of iron	0.231
Chloride of sodium	0.480
Sulphate of soda	0.274
Sulphate of potash	trace
Silica	1.390
Organic matter	0.251
Total solids	28.720

The topography of the district is interesting. The surface is occupied by a moraine of recession. The surface is beautifully diversified by low hills and hollows. It constitutes one of the most beautiful districts of central Ohio.

Brush lake occupies one of these hollows or depressions in the drift sheets. The lake has an area of 11 acres and its greatest depth is 80 feet. In its northwestern corner there are indications of the ingress of spring water in considerable volume.

(5) PLAIN CITY.

On the same line of railroad, 15 miles further eastward, another example of strong flowing water, apparently from the same geological source, was found in the epidemic of drilling which has once and again been referred to in this discussion. A deep well projected at Plain City in 1889, was carried down to a depth of 1,700 feet when the tools became fast and the drilling was necessarily abandoned; but in sinking it a powerful flow of water was struck at 387 feet. The water showed a head of 18 feet of pressure; but as the location was below the general level of the country, the head would be but 4 or 5 feet above the ordinary level of the drift plains.

A second well was located near the first and repeated its experience so far as rock water was concerned. This well was drilled 2,000 feet deep, and according to the recollection of those interested, was carried about 30 feet into the Trenton limestone.

A destructive fire swept through the business part of the town in 1894, with which the residents found themselves utterly unable to cope. This led to the recognition of the imperative need of an adequate water supply—a need that was emphasized by the frequent occurrence of typhoid fever in the village. The great flow of cool, clear, excellent water constantly escaping from the casings of the two deep wells, was before the eyes of the people, and it did not cost them long to decide upon the proper course to pursue. A public water supply from this source was decided upon, the village was bonded for $35,000 and a modern water works plant was forthwith installed. Both of the sources of danger above referred to, fire and fever, have been effectually disposed of by the introduction of this deep water. Not a case of typhoid has ever occurred in families where the deep water has been in use, and fires are extinguished so promptly that some of the people are disposed to believe that the water must have some element not found in ordinary water to account for its effects, but of course there is no foundation for such a belief.

The water does not, however, answer at all for boiler use, as its mineral contents indicate. The following analysis made for the State Board of Health by Prof. N. W. Lord gives its solids in grains to U. S. gallon:

Potassium sulphate	0.70
Sodium chloride	1.94
Sodium sulphate	1.86
Calcium sulphate	13.60
Calcium carbonate	8.90
Magnesium carbonate	10.30
Oxide of iron and alumina	0.22
Silica	1.72
Total solids	39.24

(6) HARRISBURG, FRANKLIN COUNTY.

The third case of a vigorous supply of flowing water from the porous Niagara where it occurs under deep cover, has recently been developed at Harrisburg, on the line of the Midland Railroad at the crossing of Big Darby. The Devonian limestone has an outcrop here, and as is not infrequently the case, it is charged with considerable quantities of inspissated petroleum. This petroleum has undoubtedly a local origin and has no significance whatever as indicating a source of deep oil; but the facts were not so construed by local observers. A company was formed two years ago to drill a deep well at this point. The Trenton limestone was not reached, but as has so often happened elsewhere, a noble flow of water was found. The main production comes from a depth of about 400 feet (390-405). Recently measured by Prof. C. N. Brown of the State University, its production was found to be about 850,000 gallons per diem. The flow is sufficient to run steadily a 9½ feet water wheel which is applied to grinding grain, sawing lumber and the like.

The record of the well leaves no doubt as to the horizon from which the water came. It is certainly derived from the Guelph division of the Niagara limestone. Its composition is shown in the following analysis made by Prof. N. W. Lord for the State Board of Health. The figures indicate grains to the U. S. gallon.

Potassium sulphate	0.51
Sodium chloride	2.72
Sodium sulphate	2.91
Calcium sulphate	14.61
Calcium carbonate	7.42
Magnesium carbonate	9.76
Oxide of iron and alumina	0.12
Silica	1.60
Total solids	39.65

The close agreement of the waters of the Plain City and Harrisburg wells in the details of their mineral composition is strikingly shown in the two analyses last given.

SUB-SECTION D.

ONONDAGA LIMESTONE.

(WATERLIME AND LOWER HELDERBERG LIMESTONE OF OHIO REPORTS).

This great division is by far the most important source of underground water for all the higher uses that is to be found in the state. The thickness of the formation and its area, greatly exceeding as they do, all the other limestones of our column, make such a result both intelligible and probable. Its soluble character also comes into the account. It seems certain that some beds in the series have been dissolved in a larger way than others, thus giving rise to what appear to be water horizons in an essentially impervious rock.

The principal factor in its storage quality results from the vast periods in which it constituted the surface of the state, overspread only with the results of its own decay. During these protracted ages, covering the time from the Appalachian revolution, when the state became dry land, to the advent of the glacial period, the surface of the state undoubtedly stood at a higher level geographically than it now holds, for at least a portion of the time. The joint planes of limestones would consequently be widened and the underground drainage in this rock indefinitely extended and enlarged. Only thus can the present state of the buried limestone be understood or explained. That the limestone once stood at a higher level in its relation to the main drainage streams, is made evident in the fact that the drill often finds empty chambers, several feet in depth, as much as 100 or even 200 feet lower than the present drainage systems.

In recording the storage quality of the Onondaga limestone and the use already made of water derived from it by the towns of Ohio, it is easy to see that a beginning only has been thus far made. More and more, cities, villages, hamlets and isolated homes will learn to avail themselves of the vast amount of duly purified, though somewhat highly mineralized water which is stored in the joint spaces and rock chambers prepared by the processes of solution of earlier ages.

Among the cities and villages that are already depending upon the waters of the Onondaga limestone, the following may be named: Delphos, Lima, Kenton, Upper Sandusky, Bellefontaine, Marysville, Sabina, Mount Sterling. I will speak briefly of the supplies that several of these towns have secured.

(1) DELPHOS.

This town has put in a plant at the public expense during the last two years, expending $70,000 up to the present time. A location was selected in the valley, one mile south of town. At this point, only 16 feet of drift covered the limestone floor. Indeed there is but a thin covering of the glacial deposits in all this immediate region, as has been established by the numerous wells that have been drilled here within the last few years. The ordinary drift water-wells of the region are but fifteen to eighteen feet deep, but the drilled wells of later years have been carried down from 60 to 80 feet in depth, or from 40 to 60 feet in the rock, and great improvement in the water supply has thus resulted.

At the pumping station established by the city, a receiving well was dug 40 feet in diameter and 38 feet deep This is made a common reservoir for a series of seven wells, which are set in some instances within 50 feet of each other. The wells are all eight inches in diameter and all are 300 feet deep. There was no particular vein of water found, but additions were made all the way down and at a depth where the drill was stopped, a test of the first well showed a large enough volume to meet the requirements of the town. It has not been demonstrated that the seven wells are a necessity. It is possible that one would do the work of the entire series. Certainly, they are all intimately connected, as the water rises and falls in all of them together. Under normal conditions, while it does not flow, it comes within eight feet of the surface. Siphons are set at a depth of 25 feet, opening into the receiving well, and they are so adjusted as to charge themselves. In one of the wells an air lift is located at 125 feet below the surface and it is found to work with great advantage on the entire supply. The depth to which the wells were drilled rendered it inevitable that their supply would be more or less contaminated with sulphuretted hydrogen. This substance works against the good name of the water that carries it and the village supply at first suffered some disadvantages from this source, but by the aeration of the water the odor of the gas is entirely removed. The compressed air of the air-lift is also turned into the reservoir for a few minutes each day with satisfactory results.

Water was found in the first well at a depth of 150 feet in such quantity that the authorities in charge proposed at first to arrest the work at this point, but a sample was submitted to the State Board of Health for analysis. While the water was not condemned it was criticised as exceptionally hard. According to the analysis, the total solids amounted to 73 grains to the gallon, of which about one-fifth was composed of sulphates of lime and magnesia. Most of the public water supplies are now known to exceed these figures, but under the influence of the warning, the trustees proceeded to sink their well deeper and at a depth of 300 feet obtained a new supply which was counted by the people of the town "soft" in comparison with the earlier supply. An analysis recently made for the State Board of Health by Prof. N. W. Lord gives the following results:

Potassium sulphate	0.56
Sodium sulphate	2.22
Sodium chloride	1.98
Calcium carbonate	12.65
Calcium sulphate	4.53
Magnesium carbonate	9.37
Iron oxide	0.11
Alumina	0.13
Silica and silicates	1.18
Total solids,	32.73

If the analyses fairly represent the two grades of water, the grounds of the preference that is expressed by the people of the village are obvious and justifiable, but it is hard to understand how a lower vein of water in the same limestone stratum can carry less mineral matter than the higher. The two analyses quoted show less than half the total solids in the 300 feet supply than in the 150 feet level.

The maximum production of the system thus far has been 250,000 gallons per diem, but a steadily increasing use is sure to follow the introduction of the new supply.

(2) LIMA.

The water supply plant of Lima is owned and controlled by the city. The work was begun with the construction of a reservoir, formed by ponding a small stream which flowed a mile east of the town, but this scheme proved a failure in every respect. The water obtained was unsatisfactory in quality and in time of drought a failure in quantity was experienced which was fatal. This experience led to a search for a supply in the underlying strata, the storage quality of which had been abundantly demonstrated during the last dozen years in the scores and hundreds of oil wells that had been drilled in the immediate region. In numerous wells large flows of water had been found in the upper limestone. The city turned to the use of these deep waters in 1894. Six wells, located near the earlier plant, were drilled at this time and were from 118 to 180 feet in depth. The waters seem to be derived from two principal horizons, one located at 117 feet below the surface, and the other 170 below. The drift cover is shallow in the entire region, 8 to 20 feet covering most of the sections. The wells were drilled 8 inches in diameter, and all of them flow naturally. The strongest of the group is an abandoned oil well, bought by the city in the drought of 1895. It rendered material service to the water works at that time and has done so ever since. This well obtained its supply from a depth of 117 feet.

On the Fetter farm, one-half mile east of this city well, a fine water vein was struck at the depth named above, and this experience was again repeated in a third well, one-half mile further east than the Fetter well. That these wells are directly connected, was proved by the effect that the city pumps, when in operation, had on both, cutting off their artesian flow entirely. The steadiest and severest pumping never lowers the head more than fifteen feet, and when the pumps are stopped but a few seconds are required for the wells to regain their head. The maximum production was found on a special test to be 1,500,000 gallons per diem, and it seems as if this could be maintained.

As already noted, however, the rock water supply was preceded by a surface supply of unsatisfactory water. The old system was not abandoned on the introduction of the new, but the two are united and consequently affect each other more or less. The reservoir water is preferred by all who use water for steam production, on account of the excessive hardness of the rock water. By an analysis made at the introduction of the rock water by the State Board of Health, the total solids were found to reach the unusual figures of 112.8 grains to the gallon. By a later analysis, also made for the State Board of Health, the total solids reached a still higher figure, viz., 125.425 grains to the gallon. The results of the last analysis are given below.

Calcium sulphate	49.446
Calcium carbonate	40.100
Magnesium carbonate	35.748
Sodium chloride	.231
Total solids,	125.525

The unwillingness of those using steam to introduce water of this character into their boilers, can be well understood, but the objections on hygienic grounds are not as strong as might appear from the record. There is but slight probability, for example, that the large percentage of common salt reported is derived from organic pollution. The presence of salt in most of our deeper rock waters is well known.

While the character of the water for steam production is somewhat improved by the largest possible proportion of surface or reservoir water, the domestic use is undoubtely rendered less satisfactory by such admixture. The open reservoir allows a much freer development of minute forms of animal and vegetable life than are present in the city supply. This fact militates to some extent against the good repute of the water.

(3) KENTON.

This town makes exclusive use of rock water and has done so from the first. The plant was originally put in by a private company, but the village corporation retained the right to purchase, and, a few years since, exercised this right, paying $60,000 for the plant at that time. It has since expended a considerable amount upon the works. The town is in the same region of shallow drift already described. The deposits of the glacial period do not, as a rule, exceed 10 to 30 feet.

The rock nearest the surface at the water works station is the peculiar type of the Onondaga limestone, called by Prof. N. W. Winchell, the Tymochtee shale. It is here thin bedded, but scarcely shaly in structure. It is dark blue in color, and carries many black films on the surfaces of the several layers. No fossils are apparent in this division. No other exhibition of just this character of rock has been reported in the numerous wells drilled in the region for oil, gas or water during the last ten years. It proves troublesome to the driller.

An excellent opportunity to study the formation is afforded in the large well at the pumping station. The excavation is 100 feet or more in diameter at the surface and is carried vertically down for 25 to 30 feet; then in the southern half of the pit the rock was further taken out to the extent of 25 or 30 feet additional. And within the deepest area, three wells were drilled, these being added to 10 others in the same immediate neighborhood. All are located in the valley of the Scioto river, which is but a small and insignificant stream at this place. All the wells found water at about 125 feet below the natural surface. The water appears in a fairly strong vein and is cold and clear. It is also a perfectly steady supply. There is nothing to hint at any close connection of the water vein with the rainfall. In times of severest drought just as much water can be pumped as at other seasons. The average production of 450,000 gallons per diem, is a little in excess of the producing power of the wells. At least, the pumps are obliged to labor constantly night and day to keep up the supply. And when, for any reason, the draft is temporarily reduced, the water is found forthwith at a higher level in the well.

To reinforce the supply, the present trustees have made trial of a field 1½ miles south of the court house. The exact locality is the Calhoun farm on Taylor creek. During the last year a well was drilled here to the same horizon upon which the city wells depend and a noble supply was found available. The city engineer counted it good for 600,000 gallons per diem, but the voters of the town have refused to furnish the funds necessary for bringing in the new supply.

It is, however, a great thing to know that such an addition can be made to the system whenever the necessity becomes urgent. The Calhoun well is artesian, flowing with a small supply from the top of the pipe. A remarkable flow of excellent water was struck in the explorations for gas three and a half miles to the northeast on the McVitty farm. This well was begun on outcropping Niagara limestone and draws its water entirely from this formation. It still continues to be a vigorous fountain and the flowing water finds its way to streams that supply Findlay. A recent analysis made for the State Board of Health by Prof. C. C. Howard gives the following results, viz.:

Calcium sulphate	76.97
Calcium carbonate	10.29
Magnesium carbonate	18.83
Sodium chloride	.27
Total solids,	106.35

(4) UPPER SANDUSKY.

This town is supplied with water by a private company, made up mainly of non-resident capitalists. The water works were established in 1889. Water is taken from the Sandusky river and from a shallow well dug into the rock by the side of the river and not more than fifty feet distant from it. The well, however, receives its supply from the landward side, through what are termed "horizontal crevices." Though coming apparently from the land, the water may of course have been derived from the river at a higher elevation in its course. The well is 85 feet in diameter at the top, 70 feet at the bottom, and 17 feet, 3 inches in depth, the lowermost three feet only being in limestone. It is about 65 feet below the public square. No water is derived from the drift deposits which cover the limestone at this point. The drift of the valley generally consists of a foot or two of blue or drab clay, below which is ordinarily found a mass of cemented clay that seems thoroughly impervious to water. When first dug, the well was tested and its daily production was found to be at the rate of 500,000 gallons. Sulphur water is so common in all this region that the company dared not go lower, through fear of striking a strongly impregnated vein. Before resorting to this shallow supply, two wells were sunk in the rock, one to a depth of 28 feet and the other to a depth of 80 feet. Water was found in abundance in both, but both supplies were rejected because of the large amount of sulphuretted hydrogen present. Mr. John Henderson, superintendent of the works, thinks that the production of the present well has increased by 50 per cent. since it was first sunk. Such a result is not in itself improbable.

Part of the water pumped, as already stated, is from the river direct, and there is no way apparent of determining the proportions that these two sources contribute to the pumps. The river water is naturally well stocked with microscopic life during the summer months, and also with small fish and the lower forms of vegetation which abound in such running waters. Strainers and filters are brought into requisition so that comparatively little trouble results from this source.

Though sulphuretted hydrogen is not found in the water supply, the results of analysis show very clearly that it has been there and that its sulphur has been converted by oxidation into sulphuric acid. A recent analysis by Prof. C. C. Howard, for the State Board of Health, shows the mineral composition indicated below.

Calcium sulphate	170.880
Calcium carbonate	.691
Magnesium carbonate	24.576
Sodium chloride	.138

These figures show that the lime which undoubtedly entered the water principally as bicarbonate has been almost entirely converted into sulphate. While calcium sulphate is not unusual in the Onondaga limestone, it does not seem probable that the water obtained any large proportion of the sulphate which it carries by the direct solution of this substance. An easier explanation of its presence is at hand, as already indicated. The figures of this analysis demonstrate this view. They show an extraordinary amount of calcium sulphate, with an insignificant quantity of calcium carbonate, which latter element we know can never be absent from atmospheric water traversing limestone rocks.

The percentage of calcium sulphate is the highest yet reported from the potable waters of Ohio.

(5) DELAWARE.

The water supply of this town is also under control of a private corporation which began its work in 1889. Its first well was located in the Olentangy valley, about two miles northeast of the town. The well was 36 feet in diameter and 36 feet also in depth. The deposit through which it passed was called "black gravel," the color being due to the abundant fragments of black shale distributed among the ordinary limestone pebbles of the drift.

This well furnished, when first struck, a good supply, but when the summer drought came on, its volume was reduced below the safety line. After an experience of several years the company determined to make trial of the rock in the immediate neighborhood of the well. Capt. C. W. Wiles, the superintendent, was led to expect success by the occurrence of a spring emerging from the rock in a small island in the river. Seeing water thus issuing from the rock, Capt. Wiles was led to believe that an appeal by the drill would not be unavailing. The severe drought of 1895 had made some increase indispensable to the maintenance of the city supply. Drilling was therefore undertaken in the spring of 1896. The location of the well is near the plant already established. The section found in the descent is as follows:

Soil	6	feet.
Gravel, mainly coarse	10	"
Gravel and sand	4	"
White limestone	60	"
"Brown sandstone"	70	"
Blue limestone	4	"
"White sandstone"	10	"
Limestone	10	"
"Soapstone"	6	"
Limestone, light in color	15	"
Shale, black		

This series may be geologically distributed as follows:

Drift	20	feet.
Corniferous limestone (Devonian)	60	"
Onondaga limestone (Silurian)	175	"

Water was found all the way down. It began to rise under artesian pressure as soon as the limestone was penetrated. By the time the drill was 45 feet down, the water had risen to 35 feet in the well No important additions were made after a depth of 225 feet was reached, but as the driller's apparatus was prepared to sink to 250 feet, the work was continued to that point, and even five feet below. A shale as black as the darkest of the Ohio shale was found at this point, and this would by itself have led to the suspension of the drilling, irrespective of the necessity imposed by the length of the cable.

The so-called "sandstones" of the Onondaga column, proved on examination to be, as might have been expected, magnesian limestones. The water is artesian, but the head is not more than three feet, and the flow is correspondingly feeble.

On the application of proper tests, the well was counted good for 60,000 gallons per diem. During the drought of October, 1897, the addition from this source to the drift well supply was timely and effective.

The production of the well has been greatly increased by putting in an air lift at a depth of 140 feet, the air being under a pressure of 45 pounds. It increases the yield of the well so much that the pump easily outruns its capacity. After two hours' work of the pumps, an hour's interval is required for the well to recover its normal supply.

The daily average of production of rock and drift water combined for the month of November, 1897, was 277,600 gallons. The maximum monthly average for last year was 368,945 gallons.

The mineral constitution of the water is shown in the following analysis made for the State Board of Health by Prof. N. W. Lord.

Sodium sulphate	1.58
Potassium sulphate	0.44
Calcium sulphate	17.00
Calcium carbonate	11.00
Magnesium carbonate	11.75
Sodium chloride	0.22
Silica and silicates	1.11
Total solids,	43.47

The water is used in considerable quantity by the railroads and by the electric light company. No unusual complaint has been made against it on the ground of hardness. It is said that the rock water does not appear to be more objectionable than the drift water, but perhaps the exclusive use of the former would bring ground of complaint.

(6) MARYSVILLE.

Marysville is another town making use of water from the Onondaga limestone for its general supply, which is furnished by a private company, of which John F. Zwerner is president and manager. The company began its work about 1890. The fact that underground water was available to the town had been demonstrated by a company calling itself the Marysville Gas and Oil Company, organized to test the Trenton limestone in their immediate vicinity. The well was a failure as to the purpose for which it was undertaken, but an abundant supply of water was found all through the upper limestones. At 145 feet, a strong vein was reached, and at 375 feet, a vein highly impregnated with salt and sulphur was struck. All of this water was under artesian pressure. The vein last named was forthwith utilized by the building of a bath house near the well, and this is still maintained. The salt and sulphur water is not abundant enough to meet all the demands of the establishment. It is probable if there were enough of this water that it would gain a reputation as a medicinal agent in certain forms of disease. It is quite similar in composition to that of Mt. Clemens, Michigan, which has become an important health resort.

The water company began its operation by drilling four wells in the drift in the valley, east of the court house. They found water enough and proceeded to supply the town, but after several years' use, it was found to be more or less impregnated with iron and perhaps, to some extent, with the sulphurous products previously unlocked by the so-called gas well. During the present year, this first supply has been abandoned, and the entire plant has been made to depend on a water vein reached in the rock at a depth of 148 feet below the surface, immediately adjoining the city wells. The drift was 88 feet and at a depth of sixty feet in the limestone the drill dropped three feet, having struck one of the chambers already alluded to, that stand for pre-glacial weathering and erosion under a higher altitude of this portion of the state. The water was found in a dark blue limestone which is characteristic of the Onondaga series.

The water vein found at this point proved to be exceptionally vigorous. It rose to within eight feet of the surface and a test of its capacity made at the time it was finished showed a production of 1,200,000 gallons in ten hours' time. The entire supply of the town has since been drawn from this source, the average daily production ranging between 500,000 and 800,000 gallons. The discovery is one of vital importance to Marysville and to the entire district to which it belongs.

The analysis of the Marysville water, made by Prof. N. W. Lord, is herewith appended. It is furnished by the State Board of Health. (Grains to the U. S. gallon.)

Potassium sulphate	0.62
Sodium sulphate	6.45
Calcium sulphate	43.07
Magnesium carbonate	16.78
Magnesium sulphate	5.29
Sodium chloride	1.65
Alumina and iron	0.40
Silica and silicates	1.63
Total solids,	75.89

Of the total solids, it will be observed that 55.48 grains or nearly five-sevenths are sulphates, but about an eighth of them are alkaline and do something toward reducing the hardness of the water.

(7) MARION.

The principal water supply of Marion is furnished by a private company, organized in 1890 under the laws of New Jersey, and by capitalists of that state. Thus far, it has drawn the water it supplies to the town mainly from several drift wells connected with a shallow reservoir, but in addition it has drilled five wells, each ten inches in diameter and 200 feet deep. These wells reached the rock at a depth of 55 to 60 feet. But in the immediate neighborhood there are many thinner sections of drift reported. Some of them do not exceed ten feet. Water was found all the way down and a considerable production is promised, but the rock wells are counted as merely auxiliary to the reservoir system and have not been fully harnessed into the plant. Mineral analyses of the water of the reservoir and the wells respectively, seem to show but little excess of total solids in the rock water above that of the reservoir. The figures apparently indicate a considerable amount of sulphates in both. The drift water is not thoroughly satisfactory to the company or to its patrons, chiefly because of the large percentage of organic matter derived from the growth of fresh water algæ in the reservoir, and it is probable that Marion will be obliged to follow the example of most of its neighbors and come to depend largely or entirely upon the rock supply.

The heavy pumping of the drift wells for the city line has exhausted many of the farmers' wells in the neighborhood. The latter are, as a rule, shallow, ranging in depth between ten and twenty feet.

(8) BELLEFONTAINE.

This town furnishes another excellent example of missing what it sought for at the point of the drill, and of finding as a result of its search what is worth infinitely more to it. It sought for Findlay gas or Lima oil in the Trenton limestone, and would have counted itself supremely fortunate if it had found either. If it had succeeded the result would probably have been a short lived excitement, giving rise to great expectations impossible to be realized, and accompanied with an extravagant advance in the price of real estate. After a few years the gas would have been exhausted, the factories established on it would have been dismantled, and the fictitious values of real estate would have gone through a painful readjustment. Thus the entire community would have slowly recovered from the effects of the speculative debauch called a "boom." If oil had been found, the experience of the town would have been less unfavorable, but in any case this underground wealth would have soon been exhausted without necessarily leaving any great permanent advantage to the town.

All this Bellefontaine missed, but found in place of it an invaluable supply of pure water, unnoticed at the time and only forced upon its attention by the failure of other sources of water supply, but bound to continue, now that it is discovered, through generations and centuries and, indeed, as long as the general conditions of the Mississippi Valley remain essentially undisturbed.

In drilling the trial well for gas in 1886, which was known as the Carter well from the name of the owner of the lot upon which the well was located, the drift deposits were found to be about 80 feet thick. At 160 feet a great volume of delightfully cool and clear water was struck, which carried, however, a small quantity of sulphuretted hydrogen. It rose with great force and showed a head of pressure of at least twelve feet above the surface. The water was allowed to flow unobstructed for several months. An examination of the record of the well shows that the water was found in the Onondaga limestone, the same great stratum in which so much of the water supply of central Ohio is now being found.

The town had recognized the necessity of a public supply some years before this discovery was made. In 1883 the work was begun under a board of trustees elected for this purpose. They called to their aid a hydraulic engineer from northern Ohio. Under his advice their first reliance for a supply was on springs rising in the high ground to the eastward, and also on impounded water from a small stream which flowed through the town, also from the eastward. A reservoir was constructed and the town was piped. The pressure from the reservoir was 90 pounds to the square inch at the public square, and as far as this element is concerned, it furnished ample protection against fire for the highest buildings of the town. But the supply proved far from satisfactory. It was inadequate much of the time and in summer what there was of it was warm and offensive to both taste and smell. In short, the works proved a failure both as to quantity and quality. Consequently the sight of such a noble fountain from the underlying rocks as the so-called gas well yielded was highly appreciated, and the attempt was forthwith made by the water works trustees to reach the same source by drilling on the high ground near the reservoir to the horizon struck in the well. This well was carried down 325 feet, but water was not found in it in important amount. The pressure of a summer drought was upon the board, and the decision was soon reached to come down to the source of rock water already described. The gas well, so-called, was purchased by the trustees and a pumping station was established here. A second well was drilled forthwith to a depth of 160 feet. The water vein struck in number one was found also in number two, which was removed but fifty feet from number one. Analysis of the water was made in June, 1888, by Prof C. C. Howard, of Columbus, giving the following results: (1)

	1.	2.
Carbonate of lime	8.33	20.44
Sulphate of lime	3.62	3.82
Carbonate of magnesia	5.19	3.56
Sulphate of alumina	2.92	....
Chloride of sodium	0.42	0.015
Total solids	20.48	27.840

Professor Howard called attention to the low proportion of calcium salts in this water. The water was not as hard as most rock water, or even as much drift water. He also noted that the sulphates would protect lead pipes which carried it from corrosion.

A second analysis was made by the same chemist during the present year for the State Board of Health with the following results: (Column 2 of table.)

The figures do not agree in all respects with those first obtained. The calcium salts are still low for rock water from this horizon, but they are 150 per cent. higher than the proportions reported in the first analysis. The sulphates agree approximately in both analyses. The proportions of magnesium carbonate differ largely and no sulphate of alumina is reported in the last result, while nearly three per cent. is found in the first. This substance is very rarely reported in Ohio waters, and all things considered, it seems probable that some change has taken place in this rock water owing to the circulation given to it through the action of the pumps. The common salt is only one-third as much in the last analysis as in the first.

The present supply has seemed to fully meet all hygienic demands. Typhoid fever and diphtheria were formerly of frequent occurrence in the town, but have entirely disappeared as home productions, and in other respects the new water supply has fully approved itself.

The pumping capacity of the two wells is 1,500,000 gallons per diem and a daily average of about 1,000,000 gallons is furnished at the present time. The railroads passing through Bellefontaine make large use of the city water. In September last the C. C. C. & St. L. lines used 5,000,000 gallons.

(9) TOLEDO.

This city also comes into the present list from the fact that it has numerous artesian wells that get their water from the great limestone series that underlies it. These wells range in depth from 175 to 400 feet. At the present time the new ones that are drilled are generally carried from 250 to 325 feet. The earliest wells got flowing water at 175 feet, but the supply is not abundant. A six-inch well, yielding twenty to thirty thousand gallons per diem is counted a successful well, and sometimes the production does not exceed 1,000 gallons. Since their multiplication the water has ceased to flow. It still rises a hundred feet or so from the horizon where it is found.

If the views already advanced as to the mode of storage of water in these limestone strata are correct, it would appear that during its pre-glacial history northern Ohio stood at least 300 to 400 feet higher than it now does. The action of the atmosphere could thus take effect on the joints of the limestone and on the material of the rock itself, far below any present possibilities. The deposits of the drift within the boundaries of Toledo are generally found to be about 80 feet thick.

Many other facts harmonizing well with the views above presented as to the pre-glacial action of the atmosphere on limestone rocks have been gathered in northern Ohio.

(10) TIFFIN.

This city has secured an excellent supply of rock water for all its varied necessities unless an exception should be made in the matter of water for boilers or steam production. Seven wells have been drilled, each of them ten inches in diameter and averaging 260 feet in depth. They are located in the valley of the Sandusky river, the bed of which is bare rock for several miles on either side of Tiffin. It is possible that a greater number of wells has been drilled than is absolutely necessary for the use to which they are put, and the depth of the wells may be greater than necessity or advantage requires. Perhaps five wells 100 feet deep would produce as much water as the entire system now supplies. The quality of the water would certainly not be inferior. The wells are arranged practically in line, the extremes being 1800 feet apart. They are connected together and the pump draws directly from them. The average demand for summer water is at present about one and a quarter million gallons per diem. When the pumping is steadiest, the level of the water is found to sink in all the wells alike. Their connection with each other is thus shown.

The present limit of depth has been observed so as to escape the sulphur water that would certainly be reached a little lower in the series. All the facts pertaining to this underground water have been thoroughly learned in the course of the extended search for gas and oil that has gone forward in and around Tiffin during the last 20 years.

Before drilling the wells in the rock, the water works board seriously considered the project of going to the famous Mohawk Springs, a few miles south of the city for its supply, but measurement showed the daily production of the springs to be but 500,000 gallons, which was altogether inadequate for even the demand at that time. The expense of piping the water from the springs would have been heavy and this was also considered in the final determination of the question.

No analysis of the city water was obtained, but it is fair to consider it of the usual type of water from the Onondaga limestone, i. e., moderately or excessively high in sulphates and carbonates of lime and magnesia.

(11) CLYDE

West and north of the village, artesian wells of large production have been known for a number of years, but the water is generally charged with sulphuretted hydrogen. The De Witt well, one and one-half miles west, and the Durland well, four miles north of the village, are good examples of this class.

The village has spent forty thousand dollars in the last few years in putting in a public water plant. It began with drift wells and had five such wells at its disposal when it began its public distribution. These wells are 55 to 60 feet in depth. There was added a large reservoir, 15 feet square and 45 feet deep, which reached a water vein and from which the pumps drew their supply. The water in the wells was artesian, their overflows being conducted to the reservoir above named.

In these drift wells a hard and solid stratum was found at the bottom that was counted rock by those employed in sinking the wells, but it has proved to be nothing more than a bed of cemented sand and gravel, for in subsequent work the drive pipe was forced through this stratum and a considerable thickness of drift was found below it.

The experience referred to in the preceding statement was gained in 1896, when the water works trustees determined to add one rock well to the seven drift wells already in use. The rock well was carried down 230 feet, the last ten feet of which were in the great sheet of Onondaga limestone. Water was found at the top of this stratum and under artesian pressure, the water rising to within four or five feet of the surface. The entire public supply of the village has since been furnished by this well, but it does not exceed 125,000 to 130 000 gallons per diem. The drift wells draw their supply from a common source, as is proved by the action they exert on each other. When the reservoir is pumped low all the wells that supply it cease flowing.

The water from the shallow wells is counted harder than the rock water, but as no analyses are at hand we are not obliged to adopt this opinion .

(12) BELLEVUE.

This village, like so many already named, obtains its water supply from the Onondaga limestone series, and as in so many cases already noted, it has derived its experience as to underground water from its efforts to find gas or oil while the spell of Pittsburgh and Findlay were in force upon the entire state.

A shallow cover of lake sand and gravel, together with occasional patches of boulder clay, constitute the surface in and immediately around Bellevue. The bedded rock is easily reached at many points.

Creech's quarry, one-half mile west of the village, has been worked for a long term of years and on a large scale. The quarry shows a total thickness of fifty feet. The strata belong high up in the great formation with which we are now concerned, viz., the Onondaga or Lower Helderberg limestone. This rock as found here is exceedingly permeable, through causes that have been once and again explained in the preceding discussions. In particular it is everywhere traversed by two sets of divisional planes, locally called "joints" and "crevices." The latter of these are described as always vertical, while the "joints" may depart to some extent from the perpendicular. There can be little doubt that the two regular sets of joints of stratified rocks are the dividing planes in this case. By reason of wide open passage ways, communicating freely with one another by a thousand connecting channels, Bellevue and its immediate neighborhood are provided with a very effective drainage system. All surface water is promptly taken care of by excavations in the drift, carried to the surface of the rock. The need of sewers has never been experienced here. It is also known that a strong flow of water sets through the limestone toward the lake, that is, to the northward. As will presently be shown, the village avails itself of this flowing water for a public supply, consequently it protects the region from under which its water supply passes. The artificial sink holes above referred to are allowed by the council only to the northward of the districts in which the water works are located.

The water works board of the village drilled their first well within four feet of the abandoned gas well. Water was found in large volume at 185 feet, but it was so strongly impregnated with sulphuretted hydrogen that it was abandoned as unsatisfactory for public use. It was thought at the time that the contamination came from gas escaping from the Trenton limestone, which was reached in the preceding well. But such mode of origin is not necessary; there are many nearer sources in the series that underlies Bellevue.

A second well was drilled in 1895 to a depth of 204 feet. Water was found at 60 feet, which evidently flowed to the northward, but it was thought best to go deeper. At 196 feet, the tools dropped 18 inches through a pre-existing cavity, which must stand for sub-aerial solution and removal at some earlier day. At a depth of 204 feet the drill was stopped and a double acting pump was set at work for seven days continuously. The production of the well was found to be 500,000 gallons per diem, and at the end of this prolonged test, the water in the well was found 19 feet higher than at the outset. The average consumption of the town is very near the average production of the well, but impounded water is preferred for steam production in the village, and this is separately furnished. The open character of the underlying rock is well shown in the fact that in drilling, very few chips are brought up. As the rock fragments are consecutively set free some current of water carries them out of sight.

SUB-SECTION E.

THE CORNIFEROUS LIMESTONE.

The formation now to be considered is of small importance as a source of water in Ohio, mainly because of its comparatively small area. Furthermore, its natural cover in the rock series is the Ohio shale, which is an impervious formation, when any considerable amount of it remains. We have, however, a few instances in which flowing waters and generous springs issue from this sheet of limestone, but no instance of its use as a source of public water supply occurs in the state so far as known.

(1) COLUMBUS.

In a small district of this city several flowing wells drilled to the horizon here indicated have been struck. The water in them is strongly impregnated with sulphuretted hydrogen, but it is not certain that this feature depends on the limestone. In fact, it is rather probable that the sulphurous character of the water is derived from the thin band of shale overlying the limestone. The drift of the immediate region also abounds in fragments of shale, and particularly in the pyrite nodules of this formation, which being harder than the rock that originally enclosed them have survived while the shale has perished. The wells in question are all located on West Mound and Main streets, near the intersections of Canal and Water streets. There are four wells to be counted in this series, the first one having been drilled in 1884 and the others within two or three years thereafter. They belong to the parties named below.

Schauweker Brothers, tanners.
T. Lewis & Sons, tanners.
Columbus Soap Works.
Hardesty Brothers, millers.

All these wells appear to reach the same horizon of water, though the difference in their production is large, but the production of one affects the rest to a considerable extent. It has been impossible to get the exact records of the drilling on account of the interval since they were put down, but it seems pretty well settled that all of them penetrated a thin bed of the Ohio shale at a depth of about a hundred feet below the surface before striking the limestone, and that the principal water vein is met a few feet below the surface of the limestone. In the Lewis well the greatest supply comes from 132 feet. The water has a constant temperature of 52 degrees F., and on this fact its most important uses depend, viz., for the condensation of steam in the flouring mill, and for preserving hides in the tannery in the warm weather of summer.

The water is so rank with sulphuretted hydrogen as to be disagreeable to many, but by others it has been counted medicinal in its effects and for a time it was regularly sold through the city from a wagon employed for this purpose.

Before getting down to the sulphur water other water veins were struck in drilling through the drift; but it was only the rock water that proved artesian and its flow shows but a comparatively slight head of pressure. The Hardesty well is a particularly strong one.

In the north part of the city there are several flowing wells from the drift, the most vigorous of which is one drilled a year ago at the corner of Eleventh avenue and Summit street. The well is shallow, but its original volume was large. It yields the ordinary quality of the drift water of the region. The Ohio shale lies but a few feet below the surface here and the ground rises with a considerable grade to the eastward. The natural drainage is to the westward and a large body of water is moving in this direction upon the sloping surface of the shale, and through the drift that covers it when the latter consists of gravel. There is no apparent chance for this water to secure adequate purification if once seriously polluted, but flowing from the well, as it does, with a strong current, it impresses those who see it as coming from a deep source and therefore as possessing all the characteristics of rock water.

A fine spring enters the Scioto river from the westward, a few miles below Columbus. It is known as the Wyandotte Spring, tradition connecting it with the Indian occupation of the country, a hundred years ago. This spring shows all the characteristics of a limestone spring. It emerges from the joints of the Corniferous limestone, duly widened by solution. There is but a shallow cover of drift in the immediate region. Undoubtedly if we could follow back this vigorous flow to its source, we should find a considerable underground stream, draining a large territory, receiving tributaries from either side, quite after the fashion of surface streams of like volume.

The Scioto river is known to receive notable accessions to its flow from sources like this.

Some of the water referred to this stratum may properly be referred to the succeeding formation, being affected by its contact with or stay in the lower portions of the next overlying stratum.

SUB SECTION F.

THE OHIO SHALE.

It is only at the junction of the great shale stratum with the Devonian limestone that any considerable production of water can be referred to the formation named above. Water finding its way through the lower beds of the shale attacks and dissolves the underlying limestones to a greater or less extent, and when the conditions are favorable large springs appear at this horizon.

An excellent example of these conditions can be seen in the well-known sulphur spring, six miles above Worthington, in the Olentangy valley. The spring comes in from the eastward. It has a strong flow and the water is heavily charged with sulphuretted hydrogen. A white precipitate of sulphur discolors the Olentangy for a dozen rods or so below the point where the spring enters the river.

The famous spring of the Sunfish valley in Pike county, known as Campbell's Spring, comes under this head, that is, it emerges from the rock just at the junction of the shale and limestone. The limestone at this point is not, however, the Devonian limestone, but by overlap, the shale here rests on the Onondaga. The shale from under which this spring comes to light, rises into uplands, 300 to 400 feet above the valley level. The spring has volume enough when it first comes to light for a mill stream, but it is too near the level of the valley to give the necessary head. Some years ago an attempt was made to obtain mill-power from it by confining it in a water tower built of stone for this purpose, but as soon as a foot or two of head was reached in the tower the stream burst out in a new place, 50 to 100 feet above its old point of escape, rendering all the work done futile.

The water of Campbell's spring is not sulphurous and its character has not therefore been affected by the overlying shale. It is probable that the traditions of the neighborhood in regard to the spring are well founded, viz., that a surface stream flowing in a valley several miles to the westward disappears abruptly, passing out of sight in the upper beds of the limestone. The quality of the water and the general conditions of the spring agree very well with this view.

In a well drilled 100 feet into the Ohio shale, near the center of the village of Worthington, a small amount of water was found, but its quality was too highly mineralized to allow its use as a potable supply. The mineral content of the water was principally sulphate of alumina, but the percentage was not determined. Iron is always present in large amount in this shale water. Water is also found in the great shale formation when the latter is overlaid by considerable deposits of drift, as in the extreme northwestern counties of the state. In such cases the water carries notable quantities of common salt as a rule. In numerous instances the quantity is so large as to make the water unsuitable for use as household supply or as stock water.

SUB-SECTION G.

THE WAVERLY GROUP.

No characteristic quality or condition has been noted in any of the strata composing the Waverly group, so far as the water supply is concerned, except in a single instance to be hereafter noted. The entire group is poor in water. In large areas, in which the lowermost and middle elements make the surface rocks there is an almost complete lack of water, as shown in springs. In summer droughts such regions become almost uninhabitable for man and beast, except as rain water has been previously artifically stored.

(1) MEDINA.

A single public supply is found in the upper portion of the Cuyahoga shale at Medina. The drift water of this region is excessively hard and consequently makes much trouble for those who use it in steam boilers. To secure a supply that would relieve them from this difficulty has been an object of resolute search on the part of a few manufacturers in the town, among whom Mr. A. I. Root has been especially active and enterprising. In this search Mr. Root has drilled seven wells at his own expense, the wells ranging in depth from 25 to 160 feet. He found that it is only by effectually shutting off the water derived from the drift that the character of the rock water can be recognized.

When, eight or ten years ago, all the enterprising towns of Ohio entered upon this search for gas or oil in their immediate neighborhoods, a small supply of water, differing in quality from the water in the drift was struck in the trial well that was drilled at Medina in this interest. The grist mill located near the well availed itself of the discovery and found the water happily adapted to boiler use, although it was somewhat saline. The rock water of the entire region has, however, this character. But after learning the experience of the mill in obtaining water free from lime salts, Mr. Root determined to further test the rock on his own ground at the horizon which had been already developed. He was rewarded by a moderate yield of water that was free from lime, the surface and drift waters having been carefully excluded.

Influenced by this experience, the village decided, in 1895, to establish a public water supply, and up to this time it has invested about $7,500 in its plant. Two wells, eight inches in diameter, were drilled in the valley near the original trial well and near the mill. The drift at this point is but 10 to 12 feet in thickness and at 40 feet in a sandy shale, a moderate water vein was struck, and again at 80 a vein that was counted excellent was reached. The pumps were set at work upon the supply and the yield of the new well was estimated at 90 barrels an hour, but at present its production is found on steady pumping to be about 70 barrels in an hour, which is at the rate of 53,000 gallons per diem. But as the pumps run only 15 hours out of the 24, the present production does not exceed 35,000 gallons per diem.

The water is popularly called "soda water." It corrodes iron pipes when reaching them in contact with the atmosphere, but in boilers it works very kindly. When used for sprinkling the streets, it leaves a white crust on evaporation; it is also used as potable water, but with scant favor. The State Board of Health, after a chemical analysis, gave it, though rather grudgingly, approval. As far as the hygienic indications were concerned, there was nothing to condemn the water, aside from the large percentage of common salt, but as this is known to be a constant product of the rock water of the region, no unfavorable conclusions were drawn from its presence. The unusual percentage of total solids naturally attracted attention, but as they were found to be referable neither to temporary nor permanent hardness, but principally to sodium sulphate, the water was allowed to pass muster. It is found by experience, however, to be unwholesome when used as a regular supply for drinking water.

The total solids in the two analyses were found to be respectively 243 and 238 grains to the gallon, while the chlorine in the first analysis showed 33 grains to the gallon, and in the second 69 grains to the gallon. Of the total solids, common salt constitutes, as is seen, an important part.

The Medina water is thus seen to be a distinctly alkaline water, and this fact accounts for the approval it receives for boiler use. The discovery is one of great importance to a number of counties in northern Ohio, in which drift water is now exclusively used in boilers. The constant expense for chemicals to destroy the scale, and the frequent interruption of business in getting rid of the obstructing products, together with the shorter life of the boilers themselves, make the discovery of soft water, for such practically alkaline water is, an important desideratum. Parts of Trumbull, Geauga, Cuyahoga, Wayne, Ashland, Richland and Holmes would seem to be included in this list.

As already noted, the ordinary wells in many parts of Medina county and particularly to the southward of the county seat, carry a notable amount of common salt. In a few cases it is found necessary to reject the water on this account.

A well drilled by the Electric Light and Power Company of the village, a little to the westward of the wells already described, found water of the same quality at the same horizon, but obtained a much more abundant supply.

A third analysis recently executed by Prof. C. C. Howard for the State Board of Health gives the following somewhat surprising results.

Sodium sulphate	238.70
Sodium carbonate	62.88
Magnesium carbonate	0.42
Calcium sulphate	3.05
Sodium chloride	6.066
Total solids,	361.72

Water, such as is here shown, differs in a marked degree from any other water known in the state. Its alkaline quality is pronounced. It will also be noted that the total solids greatly exceed in this analysis even the high figures previously reported.

(2) ORRVILLE.

The excellent water supply of Orrville it seems necessary to refer to the Logan sandstone, which is the conglomeritic phase of the Waverly group, though some doubt may exist as to whether the water is derived from the Waverly conglomerate or from the first pebble rock that overlies the latter, namely, the Sharon division of the Carboniferous conglomerate. On the whole the reference here made seems the more probable.

The Logan conglomerate is a less important element in northern than it is in central Ohio, but it is generally a porous rock made up of coarse sand in which pebbles, often of large size, are imbedded. It is a water-bearing stratum wherever found at the surface.

It forms a prominent shoulder of high ground in Richland, Ashland and Wayne counties, which had a very important effect in arresting the advance of the ice sheet in this part of the state. Because of its resistance to degradation, and its consequent high altitude, the glacial boundary makes nearly a right angle here, changing its direction from west to very nearly south. A physical model of the state brings out the cause of this abrupt deflection in a striking manner.

Within the last four years, Orrville has adopted a public system of water supply, and its experience has been thus far favorable in all respects. The work has been carried forward efficiently and economically, and the entire population shares in the advantages that an excellent water supply gives to a town. At the outset of their labors, the trustees tested the public square of the village, hoping to find a centrally located supply available. A well was drilled 150 feet deep at this point, but though water was struck in both drift and rock, no flow was obtained and since fine flowing wells are common in the region, the well was consequently counted a failure. They next turned their attention to the low ground north of the center, where on several previous trials made by the neighboring farmers, excellent fountains had been obtained. Two acres were purchased here; they constitute a part of the old lake bottom that gives rise to so much excellent garden land around Orrville. The altitude of the ground purchased is about 1025 feet above tide, or 35 feet lower than the railway crossing to the southward. Four wells were drilled here from 102 to 158 feet in depth; the wells were eight inches in diameter when begun, but after a little were reduced to six inches. The cover of drift was found to be about 30 feet in thickness. When the rock was reached, water was at once found, but the amount increased as the drill descended. Perhaps the drilling was continued after the full increase of the supply had been reached. None of these public wells show a remarkable production, but one of the number yielded for six weeks 125,000 to 140,000 gallons per diem. The four wells are connected now and the maximum production thus far has been 225,000 gallons in 24 hours. The severe drought of the autumn of 1897 seems to have had a temporary effect upon the production of the wells. The character of the water is not in full accord with its sandstone origin. It has obtained some mineral matter from the drift through which it must have passed into the rock. An analysis made by Prof. H. A. Weber of the Ohio State University gives the following results:

Organic matter..........	7.44	parts in 1,000,000.
Chlorine	9.00	" "
Mineral matter	285.00	" "

This is equivalent to 19.95 grains to the gallon. Prof. Weber remarks in his report that the Orrville water is chemically one of the best drinking waters he has examined in the state. In boilers it forms a thin scale, but gives less trouble of this kind than most Ohio waters. The railroads passing through Orrville approve the water and make large use of it for their locomotives.

D. F. Griffith, who has a flouring mill on the east side of the corporation, has drilled a well which obtains its water supply from about 100 feet below the surface, and which flows 31 barrels per hour. The total depth of the well is 150 feet.

Henry H. Forrer has a fountain well obtained at a depth of 72 feet, one and one-half miles east of the village. Most of the flowing wells of the neighborhood show a pressure head of ten to twelve feet. In the Forrer well, but ten feet of drift were found above the rock. A conglomerate stratum crops out near the well, which is referred to the Sharon conglomerate by the former Geological Survey of this state, but this reference does not decisively settle its character.

(3) EAST UNION.

In some of the townships south of Orrville, and notably in East Union, there are several artesian wells, and some of them are of remarkable character. They are well represented by the fountain of John S. Amstutz, who resides six miles southwest of the village of Orrville. Twenty years ago he drilled a well to the depth of 120 feet. The drift was but twelve feet in thickness, under which the Cuyahoga shale was reached. He continued in this formation, known as "mud rock" for 108 feet. At a depth of 99 feet he struck a noble vein of flowing water, which rose to a head of 24 feet, a fact unprecedented in this state so far as my knowledge goes. The head has since been reduced to fourteen feet. The original production of the well was six barrels to the minute, which is at the rate of 250,000 gallons per diem. The water originally rose with such force as to throw out stones two or three inches in diameter.

The happy thought occurred to Mr. Amstutz to utilize the power of this surprising water-head. Accordingly he constructed a water wheel 12½ feet in diameter, to which the waste of the flowing well was conducted. By means of this power he grinds feed for his stock and executes other mechanical work appropriate to the demands of a farm.

A noble fountain is also found in a well drilled for School House No. 7, East Union Township, 7½ miles southwest from Orrville. The well is 89 feet deep, and its flow completely fills a three-inch pipe. Its splendid production makes it well known throughout this part of the county.

(4) NEW LONDON.

This village has no public water supply and a comparatively small number of satisfactory private wells. The latter are either shallow drift wells, or else deep and expensive drilled wells; the latter are operated mainly by wind pumps. Of the deep wells the number is small.

The drift beds in the village and in the immediate vicinity are generally heavy. Sections occur of at least 100 feet, dry from start to finish, particularly after 10 to 15 feet of the uppermost beds have been passed.

The first bedded rock to be reached below the drift is the Cuyahoga shale, but as this is for the most part destitute of water, the Berea grit constitutes the objective point of the driller. The upper portion of the Berea is found to be moderately productive of potable water, but salt is generally found in the water when the drill is continued to the bottom of the sandstone formation.

Occasionally, however, the Cuyahoga shale assumes a sandy character and yields an acceptable supply for a farm, including domestic use and provision for stock. Such an example is to be found on the farm of Mr. A. Crittenden, a little to the east of Ruggles' Corners.

In the village, the well of George E. Washburn, Esq., may be taken as a representative of the deep wells of the vicinity. He found 105 feet of drift, casing the water off to that depth. Below this there were but 60 feet of Cuyahoga shale, the balance of the formation having yielded to pre-glacial waste and glacial erosion in past time. At 150 feet, the Berea shale, namely, the band of black shale that directly overlies the Berea grit, was struck. Of this, the usual thickness, viz., 15 feet, was found, and at 165 feet the surface of the Berea sandstone was reached. The uppermost 20 feet of the stratum were moderately coarse in grain and water appeared in it in fair quantity. As the drill descended, salt water came in. The work was continued until a total depth of 235 feet was reached. The entire thickness of the Berea was penetrated, and possibly a few feet of the underlying Bedford were included in the well section. If all the rock below 165 feet is assigned to the Berea grit, its thickness here is 70 feet.

This well is a failure as a source of domestic supply, and also for stock water, though horses will drink it when very thirsty. If the drill had been stopped at 185 feet the well would in all probability have been at least moderately successful.

The Arnold well, also located within the village limits, reaches the Berea grit by a section very like the one already described, but does not penetrate the entire stratum, and thus furnishes water of acceptable quality. The wind pump connected with it will fill a 200-barrel tank in about fifteen hours.

North of the village salt water has not been reported as troublesome in wells.

Mr. D. W. Smith of New London is the reliance of this entire district in the matter of drilling wells. He has made himself thoroughly familiar with the underground geology of the region and his observations are of great interest and value. He has come to believe that the water question is steadily becoming a more difficult one for this part of the state, because of the drying out and consequent hardening of the great sheet of boulder clay which covers the country. He claims that an increasing percentage of the rainfall escapes in the run-off. I am not prepared to express an opinion on this question.

SUB-SECTION H.

CARBONIFEROUS CONGLOMERATE.

The group of three great sandstones now to be considered has a much more important relation to water supply than the formation last discussed, although the present group does not equal in volume the preceding one.

The lowest stratum is the Sharon conglomerate which is often a white and pebbly sand of great purity. Near Youngstown in Trumbull county it occurs in fine development as a surface rock. Quarries have sometimes been opened in it. The stone from which the fine residence of the late Hon. Chauncey Andrews was built, was derived from this source. This stratum probably takes part in the water supplies of more than one town in northern Ohio, but the only case in which the public supply can be possibly referred to it is that now to be named.

(1) MASSILLON.

A private company holds the franchise for supplying this thriving and important city with water. It it known as the Massillon Water Supply Company, the principal stockholders in it being eastern capitalists. The present company bought out an older company in 1887, paying $80,000 for the franchise and plant. Up to the present date the company has made its total investment about $300,000.

The original company obtained its water supply from Sippo Lake and this proved unsatisfactory to the people of the city on every account. It had all the disadvantages of an inadequate surface supply.

In 1890 the present company undertook to find a new and approved supply, and in this interest drilled a six-inch well in the valley west of the town. It found 73 feet of drift at this point. The first rock reached was a pebbly sandstone which is referred with all confidence to the Sharon horizon. This stratum seems to have continued with but slight changes to a depth of 200 feet. The drill was kept at work for a further depth of 60 feet, but no new stocks of water were reached after the sandstone was passed. The rock in which the water was found was popularly identified with the Massillon sandstone, but this identification is certainly in error, for the great Massillon quarries rise 75 to 100 feet above the river and not more than 1,000 feet distant from the location of the well; while the water-bearing sandstone has not been reached until the drill has descended 60 feet below the same level.

The supply of water from Well No. 1 has proved generous. For three years it was made to yield 500,000 gallons daily. The water betrays contact with other formations than the sandstone, as the following analysis shows. The results of the analysis seem to stand for careful work, but I was unable to find where or by whom the analysis was made, except that it is credited by the company to Professor Smith.

Potassium sulphate	0.13
Sodium sulphate	1.16
Sodium chloride	0.76
Sodium phosphate	trace.
Calcium sulphate	0.79
Calcium bicarbonate	12.65
Magnesium bicarbonate	5.47
Alumina	0.005
Silicic acid	0.59
Iron bicarbonate	0.06

These figures stand for grains to the gallon. That the water comes from a more elevated situation is apparent from the fact that it begins to flow as soon as the sandstone is struck. It attains a final head, however, of but five feet above the well mouth. A temperature of 52° F. is maintained throughout the year. The analysis shows a considerable amount of temporary hardness, viz., 18.12 grains to the gallon. Some complaint is made of this element by those using the water for steam production. Local changes in the rainfall of the region do not seem to affect the production of the well.

In 1893 four acres of ground in the river bottom and adjacent to the location of Well No. 1 were purchased and five new wells were drilled here. All are six inches in diameter and all are 200 feet deep. Well No. 2 found 60 feet of drift, while in another but 12 feet were found, and in a third location the drift was penetrated to a depth of 150 feet without reaching bottom. This location was on this account abandoned.

It was at first proposed to place all the wells near together so as to secure the greatest economy in pumping, but after four were sunk it became evident that the wells affected each other, consequently longer intervals were established between the wells already drilled and the two remaining. Well No. 5 was located at least 600 feet from the nearest of the old wells and Well No. 6, a thousand feet from any other. The quality of water from all the wells is counted identical, but the several wells vary to a considerable degree in their production. Where the grain of the sandstone grows finer, the production is correspondingly diminished.

The capacity of the system has never been fully tested. The maximum production reached thus far is 1,000,000 gallons per diem.

The water seems to meet all hygienic demands; not a single case of typhoid fever is known to have occurred where the city water has been exclusively used. This scourge is not of rare occurrence in parts of town which depend on wells or other local supply.

At the grounds of the new asylum, 1½ miles south of the court house, two six-inch wells have been drilled to a depth of 250 feet. They yield a good volume of water, but it does not rise higher than 190 feet in the pipes, which is 60 feet below the surface. The water has not been analyzed, to my knowledge, but it was reported as distasteful for some reason to the workmen employed in the construction of the building.

(2) CUYAHOGA FALLS.

This village has thus far provided no public water supply, but nevertheless it relies almost entirely upon rock water. The Sharon conglomerate appears in great force in this region, and the Cuyahoga river has cut a post-glacial valley through it, 50 to 100 feet deep, providing everything that can be asked in the way of natural sections. Thin layers of clay are occasionally interstratified with the pebble and sandstone beds and some of them are persistent enough to make local water-bearing horizons. There seems to be one of these horizons about 60 feet below the general level of the village, to which the private wells which supply most of the people with water are generally sunk.

Throughout the entire territory, but particularly in the higher portions of the valley, beds of drift are found, which sometimes reach a thickness of 50 to 75 feet, but not often exceeding 30 feet. They consist largely of sand, derived from both the glacial and pre-glacial waste of the great conglomerate ledge which makes the surface rock of this entire district. Deposits of clay carrying more or less calcareous matter are, however, occasionally found in the drift series.

Along the natural outcrops, or sections rather, of the Conglomerate, springs are of frequent occurrence. One of fine volume is almost central in its location. The water of most of them contains lime, though not in extravagant amount. The springs undoubtedly derive this element from the drift beds through which almost all of even the sandstone water is obliged to pass.

Well considered plans for a complete water supply for the village, prepared by a competent and experienced engineer, John Paul, Esq., have already been approved by a majority of three to one on a popular vote. It is probable that these plans will be carried out in the immediate future.

SUB SECTION I.

CARBONIFEROUS SYSTEM.

The water supply of the large and varied rock system that we are now to consider stands by itself in this respect, viz., that while heavy beds of sandstone, some of them coarse and conglomeritic, are included in it, which would serve an admirable purpose as reservoirs, the system contains so many impervious beds in layers and bands of fire clay and in strata of shale and limestone, that no adequate provision is found for filling the reservoirs, or at least, for constantly replenishing them where they are made the basis of a public water supply.

For this reason the entire series must be pronounced poor in rock water. Supplies for dwellings and farms can be secured almost everywhere, and in the majority of instances the character of the water obtained is all that could be asked, but any considerable and growing towns that are located within the boundaries of this formation, if forced to rely on rock water, are confronted with a difficult problem in the matter of an inadequate supply. Illustrations of the facts involved will be found in the few instances in which the trials have been already made.

It is to be further noted that the towns nearest to the boundary of the formation are more favorably situated in this respect than those that lie well within the coal measures; for upon the boundary, uncovered areas of the great sandstones that belong in the series are more likely to be found. It is also to be observed that the drift beds which are the great storage basins of the rainfall for such portions of the state as they occupy, are entirely wanting over most of the carboniferous territory. The proximity of the glacial boundary serves much the same purpose that such outcrops as have been named produce.

On the other hand, most of the cities and larger villages situated within the coal measures find easy access to the great waterways of the state and have it in their power to obtain ample and, by the use of adequate systems of purification, safe water supplies from the rivers in the valleys of which they are situated. In such a list are to be found Youngstown, East Liverpool, Steubenville, Bellaire, Pomeroy, Marietta, Ironton, Zanesville and Coshocton, in other words, the principal towns of the Ohio valley and its largest tributary, the Muskingum River.

(1) CANTON.

This town, while well within the coal measures, lies upon the main terminal moraine of the state, and derives considerable advantage in respect to its water supply from this source. All the territory to the northward of the city is drift covered, and heavy deposits of gravel and gravelly clay are common here, from which small lakes and spring-fed streams derive their waters. The streams that run through Canton are the several forks of the Nimishillen which is an important tributary of the Tuscarawas River, but these take more or less drainage from coal mines and clay works and also from the farming districts through which they pass. Certainly the water which they bring to the city is more or less impure and unsatisfactory. Along two of the main branches of the Nimishillen above the town, swamps of considerable size occur, and when the water question was first discussed by the city these were believed to be underlaid by considerable deposits of drift gravel from which it was thought that water could easily be obtained in large amount. The results of explorations have not justified these expectations.

Eight years ago necessity drove the city to move in the matter of public water supply. Attention was first turned to the nearest of the swamps already alluded to, viz., that on the west fork of the creek, about two miles above the city limits. The record of the drilling at this point showed six feet of black muck, five feet of clay and but four feet of sand and gravel, below which the bedded rock was struck. The first stratum reached was the well known Lower Mercer Limestone. It was three feet in thickness, and next below it came 60 feet of shale, called "slate" by the driller. Then fifty feet of sandstone occurred in which a moderate stock of water was found. Another and heavier deposit of shale was next recorded, below which a second sandstone of the same thickness as the first, viz., 50 feet, was met, and, like the first, carrying a stock of water. The first well was carried to a depth of 365 feet, but no additions to the water supply were made below 275 feet, and consequently all the subsequent borings were limited to this depth. The water rose under artesian pressure, but did not flow from the surface of the trial well.

Thirty-five wells have since been added to the first, the record of which has been partially given above. They all strike the water horizons reached by well No. 1. In all artesian pressure was manifest, and in four of the number the water flowed from the well mouth, but in a feeble stream. The head of pressure in no case exceeded two feet.

These wells are divided into two groups, viz., 6 in the northern part of the field and 28 in the southern part; but their total production does not exceed 1,000,000 gallons per diem, which is an average of less than 30,000 gallons to the well. But this amount is only one-third of the demand of the city; consequently, two-thirds of the supply are drawn from the raw water of the West Branch. The character of this water has been already noted, and by its admission to the city supply the quality of the whole is unfavorably affected.

The rock water is known as "race water," because it comes to the pumping station through an old mill race. The yield of the wells does not appear to have been reduced since they were first drilled, but as the city has been growing rapidly meanwhile, the supply has become inadequate and its inadequacy becomes more and more noticeable.

The water works board has recently been considering an increased supply of water of the best available quality, and has directed its attention to the Middle Fork of the Nimishillen. The drainage area of this stream is 45 miles against 35 square miles for the West Branch.

It was also hoped that larger deposits of gravel would be found in this valley than in the valley to the westward. Two wells have been located in the new field, but the results of the exploration have thus far been in some respects disappointing. The bedded rocks were found at a like shallow depth as in the western valley. The sections of two drift wells are as follows:

	No. 1.	No. 2.
Sand and gravel	14 ft.	19 ft.
Sand rock	10 "	8 "
Shale	49 "	48 "
Sand rock	48 "	55 "
Total	121 ft.	130 ft.

The lower sandrock proved in both wells to be a much more vigorous source of water than the sandstones of the western wells. In both there is an artesian head of six feet and on a pumping test, continued for several hours, Well No. 1 produced 150 gallons per minute and Well No. 2, 240 gallons per minute. These figures are at the rate of 216,000 and 345,000 gallons per day respectively, or nearly ten times the production of the first series of wells. The water in the casing was lowered by the pumping test a few feet, but in No. 2 it flowed again from the well head 22 minutes after a test of three hours had been completed. This source has not yet been added to the city supply, but it is full of promise in this regard.

The water works and sewage purification plant of the city are under the charge of L. E. Chapin, Esq., City Engineer, who has an excellent reputation throughout eastern Ohio on these lines of work.

The experience of Canton is typical and representative for the Coal Measures territory, except that the production of the Middle Fork wells is better than most towns have a right to expect.

(2) LOUISVILLE.

This village is a small one but it has wisely provided its people with public water. Two wells have been drilled, 114 feet in depth and 6 inches in diameter. They have proved eminently successful in every respect. They are found to yield at the rate of 750,000 gallons in 24 hours and the quality of the water is approved. The village lies within the drift area of the state and doubtless receives some advantage from this fact.

(3) CARROLLTON.

From L. E. Chapin, who constructed the works for this village, it is learned that five wells have been drilled for public supply, each 100 feet deep and 10 inches in diameter. The surface deposits in the valley where the wells were sunk were found to be forty feet thick. The best of the wells has been found to produce 7,000 gallons per hour, which is at the rate of 168,000 gallons per diem. But pumping at this rate makes too heavy a draught upon the stock of rock water as is seen by the rapid reduction of its level in the pipes. The wells obtain their water from the sandstones of the Lower Productive Coal Measures, and presumably from the Kittanning sandstones. The water in these wells rises under artesian pressure but does not flow.

(4) CADIZ.

From a description in the report of the State Board of Health in 1895, the following facts as to the public supply of Cadiz have been gathered.

The village water works were established under the direction of L. E. Chapin, consulting engineer.

Five wells have been drilled for the public supply to a depth of 212 feet. The wells are of different diameters, one being eight inches and the others five and five-eighths inches, which is the usual size of oil wells. The average production of the system is about 250,000 gallons per diem. But this amount is somewhat in excess of the natural production of the rocks as is shown by the fact that it draws the level of the water down fully 100 feet.

(5) COLUMBIANA.

This town introduced a public water supply in 1895, an account of which is given in the report of the State Board of Health of that year. The wells are 72 feet deep, the uppermost 22 feet of the section being unconsolidated materials, and the lower 50 feet being in sandstone. The water rises in the wells to within four feet of the surface. The production of a single well, in tests that have been made, has been found to be a little more than 3,000 gallons per hour, which is at the rate of about 75,000 gallons per diem. The sandstone from which the water is derived, is some division of the Lower Productive Measures.

PART II.

THE FLOWING WELLS OF OHIO.

As stated in the introductory paragraphs of this report, only those flowing wells of the state that are found in considerable areas, and furthermore, those deriving their water from a considerable depth and having also considerable head of pressure are to be treated here. To render these qualifying terms serviceable, it becomes necessary to specify more particularly what they severally cover. The areas to be considered will range from five square miles upward, the largest, probably not exceeding 25 to 30 square miles. The head of pressure in the regions to be reviewed is seldom less than 5 feet, and often several times this amount. The depth of the wells generally ranges between 50 and 250 feet, but in a few instances account is taken of wells of even less than 50 feet.

The wells of the class now to be discussed belong entirely to the drift. It is true that some of them derive their water from the uppermost beds of deeply buried rock strata, but it is mainly the arrangement and disposition of the drift beds after all that gives the artesian character to these fields.

The facts as to the actual elevation of the rocky floor of the state, in the regions which have been overrun by the glacial drift, are of great interest. They involve the large questions of the preglacial drainage systems of large parts of Ohio, and thus lead us to some surprising and unexpected conclusions. The work of investigation is still going on, but it seems to be already established that the Ohio river, as we now know it, is a stream of recent origin, and that the main volume of water gathed in at the present time originally flowed across the state to the northward as far at least as Auglaize and Mercer counties, where it turned to the westward, toward the present lines of Wabash drainage in Indiana. The facts that support such a conclusion, as far as central and northwestern Ohio are concerned, have been principally accumulated through the deep wells drilled for oil and gas during the last dozen years. In the regions referred to, wells have been sunk by the hundred and if the facts as to the thickness of the drift had been carefully gathered as they were discovered by the driller they would have proved of priceless value to the geologist. As it is, multitudes of these records have been lost beyond recovery. The great oil companies, however, have kept records that are even now available, and for many hundreds of wells, located accurately as far as the particular fraction of the quarter section in which they were drilled is concerned, we can learn the exact thickness of the drift.

The drilling of water wells has in some cases added valuable facts to this series, as will presently appear.

It is becoming increasingly evident that connected investigations are necessary for the final determination of these questions. But inasmuch as the discovery of the particular localities where the rocky floor has been deeply eroded is altogether haphazard and accidental, depending on the caprice of the driller in locating his wells, the exact courses of the old drainage systems cannot be settled at present. It is not too much to expect, however, that their general direction can be made out with a good degree of confidence.

What is needed in this connection is a model or at least the data for a model of the rocky floor of the state. In the regions where drilling has been carried on most largely, sufficient data are already available for this purpose. The elevations of the rocky floor above tide can be determined for many consecutive miles, and the general direction of the old valleys can thus be clearly established.

The state could do no better work in connection with its geology than to make use of all the accessible data in this line at once in constructing a model of the rocky floor of northwestern Ohio.

It is possible, however, that the question may be complicated by recent warpings of the earth's crust. We know that in New York and Ontario, at least, there has been considerable differential movement of the surface since the disappearance of the glacial ice.

SECTION I.

WILLIAMS, DEFIANCE AND FULTON COUNTIES.

The best known fields of flowing waters of the state are to be found in its extreme northwestern corner, viz., in Williams, Defiance and Fulton counties. Several subordinate divisions of this flowing-well-territory are to be recognized, one, including Bryan, another Hicksville, a third, West Unity, while still other districts are to be found in the southeastern and northwestern townships of Fulton county. Several minor divisions will also be discussed. Whether all these districts deserve to be considered together as parts of one general field is not established. They have been popularly so regarded by the more intelligent observers of the region and have generally been referred to an ancient water course or buried river channel that could be followed by means of these fountains from the western end of Lake Erie to the Indiana line. Dr. Wood, a former resident of Toledo, thought he could trace by means of flowing wells an ancient channel through the whole interval. As he regarded it, this river must have been a tortuous one, and it would now be considered much more so if it were made to include all the flowing wells that have since been developed. The breadth of this old valley would, on such an identification, be considerable, if measured by a line at right angles to the main trend of the fountain belt; in some instances it would reach six or eight miles.

In general terms, it is true that the best characterized flowing well territory extends in a northeast direction from Hicksville by way of Bryan to the southward of West Unity and into Gorham and Chesterfield townships of Fulton county. It continues to the northeast into Lenawee county, Michigan, in one part of which almost every farm has a fountain. The following townships would be included in the above named belt: in Defiance county, Hicksville, Mark, Farmer, Washington; in Williams county, Pulaski, Center, Springfield and Brady townships; in Fulton county, Franklin, Gorham, Chesterfield and Dover. By geographical rights, German township of Fulton county should be added to the list, but no record of flowing wells within its limits has come to hand. But even if fountains are at present wanting, it may well be because proper effort has not been made to develop them.

The main belt can also be described as extending along the course of Tiffin river (Bean Creek). Several of the townships named are traversed by this stream.

The topography of this entire region is simple. The surface approximates a plain, but there is fall enough in almost every part of the district named to give good current to the surface drainage. In any case, the valleys of the region are but shallow furrows in the drift.

The altitude of a few of the principal points will be given here, derived from the railroad elevations at the stations named. Hicksville, 762 a. t.; Mark Center, 731 a. t.; Bryan, 767 a. t.; Stryker, 715 a. t.; West Unity, 775 a. t. (approximate). The inclination of the general surface is to the southeastward, but the principal streams of Williams county flow southwest. The part of Defiance county included in this belt delivers its surface drainage to the Maumee river.

The most marked features of the district are moraines of the glacial period and old beaches of Lake Erie. Several of both of these forms of structure cross the counties named, exercising a great influence upon the surface drainage.

The geology of the district is as monotonous as any area made up of the glacial drift can be. The thickness of the drift beds generally ranges between 75 and 150 feet. No outcrop of the underlying rocks is reached throughout the district named. The first sheet of rock that is struck after the drift beds have been penetrated is the great shale formation known in our geology as the Ohio shale. We nowhere find in this part of the state the normal cover of the shale and cannot therefore determine its full thickness, but in adjacent counties of Michigan and Indiana entire sections occur and we learn from them that the normal volume of the shale series in this part of the country is less than 300 feet, perhaps not much above 200 feet. At Delta, a section of 135 feet was found by the drill, at Wauseon a section of 194 feet, and at Bryan, 157 feet.

In the field now under consideration we seldom meet more than 100 feet of the shale, and it is often reduced to 25 or 30 feet. From these facts we learn that the larger portion of the shale, let alone its normal cover, was eroded during pre-glacial time. Such a fact can occasion no surprise for the shale is a soft rock and obviously an easy prey to erosive agencies. Moreover, the time during which it stood exposed to atmospheric waste was certainly long, aggregating many millions of years.

The drift is largely composed of boulder clay, yellow at the surface and blue below, but all of the face of the country that is here considered was subsequently overrun for protracted periods by the waters of Lake Erie when they stood 200 feet higher than at present and a blanket of lacustrine deposits, viz., the first and second beaches, constitutes the present surface. In these last named formations we find stratified clays, sands and gravels, with a sparing distribution of boulders. This blanket does not reach a great thickness in any part of the field. It is very irregular, but its deposits seldom exceed 15 to 20 feet. The prevailing and characteristic feature of the blanket is lake sand, the beds of which give rise to multitudes of shallow water wells, upon which much of the country when first occupied entirely depended.

This boulder clay carries within it many lenticular beds of sand and gravel, which sometimes reach the surface. Some of them receive and store rainfall and discharge water in the shape of springs. A very fine-grained clay, free from pebbles and grit, is occasionally met with. It is as tenacious as wax and makes trouble for the driller when encountered in wells. It is called the "beeswax clay."

Another and a constant element is what is called by the driller "hardpan." It consists of gravel, fine and coarse, with the spaces between the pebbles packed close with clay. The hardpan does not admit the passage of water and is consequently always dry. It occurs in beds of 10 to 40 feet.

The lowest formation of the drift series is a streak of gravel, the constituent fragments of which vary greatly in size. Some of the pebbles are 3 or 4 inches in diameter, others are of the size of grains of wheat, or even smaller. This is the water-bearing stratum of the country on which most of the fountains absolutely depend for their supply.

Next to the rock, a streak of cemented (?) gravel is sometimes met with. It never exceeds a few inches in thickness. This horizon, when found, is also water-bearing. In considerable districts all wells obtain their supply from the upper surface of the shale. Many fountains have such a source. Such water is often slightly saline and more frequently sulphuretted.

The several fields will now be briefly described.

(1) BRYAN.

This is the best known field of flowing water in Ohio, and no district has thus far found a better or more durable water supply. In its early days the village had much difficulty in the matter of obtaining water for domestic use. Shallow wells were the entire dependence of the first settlers, but the water furnished by them necessarily became contaminated by surface impurities and the health of the people suffered much in consequence. In any case, these wells were unable to furnish water enough for protection against fire, and by the year 1840 it had come to be recognized by all that an improved water supply was essential to the prosperity and protection of the town.

The history of the first flowing well, though it goes back only fifty to sixty years, is not free from contradictions and discrepancies, but a circumstantial account from one source relates that Dr. William Trevitt of Columbus, who owned a large number of village lots and was consequently interested in the growth and prosperity of the town, recognizing the necessity of a new water supply, offered a man named Wyatt one of his lots if he would find somewhere near the public square better water. Mr. Wyatt began the search and located a well near the old hotel at the southeast corner of the court house square. After laboring many days he left the excavation one night with a depth of 43 feet. Returning in the morning he found the well full to the top and running over. The water was evidently from a deep source. The problem was solved and the prosperity of the village was assured.

Other wells followed in short order. Most of them were 50 to 60 feet deep and they developed a head of pressure varying from one to six feet. In some wells, however, the water rose, when properly confined, to the second stories of the dwellings. But the village was growing to the eastward and in this direction the surface declined, becoming a few feet lower than the public square. Flowing wells were found at shallower depths in this direction, and as their number increased it was found that the head of pressure in the older wells began to decrease. In short, it soon became evident that if the town was to retain flowing water, it would be necessary to find some new horizon. Wells retaining their artesian character were in this new search gradually increased in depth to 80, 100 and 125 feet. In other words, new veins had been reached. It is claimed that the quality of water from these veins is distinct, differing in amounts and kinds of mineral elements, but in default of analyses we must conclude that such differences cannot be important.

About 1893 the village undertook a public water supply. A lot was purchased and five 8-inch wells were drilled, but the water-bearing stratum, when struck, proved to be thin and the production correspondingly small. A new location was therefore accordingly secured and eight 3-inch wells were drilled which found an unusually good vein of water-bearing gravel at 100 to 125 feet. Every well completely filled a three-inch discharge pipe. The flow of the strongest was measured, and it was found to yield 80 gallons per minute, or more than 100,000 gallons per diem. The entire series produces 240 gallons per minute, but this production has affected the other wells within and around the corporation, destroying, as a rule, their artesian character.

In Pulaski township, outside of the corporation of Bryan, not less than 200 fountain wells have been drilled from first to last. Though called by this name, not all are really living fountains at the present time, but all have been such at some earlier date and the water still rises nearly to the surface. On farms at a distance of several miles from the village, the old conditions are best preserved.

The total thickness of the drift has been determined in drilling wells for gas and oil in and near the town during the last ten years. Four examples show the length of drive pipe to be respectively 146, 154, 176 and 157 feet. These altitudes cover a range of one mile or more.

Water is found in the limestone series underlying the shale in considerable quantity, and the limestone water is also artesian, rising 18 to 20 feet above the surface of the ground. That obtained in the upper beds of the limestone is generally potable, but sulphur water is soon reached as the drill descends. These facts are in keeping with the geological character of the Corniferous and Onondaga limestones, as previously described. From one of these deep wells an extraordinary volume of water was produced, keeping a six-inch pipe completely filled with its flow. Sulphuretted water is occasionally found in drift springs in the neighborhood. Such cases would seem to be in some way connected with the shale system that underlies the country or possibly with large masses of shale in the drift.

The Bryan district has enjoyed and still enjoys in its fountain wells a great advantage over much of the surrounding country. They add to the value of farming lands, certainly to their saleable quality. It would be hard to overrate the convenience and serviceability of such a water supply.

(2) STRYKER.

This village is located in Springfield township, seven miles east of Bryan, but while there are many flowing wells in the township the conditions of their flow differ to some extent from those reported in the previously described township.

Well diggers of large experience and thoroughly acquainted with the immediate region estimate the number of flowing wells in this township, as but little, if any, less than 100. From the same sources, the general section of the drift of this region has been obtained. It is as follows:

Soil and subsoil	2 to	5	feet.
Yellow clay	10 to	15	"
Blue clay	40 to	60	"
Hardpan	15 to	40	"
Water-bearing gravel	0 to	30	"
Ohio shale, struck at	140 to	150	"

When a bed of clay is found below the hardpan it is generally of the "beeswax" variety already described, i. e., fine-grained and free from pebbles. Water is sometimes found on top of the hardpan, as well as below. In such cases there are a few inches at least of sand or gravel covering the hardpan, but in most instances in this township, the uppermost beds of slate constitute the real water-bearer. It is in this fact that the difference referred to above between the wells of Springfield and Pulaski townships lies. The driller does not, as a rule, go more than ten feet into the shale. Experience has shown that if good water is not found within this limit, it is not likely to be found at all. The water derived from the shale is generally counted lower in hardness than the water from the drift gravels, but no analyses are at hand to establish or disprove this claim. On its face it seems improbable as all the water borne by the shale must have come through the drift. The shale water, when obtained from the formation below its uppermost beds is generally charged with sulphuretted hydrogen. It is also saline in many instances.

The wells unquestionably grow weaker as their number is multiplied. One well often cuts off several that have preceded it in the same neighborhood. For example, the mill well in the village is 155 feet in depth. When worked hard the other wells of the village ceased to flow. But the mill well is not drawn upon during the night and by morning all the wells recover their artesian character.

In a few instances the drill has been carried deep enough to determine the thickness of the Ohio shale. Though there is considerable variation in this stratum, the cases in this township are few in which it exceeds 100 feet.

In a well that was being sunk in the village in the fall of 1896 an opportunity was afforded to examine the hardpan which had just been reached. It consisted of fine gravel of the size of wheat grains distributed through a compact bed of clay.

Boulders are sometimes struck in the hardpan and also in the blue clay. In one well east of town the size of a deep boulder was so great that after the derrick had been moved five feet the same obstruction was again encountered. The derrick was once more moved and in this case three feet from the first station and in an opposite direction from the second trial and the drilling then went forward without obstruction.

The original head of pressure was never great, but by the multitude of fountains it has been so reduced that the owners of wells are obliged to be satisfied with any flow of the water whatever. But in any case the water is always near at hand. Pumps have but little lifting to do.

In 1865-1867 a well was drilled in town in the search for oil to a depth of 860 feet. At 230 feet a considerable volume of mineral water, of very much the same character as the mineral water of southern Michigan, was struck and it reached the surface in geyser fashion. Several veins of gas had been found at different horizons as the drill descended, and the gas, rising with the water, caused it to flow intermittently, after the manner of a geyser, as above indicated. A sanitarium was erected in the course of a few years to give the people an opportunity to avail themselves of the peculiar water yielded by the well. In 1870 an analysis was made of the water by Dr. S. H. Douglass of Michigan University, and the following results were obtained:

Chloride of magnesium	118.96
Chloride of sodium	281.86
Sulphate of potassium	185.34
Carbonate of calcium	68.30
Carbonate of iron	9.93
Sulphuretted hydrogen	4.49
Silica	2.63

In a note appended it is mentioned that the amount of sulphuretted hydrogen originally present in the water was greater than the figures above given would indicate.

In this well the thickness of the drift was found to be 129 feet, and from this figure we can determine the altitude of the upper surface of the shale at this point. It is 586 feet above tide, which is but 13 feet above the present level of Lake Erie.

(3) WEST UNITY.

A fine field of flowing water is found along the valley of Tiffin river in Brady township. Better examples of this type of wells cannot be asked for than are to be found on the farms of G. L. Martin, William Miller and others in the same neighborhood, two to three miles south and east of the village above named. The depth of the wells in this district is shallower than in other parts of the county. On the Martin farm a strong and persistent flow is derived from 28 feet. On the Miller farm there are four flowing wells. Two of them, at depths of 43 and 54 feet respectively, yield well-marked sulphuretted water.

The deepest flowing well of the township reached the shale at 110 feet, but the drill went through the shale to the limestone and artesian water rose from this last named source. The shale was found 100 feet thick. Its upper surface was therefore about 625 feet above tide. Whether this observation is a representative one there has been no opportunity to determine. The thickness of the drift is about the same that is generally reported for the region, i. e. 100 feet.

Following still further in a northeasterly course we come to the townships of Franklin, Dover, Gorham and Chesterfield, Fulton county. The area here named includes a large number of flowing wells of excellent character. In Gorham township the pressure head is sometimes 20 feet. While every trial is not successful in this respect, still success attends so many of the undertakings that every farmer counts upon a fountain when he drills a well of even moderate depth. These same conditions extend beyond the state line into Michigan. Almost every farm in the vicinity of Morenci, Lenawee county, has a good flowing well.

SECTION II.

DEFIANCE COUNTY.

Returning now, to the so-called belt of flowing water, we find at its southwestern extremity one prominent division that remains to be described, viz., the Hicksville field. There are more than fifty flowing wells in operation in this village and township, and the work of testing the territory is constantly going forward, particularly when summer droughts are upon the country.

(1) HICKSVILLE.

The first flowing well of the village was struck in 1857 in the rear of the Central Block at a depth of 71 feet. The second well was drilled a year or two later, south of the village, on the farm of Judge Patton. It was only 50 feet deep but it proved entirely satisfactory. It was not until 1895 that the deeper water horizons of the drift were tested here. This testing was done by the village corporation in its search for a public water supply. A beginning had been made in this line five years before, when four wells were drilled to a depth of about 40 feet. They proved artesian, but their head was feeble and their supply was affected to a dangerous extent by the droughts that occurred. In 1895, in particular, the ground water of northwestern Ohio was greatly reduced and the public supply of Hicksville was overtaxed. The village authorities took this occasion to test their possibilities by sinking deeper wells. Two new wells were located near the old ones and instead of stopping at 70 feet their depth was doubled. The result was in every way satisfactory. The water rose in large volume and with a head of pressure of eleven feet.

The Coulter well in the village gives a clear section of the general arrangement of the drift beds for this region. The well was begun in the old beach that passes through the town and is carried to the black waste which is the immediate cover of the Ohio shale. The record is as follows:

Sand and gravel	9 feet.
Yellow clay	4 "
Quicksand	1 "
Blue clay	94 "
Numerous sand veins, 5 to 6 inches thick, intercalated.)	
Hardpan, blue	19 "
Blue clay and sand	15 "
Ohio black shale, at	142 "

The well flowed 56 gallons per minute, which is at the rate of 80,640 gallons, or 2,200 barrels, per diem.

(2) MARK TOWNSHIP.

This township is also included in the belt of flowing wells. A fine well was struck one year ago, 1½ miles north of the center at the Laws Tile Works, and a half mile west of that point another successful well has been drilled. On the Coy farm a fountain of unusual volume has recently been struck. All the conditions seem similar to those of Hicksville township, and a considerable number of flowing wells have already been drilled.

In the two townships, Farmer and Washington, to the northeastward of Hicksville and Mark, fountain wells have abounded for the last 40 years and it is understood that the conditions are similar here to those in the territory already described.

The northeast and southwest belt of fountain wells already described can be followed still further within the limits of Ohio. The northwestern township of Paulding county which adjoins Hicksville, viz., Carryall, has flowing wells by the score and their occurrence stands for a measure of uniformity in the geological conditions of the region so favored. It is in the northern portions of the township, and largely in sections 2, 3, 4, 5, 10, 11, that the fountains have chiefly been found. Every farmer in drilling for water expects a flowing well, and but few are disappointed.

The wells are not as deep as in the several fields already described. All of them go, however, to the bedded rocks which are reached at 30 to 50 feet. Not all wells that are drilled to the rock are successful, and it is also to be noted that artesian water is occasionally found before the rocky floor is reached by the drill.

SECTION III.

FULTON COUNTY.

In and around Swan Creek township there is still another district of fountain wells that cannot by any reasonable construction be considered as belonging to the "belt" already described.

(1) SWANTON.

The first artesian well at Swanton was discovered in 1862 on the Hepfinger farm. Flowing water was found at a depth of forty feet and the well has proved a strong and steady supply from that time to the present. Nevertheless a prolonged drought like that of 1895 reduces the flow, but does not destroy it. In the vicinity of the village there are not less than seven of these fountain wells. A well in this district is counted good when it yields 500 barrels per diem.

The conditions in this region are very like those already described in the vicinity of Stryker. The Ohio shale, which is the underlying rock is the water-bearer. All wells are drilled entirely through the drift series. The general section is as follows:

Lake sand	18	feet.
Blue clay	30	"
Sandy clay (uncertain)		
Hardpan	3 to 15	"
Gravel	3 to 9	"
Ohio shale struck at	50 to 75	"

To the southeastward of Swanton there is also a considerable number of flowing wells, extending towards Whitehouse and Waterville. In this direction, however, a change in the bed rock occurs, limestone underlying the drift instead of shale.

Looking at the facts as developed at Swanton, and yielding to the natural tendency to put isolated facts into a connected and thus a more intelligible series, it would be justifiable to conclude that Swanton belongs in a belt of flowing water which extends in a northwesterly and southeasterly direction. Certainly flowing wells are to be found in both directions; but a broader or at least an earlier generalization has already assigned the flowing well district of northwestern Fulton county to a northeast and not to a southeast belt.

(2) WAUSEON.

This village is not at present supplied by flowing wells, but nevertheless its waters deserve to be called artesian. At a few points where the proper tests were first made the water originally flowed, but the multiplication of these deep wells has cut off the small head that was originally found. The water still rises to within 15 or 20 feet of the surface through considerable areas, and its artesian character can be assumed on this ground.

The drift of the immediate region is 140 to 160 feet thick. The uppermost ten to fifteen feet are yellow clay (oxydized). Below comes blue clay, often so charged with slate fragments and waste as to be almost black. Thin seams of sand are irregularly distributed through the mass. Large boulders, though rare, are not unknown. The boundary between the yellow and blue clays is not sharp or well defined. The change in color simply marks the line to which surface water has been able to descend. The blue clay reaches a general thickness of 130 to 150 feet. Below it about five feet of hardpan is found. This is here described as cemented gravel. Under it a few inches of sand are generally found and then the Ohio shale is reached. This last formation is usually covered for a few inches with its own fragments.

The shale is the main water-bearer of this central district of the county; but since the body of the formation is impervious, its storage quality can consist only in the widened joints and the generally fractured surface resulting from its prolonged exposure in pre-glacial time. Water descends through the drift by channels, the existence of which we are obliged to infer, but the location of which we can never expect to determine, carrying with it the soluble minerals of the beds through which it has been filtered, and diffuses itself through the fractured surface above described. Its principal storage basins must be, as already remarked, the widened joints of the shale, and this will account for the frequent failures to obtain water. Of the deep wells in and around the village, it is estimated that one-third have proved dry holes. Sometimes if the derrick is moved but a few feet the new well is successful. Three trials were made, however, on one village lot at Wauseon, and all of them were failures. On the next lot a good well was obtained at the first trial. A well in this region is counted good when it can be depended on for at least 10,000 gallons, or 330 barrels, per diem.

The hardpan of this region is described as cemented gravel, but no example was met with. The drillers report it as hard to penetrate as ordinary sandstone. Wells are drilled into the shale generally a few inches, and seldom more than a few feet.

All the shale water of this district contains a noticeable trace of common salt, but the percentage is so small that it soon passes unnoticed by those who make constant use of the water. It occurs but rarely in large enough amount to render the water distinctly objectionable. Its normal presence in the shale water needs to be noted by chemists who are called upon to make analyses of the water of this class of wells.

A deep well drilled here for gas or oil in the Findlay excitement found the shale series in the village to be 194 feet in thickness, and one mile to the northward a white shale, 18 to 20 feet thick, was found overlying the black shale. The "white shale" is probably the Bedford shale which is the normal cover of the Ohio shale. It is thus probable that nearly the entire Ohio shale section is found at Wauseon.

Inflammable gas is frequently struck in drilling through the drift, and almost always struck when the shale horizon is reached, but it is seldom found in large enough volume to be of economic value. In a few cases it had been utilized in a small way. Occasional "blowers" are met with which are noisy and troublesome for a few hours or days.

The gentle roll or ridge that passes 1½ miles to the westward of the court house, and which is known as Wauseon Summit, where it crosses the Lake Shore railroad, has an altitude of 15 to 20 feet above the general surface of the surrounding country, and increases the depth of water wells by this amount. The ridge is a part of the second beach formed when the level of Lake Erie was 200 feet higher than it now is.

An old trough or valley in the shale has been brought to our knowledge by the drilling of water wells south and east of the village. It lies about a mile and a half from the court house in a due south line. It cannot be more than a quarter of a mile in width and may not be more than an eighth. There is no sign whatever of its existence upon the surface of the district which it traverses.

It was discovered by the fact that wells reaching to the surface of the shale are about 140 feet deep for a mile and a half south of the town, but suddenly the depth to the same boundary increases to 225 feet, while a little further on the old figure is restored. The general depth of wells for many square miles is about 140 feet. A valley 225 feet deep is lower than the surface of Lake Erie by 30 or 40 feet. It would carry drainage away from Lake Erie, not towards it.

By continuous drilling the course or direction of the valley has been roughly determined for a distance of about nine miles. It bears directly west for five miles, passing a little to the southward of Pettisville. From the point of beginning it can be traced to the northeastward, and various departures from a straight course are shown by the deep wells that indicate the old valley. To the westward, its depth is said to be slowly increased, but no figures were obtained and its direction and further course have not been determined. Facts to be accumulated in the future development of the country will clear up these points and show more clearly the direction and office of this ancient valley. It is filled with sand and gravel and thus is a great receptacle of water. The water supply of Wauseon has always been recognized as a difficult problem. It is possible that it will not be solved until this great channel to the southward is drawn upon.

GEOLOGICAL CONDITIONS OF THE FLOWING WELL DISTRICTS.

The fountain districts of northwestern Ohio, some of the prominent facts and features of which have now been put on record, has several geological conditions that are common to its whole extent.

1. The entire region is underlaid by the Ohio shale, i. e., the Ohio shale is the first rock stratum to be reached below the drift.

The shale series constituting this floor is a remnant of a much larger series of shales belonging to the same general class of rocks. Above the Ohio shale in its entirety, there are geologically due the following elements: the Bedford shale, the Berea grit, the Berea shale, the Cuyahoga shale, in all, four to five hundred feet of soft rock. The only exception would be found in the Berea grit, but this is often thin and impure and would give way to erosive agencies nearly as easily as shale. From most of the area in question, we are obliged to conclude that several hundred feet of what was originally deposited as shale rock have been removed, mainly by atmospheric agencies. We find at Delta 133 feet of the shale series and at Wauseon 194 feet. As previously remarked, it is probable that in the latter case we have an approximately complete section of the Ohio shale for northwestern Ohio. But though the sections of the shale throughout the district are unequal, the surface of the country is approximately level. Its altitude ranges between 700 and 750 feet above tide. This uniform elevation was brought about largely by the glacial deposits which have filled up the hollows and furrows due to former denudation and have gone far towards restoring the surface to its original monotony. But another agency is to be taken into account in this connection.

2. The shale series itself has been reduced to nearly one level before the drift storm overspread it. The old agencies of erosion had practically completed their work upon it in pre-glacial time, as the following elevations of the shale floor show.

The elevations are as follows:

Delta	704.
Wauseon	6 2.
Pettisville	610.
Archbold	584.
Stryker	588.
Bryan	611.
West Unity	625.
Hicksville	634.

The average elevation of the shale floor by these figures is 631 feet; or, omitting the first example, which is somewhat out of correspondence with the rest, the average is 609 feet. This seems to show that the region was practically base-levelled before the drift.

The only fact that seems to militate against this conclusion is one already cited to the effect that a valley 85 feet deep and not more than a quarter of a mile and perhaps not more than an eighth of a mile in width, is found traversing the shale in the central part of the county. When erosion has done its perfect work as in a base-levelled country, it is not likely to leave valleys of such a character as the one here described. We should expect them to be wider and shallower.

3. Two important facts in connection with the storage of the large quantity of water of the counties now under consideration are found in (1) the effect of erosion which the soft rocks of the original surface have undergone, and (2) in the great amount of gravelly drift which has been dumped into the basin formed by the wearing away of the shale.

(1) The rock floor lies at a distinctly lower level than that of the district immediately south of it. From the Wabash valley, southward, limestone constitutes the floor of the country, and this everywhere stands at a noticeably higher level than the shale region which it bounds.

(2) The drift deposits which have been laid down upon the region under consideration certainly exceed 100 feet in average thickness. They make up a varied series and stand for several distinct stages in the complex and puzzling history of the great ice age. The division termed "hardpan," for example, throughout the district, is everywhere sharply distinguished from the boulder clay, and these two elements must have a different history.

The artesian wells of Paulding and Van Wert counties, aside from the northwestern corner of Paulding county, (Carryall township) already described, are excluded from present consideration because of the shallow depths at which they are found, and because of the lack of large connected areas in which they occur. There are large districts in these counties in which the drift does not exceed 15 to 20 feet in thickness, and in comparatively small portions does it exceed 40 feet. Artesian wells are scattered throughout these entire areas, one here and another there, but they do not reveal any general structure.

SECTION IV.

MERCER COUNTY.

A somewhat different state of things appears in this last named county. The drift is deeper and entire townships can be described as flowing well territory, though not every well that is drilled within their limits proves to be artesian.

The northern townships, viz., Black Creek, Dublin, Union, Hopewell, Center and Jefferson, show this character more prominently and connectedly than the southern portions of the county, with the exception of Franklin and Butler.

In Black Creek township the general depth of the wells, up to 1895, when the severe drought of the summer of that year reduced the ground water so seriously that it became necessary to obtain a new source, was 45 to 50 feet. At this time, many of the wells were deepened, being drilled to a depth of 90 to 110 feet, and with the most satisfactory results. The head of pressure is four to five feet. Flowing wells are known in Sections 10, 11, 15, 22, 23, 24, 25 and 34. In single sections many flowing wells have been obtained.

In Dublin and Union townships, the depth of the wells ranges between 20 and 85 feet, but the thickness of the drift is often as much as 40 feet. A typical section of the drift may be given in the following terms: soil, 2 feet; yellow clay, 7 feet; gravel, 7 feet (uncertain); hardpan, 20 feet; rock.

In Jefferson township, the drift is 50 to 75 feet. The head of pressure sometimes exceeds ten feet.

In Franklin township the general depth of the flowing wells is 40 to 50 feet, but the rock lies deeper and the more permanent water supply is found by sinking wells to the surface of the solid floor. This is one of the townships that has been overrun by the drillers of deep wells for gas and oil, and these wells have, in multitudes of instances, cut off previously flowing fountains, in some cases at one and one-half miles distance. If the artesian flow of the deep wells is arrested, the old wells, after a time, resume their production.

In Butler township fountains are common in sections 11, 12, 13, 23, 24. Some of them show a head of pressure of ten feet.

The general section by which water is reached in this township is very like that already reported for Dublin and Union. Soil, 2 feet; dark or black clay, 6 to 10 feet; blue clay, 10 feet; hardpan, 5 to 20 feet; gravel and water.

In some parts of the county, flowing water is so easily obtained that a farmer will drive a pipe 15 to 20 feet in any field in which stock is to be kept for a time, and when the pasture is exhausted will withdraw the pipe and establish it in a new location.

SECTION V.

DEEP PREGLACIAL CHANNELS IN ALLEN, AUGLAIZE AND MERCER COUNTIES.

By the deep drilling that has been done in the counties named above in such large amount during the last 10 or 12 years, some facts of unusual interest have been developed as to the pre-glacial drainage system of this part of the state, and, within the same territory, the strongest artesian wells of the state have been developed. A brief account of these two lines of facts will be given here.

In Allen county, the deep excavations that will be noticed are first brought to light within the limits of the city of Lima. A channel has there been revealed 170 feet below the surface. In Perry township, a deep channel, or a series of deep channels has been revealed by drilling in the following named sections:

Section 17, thickness of drift, 195 feet.
" 20, " " 235 " and 248 feet.
" 21, " " 238 " and 255 "
" 22, " " 205 " and 211 "
" 28, " " 230 " and 258 "
" 29, " " 244 "

In Shawnee township:

Section 2, thickness of drift, 178 feet.
" 3, " " 200 "
" 10, " " 194 " and 265 feet.
" 11, " " 265 "
" 13, " " 281 "
" 25, " " 204 "

In Duchouquet township, Auglaize county:

Section 3, thickness of drift, 428 feet.
" 34, " " 300 " 335 and 340 feet.

In Moulton township, erosion to an equal degree has taken place, but the data have not been secured.

In St. Marys township:

Section 2, thickness of drift, 228 feet.
" 8, " " 400, 401, 402 feet.
" 9, " " 249, 396 feet.
" 11, " " 480 feet.
" 12, " " 400 feet.
" 13, " " 350 feet.
" 15, " " 104, 406, 406, 406 feet.
" 22, " " 392 feet.

In Center township, Mercer county:

Section 29, thickness of drift, 400 feet.

In Dublin township, Mercer county:

Section 16, thickness of drift, 319 feet.

In Jefferson township:

..................., thickness of drift, 400 feet.

In Franklin township:

Section 35, 400, 402, 414, 444, s. w. ¼ 398, E. ½ 430 feet.
" 32, east half, 430 feet.
" 2, southeast quarter, 367 feet.
" 31, southwest quarter, 326 feet.

In Marion township:
Section 13, thickness of drift, 444, 500 feet.
" 11, n. w. ¼ thickness of drift, 388 feet.
In Granville township:
Section 26, northeast quarter, 280 feet.
" 26, southwest quarter, 330 feet.
" 24, northeast quarter, 270, 280 feet.

In this region, the first stratum below the drift is either the Onondaga limestone or the Niagara limestone, or in a few highly exceptional cases, the Medina or the Hudson river shales. The first named stratum is struck in Allen county and in Duchouquet and Moulton townships of Auglaize county. In St. Marys township, Auglaize county, and in Mercer county, the first rock reached is the Niagara, or in the exceptional cases named above, the Medina or Hudson river shales. This limestone floor has been gashed and dissected by the work of a great river system, continued through protracted ages. Channels, main and tributary, have been cut from 100 to 400 feet below the general surface of the limestone. Where the Niagara limestone made the pre-glacial rocky floor, erosion to such a depth would necessarily penetrate its entire thickness and the underlying Clinton limestone as well and bring the level of the erosion down into the soft rocks of the Medina or Hudson river shales. This is what the driller finds. The drive pipe of these deep wells meets with no cap limestone whatever, but strikes the original rock in the fine-grained shales of the series named above.

The main channel of the old river can be plainly followed from St. Mary's in an almost directly west line through the Mercer Reservoir, but a little to the north of the middle line of this body of water. Just before it reaches the west end of the reservoir, it receives an important tributary, the course of which can be traced fully 11 miles to the northward through Jefferson, Center and Dublin townships by strings of drive pipe 320 to 400 feet in length. This part of the ancient stream came from the northward; but after leaving the reservoir, the main channel bends abruptly to the south and afterwards bears to the east so that for the next eight or ten miles its direction is approximately southeast. It has not been located as closely in Franklin and Marion townships as in those previously named, but it turned west once more in Marion township, where drive pipe of 500 feet has been recorded in a single instance.

As the main channel is followed through the reservoir, its breadth is found to be one mile to one and a fourth miles. The northern tributary already described is much narrower; and though of about the same depth with the main valley, its breadth is less than one fourth of a mile.

It is a singular coincidence that the modern reservoir should be located directly above the deepest pre-glacial valley of the state. It is still more surprising that after this part of the country had been converted into a permanent lake, we should by any chance be able to learn the thickness of the drift under the surface of the water. This last discovery has come about through the enterprise of the oil well driller. Following productive oil territory directly up to the margin of the reservoir, it was evident that the chances of finding good oil wells were not lost because the surface happened to have a shallow covering of water over it. The consent of the State authorities to drilling within the reservoir was finally obtained, and wells by the score and the hundred have since been drilled here. In sections 7, 8, 16 and 17 of St. Marys township, and in sections 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18 of Jefferson township, the long and irregular lines of drive pipe already referred to have been found necessary.

It could not be otherwise than that this channel would be struck by the driller at various points of its declivity, sometimes on the edge, sometimes half way down the slope, and occasionally, perhaps, at its greatest depth. The longest string of drive pipe that has been reported from the reservoir is 406 feet in the northwest corner of section 15. One "location," (400 feet) from this point, only 100 feet of drive pipe were required. On section 8, one driller found 400 feet of drive pipe required in each of two wells, 401 in a third, and 402 in a fourth well. In another instance, by a change of one "location" (400 feet) the necessary drive pipe was increased from 97 to 240 feet. In Union township on the northern tributary, the drive pipe was lengthened from 40 to 100 feet in a single "location". This was on the J. H. Coil farm, near Mendon.

The main channel can be traced from Section 11, St. Marys township, to Celina. On Section 11, St. Marys, the Barrington well is located, which will presently be referred to as the most remarkable flowing well of the state.

On the C. Wilkins farm, in the same section, four successive wells showed 90, 215, 240 and 350 feet of drive pipe. These wells are all to the south of the main channel. Another of the Wilkins wells was located, as the event proved, exactly on the brink of a precipitous wall several hundred feet in height. The driller struck the rocky floor as he thought at 180 feet, but after advancing a few inches, he found that he was in drift clay again. As he drove still deeper, he continued to strike projecting shelves of the rocky wall as far down as 370 feet, and here he finally abandoned the location.

The main channel, as at present recognized, passes from the west end of the reservoir, southward toward Montezuma; thence southeasterly, near Chickasaw and St. Johns, reaching its deepest point west of the latter place in Marion township, where as already noted, 500 feet of drive pipe were required.

Fragments of old channels have been struck in Washington township, Auglaize county, near New Knoxville, and in Dinsmore township, Shelby county. At Anna Station, drive pipe exceeding 400 feet was called for and the drift was not entirely penetrated.

SECTION VI.

THE ARTESIAN WELLS OF THE DEEP CHANNELS.

Decidedly the strongest flowing wells of Ohio are found in these deep buried channels. They are to be counted by the score within the limits named, but so far none of them have been turned to practical account. A few will be specifically named. In Sections 15 and 16, Shawnee township, Allen county, in what is known as the Children's Home neighborhood, several wells have been struck at a depth of 200 to 250 feet. The water rises with at least two feet of head between $8\frac{1}{4}$ and $5\frac{5}{8}$ casing and flows off in a large stream. The present outflow from one of these wells is estimated at not less than 2,400 barrels per diem.

Throughout Moulton township similar phenomena are of frequent occurrence. The channels marked by deep drive pipe pass through this township. But flowing wells reach their highest mark in St. Mary's township. A number of old channels meet and unite within this and the adjoining townships. Large quantities of river gravel, some of it very coarse, fill these old beds, and the water contained in the gravel basins is in reality the equivalent of a lake. It is under enormous pressure. The highest head that has been noted is given as 40 feet; but it is doubtful whether this figure is the result of careful measurement. It is probable that estimates had something to do with it. At any rate, the pressure is beyond all precedent among the artesian wells of the State.

A well drilled on the farm of Mrs. Caroline Barrington, Section 11, St. Mary's township, gives perhaps the most surprising record. When the drill reached the gravel of the old channel, a mighty flood of water poured into the casing, and rose to a height of 20 feet in an unbroken volume. It would probably have gained a height of at least 30 feet in an enclosed pipe. With the water a shower of gravel was thrown out, falling back into the derrick. Several wagon loads of gravel were accumulated here in this way. Though all the gravel was obliged to come through the six-inch casing, a single stone was found that weighed $6\frac{1}{2}$ pounds. This flow was struck at 350 feet. The casing was finally driven to a depth of 364 feet. At a depth of 360 feet a log of considerable size was found imbedded in the drift. Wood, by the way, has been reported in a number of these deep wells. In a well drilled on the Hickman farm in Butler township, a log of light colored timber and apparently as much as three feet in diameter, was found at a depth of 60 feet. Again, in Section 19, Marion, a good-sized log, dark in color, was struck at 270 feet. In this last well, which was drilled on the Grieshof farm, the depth of the drift was 444 feet. Great floods of water have been struck at the same horizon throughout the reservoir.

The facts that have been reported in the preceding pages have been gathered from various sources, some of which are indicated in connection with the statements with which they are associated, but the very interesting revelations as to the deep channels of Fulton county and also of Auglaize and Mercer counties can be more definitely credited. Without making the persons named herewith responsible for particular statements, it is only just to say that the names of those whose statements I have used most freely are embraced in the following list. To these persons I return herewith public acknowledgement of the value of the information supplied by them:

W. H. Harper, Wauseon.
A. B. Robinson, Wauseon.
W. W. Croninger, Wauseon.
A. C. Reichelderfer, Lima.
The Ohio Oil Co., Lima, by J. C. Lufkin, manager.
The Manhattan Oil Co., Lima, by W. H. Holmes, manager.
Neely & Clover, St. Marys.
A. B. Curtin, St. Marys.
I. F. Rodebaugh, Celina.
C. W. Andrews, Celina.
H. B. Bennett, Celina.
Isaac Brandon, Celina.
Geo. Houser, Celina.
B. C. Miller, Celina.
Joseph Palmer, Celina.
R. E. Hill, Chickasaw.