Water-Supply and Irrigation Paper No. 79 Series L, Quality of Water, 5

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

NORMAL AND POLLUTED WATERS

IN

NORTHEASTERN UNITED STATES

BY

MARSHALL ORA LEIGHTON

WASHINGTON
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1903

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[See last page of this cover.]

(Continued on third page of cover.)

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
HYDROGRAPHIC BRANCH,
Washington, D. C., November 13, 1902.

SIR: I have the honor to transmit herewith a manuscript entitled "Normal and polluted waters in Northeastern United States," prepared by Marshall O. Leighton, resident hydrographer, United States Geological Survey, and to request that it be published as one of the series of Water-Supply and Irrigation Papers.

This paper is principally a review of the more readily available records, published and unpublished, of examinations made of water supplies derived from streams in the northeastern part of the United States, the principal streams examined being the Merrimac, Connecticut, Housatonic, Delaware, and Ohio rivers, and the various important branches of the latter in the States of Pennsylvania and Ohio. It is, in effect, an account of the important work done in river examination up to the present date, a few unfinished inquiries now in progress being omitted.

The introduction treats of the characteristics of normal and polluted waters in general and seeks to explain, in language intelligible to those not versed in chemistry, the meaning and importance of the various determinations made in an ordinary water analysis. In dealing with the various rivers which have been subjected to examination, wherever the courts have been invoked to pass upon the legality of any existing state of pollution, or to adjust damages occasioned thereby, the cases are cited and pertinent excerpts are given from the decisions.

This paper forms one of a series of reports on examinations made as to the character of the natural waters of the United States and the pecuniary damage to municipal water supply occasioned by city and industrial wastes. It is expected that examinations of like nature will be undertaken by the Survey in cooperation with the various universities and State laboratories in the country, the character of the work differing according to the conditions and demands in each case.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey,
Washington, D. C.

NORMAL AND POLLUTED WATERS IN NORTHEASTERN UNITED STATES.

By M. O. Leighton.

INTRODUCTION.

In order to properly determine the water resources of a country, and to define the limitations of use which apply to various rivers, it becomes necessary to know the character of the water in each case. Water is a source of wealth by reason of the uses to which it may be put, and these are dependent to a large extent upon the nature of the water. It follows, then, that for each branch of water utilization there is established a standard to which water must reasonably conform, in order that it may properly fulfill the requirements of the particular case.

By reason of their physical features and their artificial development, different rivers may possess characteristics which make them very different in their form or kind of utility. Sewage pollution may destroy every resource of one river, yet may not sensibly affect the value of another. One stream may be highly useful as a source of power; another may be best utilized primarily as a commercial highway; still another may serve as a source of water supply. There are waters which are more valuable as a disposal area for manufacturing refuse than they would be if maintained unpolluted as fishing grounds or ice fields. Therefore a thorough hydrographic investigation should serve to indicate the peculiar uses to which a stream is best applicable, and by it we should be able to determine the normal resource in each case and the damage done by unwise or unlawful procedure. Of especial importance is the fact that the utilization of a river in one State may be so damaging to its purity that the people of another State through which the same river flows may be totally deprived of its use, and, under present conditions, with little if any opportunity for redress.

Let us glance briefly at the characteristics that are demanded of waters required for different uses.

ESSENTIAL QUALITIES OF WATER FOR VARIOUS USES.

Commercial highways.—The character of a water has nothing to do with its use as a means of transportation. For this purpose it is

only necessary that it shall be sufficient in amount to float vessels and that the course in which it runs shall be deep and broad and uninterrupted by impassable obstructions.

Power.—For utilization as a source of power a stream should have sufficient grade to allow the conservation of large quantities of water behind dams, so that it may be forcibly delivered upon water wheels, and, by means of the power developed by this impact, may operate mechanism applied to human purposes. If the gradient is abrupt—that is, if it is largely concentrated in one or several places, so that the water falls over precipices or runs in rapids—the power available will be greater and the expense of development will be less than if the fall of the stream is gentler or the stretches between rapids are longer. The constituents of a water used for the development of power are not of great importance except in such cases as its impounding by dams may be the means of holding back or depositing accumulated impurities which become a source of discomfort and thereby depreciate the value of real estate.

Manufacturing.—It is essential that a water used in manufacturing processes shall not contain anything which, from a chemical or sanitary standpoint, shall be injurious to the products of manufacture. The manufacturing uses to which water is put are very numerous, and when it is to become one of the constituent parts of the product it is necessary, in most cases, that it shall be pure and not liable to damage the product by reason of any substances which it may carry in solution or suspension. If, on the other hand, it is intended that the water shall be employed merely in the process of manufacture, as in washing products or in dissolving ingredients, it is readily apparent that foreign substances in the water may defeat this purpose.

Use in boilers.—Normal or pure water has a certain action upon metals, iron being one of those easily affected. If, therefore, a pure water is used in a boiler there must necessarily be some action which has its part in shortening the term of usefulness of the boiler. When a water is used which contains ingredients that hasten this action upon iron or which deposits sediments within the boiler, the usefulness of the boiler is shortened unduly, and the value of the water as a boiler water is lessened by an equivalent amount. An idea of the damage done by calcareous matter in water, which is deposited as an incrustation within the boiler, can be formed by considering the experience of the engineers on the Nebraska Division of the Union Pacific Railroad, where the water used held in solution a large quantity of sulphate of lime and magnesia. When such water is boiled the sulphate is deposited on the inside of the container. The expense of cleaning and repairing boilers by reason of this deposit amounted in two years to $2,860, equal to 8 cents per mile of distance run. In addition to this the total mileage of each engine was probably reduced one-half

Fisheries.—It requires only a slight study of the subject of fresh-water fisheries to appreciate how acute is the effect of water pollution upon the living organism. Many waters in the United States that were once good fishing grounds have, within recent years, become destitute of fish because of the dumping of wastes from factories or public sewers into lakes or rivers.

Nuclei of parks.—The development of park systems in this country is a striking revelation of a growing civilization. That there should be recognized, in this highly commercial atmosphere, the need of establishing pleasant places of rest, where the careworn citizen may escape for a short season from his business encumbrances, is a cause for gratification. No one has properly estimated the value of these shelters to the workingman, the isolated housewife, or the dust-stifled child. It is fast becoming the conviction of popular representatives that the people have a right to retain unto themselves certain convenient portions of the country in its natural state. Of such there could be many within easy reach of every city, but too often their establishment is made impossible by the foulness of the water flowing past available sites or standing close by in natural reservoirs. A body of pure water is the proper nucleus of such a place, for bathing, boating, fishing, and pleasant atmosphere are all necessary accompaniments of the perfect park. But in a place where bathing becomes suicide, boating resembles a voyage with Charon, and even breathing taxes the strong stomach, there is little prospect that a park will be established.

Ice supply.—The requirements of a water to be used as a source of ice supply closely resemble those hereinafter described with reference to water supply. The difference lies in the fact that a large proportion of foreign matter in water is excluded upon the formation of ice. Just how much is yet uncertain, but the most recent investigations show that the microorganisms which produce disease do not live long in ice.

Irrigation.—Water used for purposes of irrigation must contain none of the various mineral impurities, such as those found in manufacturing wastes, which are known to have a deleterious effect upon vegetation. This danger to irrigation is so remote as to be unworthy of a passing remark. Irrigation districts are not, and probably never will be, manufacturing ones.

Drinking water.—The standards set for a drinking water are more precise than those prescribed in any other branch of water utilization. Water is necessary to the continuance or even the existence of life, powerfully affecting human beings for better or for worse according to its character, and as the immediate preservation of human life is the principal object of society, this phase of the water question is more important than all those previously discussed.

It is not necessary that a water for public supply shall be chemically pure; indeed, such a water would be in many ways undesirable. Generally speaking, that which flows off or out of the land in its

natural state is usually well suited to the needs of man. If, however, in flowing out of a drainage area it becomes contaminated with the ejecta of man or of domestic animals; if into the courses in which it flows there is emptied the refuse from mills and factories; if upon the land drained by the stream there has been spread any animal refuse whatsover, then the run-off water will be changed in character, and even though it may subsequently be treated, naturally or artificially, in such a manner that it is not prejudicial to health, it will bear to its final destination the marks of its former bad associations.

The value of a water is commonly reckoned according to its availability for public consumption. To be acceptable to the public it must have little or no turbidity and must contain little or no sediment or organic waste, color, taste, or odor. It will, therefore, be useful to follow the course of a quantity of water from its source in the ocean around its cycle of changes until it again reaches the ocean, in order to show how great are the obstacles that prevent it from meeting these several requirements.

IMPURITIES IN NATURAL WATERS.

RAIN WATER.

Water is raised by evaporation from oceans, lakes, ponds, and from the surface of the earth, and carried aloft, there to float in the form of clouds until the air sustaining it is saturated, when it is condensed and precipitated upon the earth. In falling through the air rain water naturally washes out any impurities held there in suspension. These impurities consist of dust composed of organic and mineral matter, such as pulverized earth, soot, pollen, and dried and finely divided particles of plants and insects, as well as ammonia, carbon dioxide, sulphuric acid and other gases, all of which are dissolved or held in suspension by water. Consequently when the rain strikes the earth it is not, as is commonly supposed, pure water. The amount of impurities it may contain depends on local conditions. If the air washed is that lying over a large manufacturing city it is manifest that the water on reaching the earth will be less pure than that falling upon a primeval region. Nevertheless, even in the latter case, the air always contains a certain amount of foreign matter. It is also manifest that rain water falling during the later part of a storm will be purer than that which first fell, for after a time the air will be cleared of its impurities.

On striking the earth, assuming that it falls on a mountain or on sloping land, there are several courses that water may take. Some of it is immediately absorbed by vegetation or directly evaporated from the earth's surface as it was from the ocean. The larger part, however, takes two other courses: (1) It runs directly off the surface in rivulets, converging into rills, streams, brooks, and rivers; (2) it sinks into the earth and, after filtering to a greater or less depth, reappears as springs or is intercepted by wells. Let us first follow that which runs directly along the surface of the earth.

SURFACE WATERS.

Some of the impurities which the water gathered in the air are lost as soon as it comes in contact with the earth, but in its course along the surface many more are gathered up—particles of sand or silt; pieces of dried or decayed leaves, wood, and grass; microscopic insects, and myriads of bits of other material of an almost imponderable nature which in the aggregate amount to a surprisingly large quantity. These particles ultimately are dissolved, or if sufficient time is not afforded to dissolve them they are deposited on the bottom of the stream in places where the current of the stream is checked. We have, therefore, the following classification of impurities in water:

Impurities in water.

- 1. Suspended matter
  - Inorganic or mineral — Sand, clay, and various pulverized minerals.
  - Organic
    - Animal: Living microscopic animals, dead fish and pieces thereof, feathers from birds, etc.; decayed animal refuse; manufacturing wastes, such as wool scourings, blood from slaughterhouses, etc.; excrement from sewers, etc.
    - Vegetable: Dried leaves, grass, and flowers, decayed wood, peaty matter; algæ and other plant life, including bacteria; wastes from cotton, silk, and linen mills, and from distilleries, etc.
- 2. Dissolved matter
  - Gaseous
    - Carbon dioxide.
    - Hydrogen disulphide.
  - Solid
    - Inorganic metals in general.
    - Organic
      - Animal (see above).
      - Vegetable (see above).

Organic matter.—Water as it passes over the earth, therefore, becomes more and more impure, the extent of its pollution depending on the character of the matter which it gathers up and carries along or which is poured into it by artificial means. Matter which is merely held in suspension would not seriously affect the character of water but for the phenomenon of solution, by reason of which the state of suspension is not permanent, for sooner or later a large part of the suspended matter is dissolved. It is a familiar sight to see inorganic matter dissolve in water, and the process seems simple; but the explanation of the solution of organic matter presents difficulties. How is it brought about? In order to explain this it will be necessary to discuss briefly the composition of organic matter.

Organic matter—that is, matter which is the product of life processes—consists chiefly of the four elements, carbon, oxygen, hydrogen, and nitrogen. These elements stand closely in union as long as life endures. Immediately upon the occurrence of death, however, there comes a breaking down. The chemical combination in the original living matter may be expressed thus:

```
Oxygen—Carbon
   |   ×   |
Hydrogen—Nitrogen.
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When there is no longer a bond of union between the four elements there comes dissociation and a reuniting of elements having attraction one for the other. In this case one of the first steps in the breaking down of the above combination may be expressed as follows:

$$\frac{\text{Oxygen—Carbon}}{\text{Nitrogen—Hydrogen.}}$$

The oxygen in this and in the other processes here described is derived to only a limited extent from the decaying organic matter itself, but is drawn in large part from the atmosphere and from the store of oxygen suspended in the water. The oxygen and carbon combination, known as carbon dioxide or popularly as "carbonic acid," combines with other elements or goes into solution as such, and its connection with the old combination is permanently severed. The nitrogen and hydrogen combine and form ammonia. This completes the first step in the process. We have the organic matter, once in suspension, then in solution, now broken up into two very familiar compounds, both inorganic.

The process is not yet finished. The combination, nitrogen-hydrogen, is not a strong one. It is easily disturbed in several ways, and one of these is the introduction of more oxygen, which is nearly always present in water and always in air and in innumerable chemical combinations. Both of the above elements are more strongly attracted by oxygen than they are by each other, and therefore there is a further breaking up. The next step may be represented as follows:

$$\frac{\text{Nitrogen—Oxygen—Hydrogen}}{\text{Hydrogen—Oxygen.}}$$

Now the hydrogen-oxygen combination is water, a very stable compound, and therefore that portion of the hydrogen and oxygen which is combined as indicated in the diagram is permanently disposed of. No further change takes place in it. Not so with the nitrogen-oxygen-hydrogen. As it is first combined, one part of nitrogen and one part of hydrogen, hold together two parts of oxygen, so that the combination is more accurately expressed:

$$\text{Nitrogen}\left\{\begin{array}{l}\text{Oxygen—Hydrogen.}\\ \text{Oxygen.}\end{array}\right.$$

This combination would remain stable if there were not more oxygen present and available. But as the element nitrogen can hold in combination three parts of oxygen, there can be no permanent chemical compound formed until this possibility is accomplished; so another change takes place, and the nitrogen finally holds three parts of oxygen, thus:

$$\text{Nitrogen}\left\{\begin{array}{l}\text{Oxygen—Hydrogen.}\\ \text{Oxygen.}\\ \text{Oxygen.}\end{array}\right.$$

The first compound is one of the substances that are necessary to the formation of a nitrite; the second forms the foundation for a nitrate, the essential distinction between these consisting of a difference in the amount of oxygen present. A nitrite represents a very unstable, transitory combination, which takes place in the oxidation of organic matter, and which in any case is not permanent. A nitrate, however, represents the final condition of mineralized organic matter. It is the stage where the decay of that which was formerly living matter stops, when every chemical demand is satisfied. A nitrate is a permanent, stable compound which is not readily broken up nor acted on by other elements or compounds.

It must be remembered that the changes above described, as will hereafter be noted more fully, take place in the presence and by the action of living organisms, and while the processes roughly outlined are not so simple as has been indicated, the foregoing explanation will nevertheless, it is hoped, give a general idea of their character. As a concluding remark, it is sufficient to note that under the circumstances the condition of nitrogen in a water faithfully represents the condition of the organic matter in that water.

Bacteria.—Having traced the changes that take place in the organic matter of a surface water, let us now consider the means by which such changes are effected. In the list of organic materials above enumerated it will be remembered that bacteria found a place among those matters "suspended." It is by their agency that the changes above described take place. They are not the bacteria which are known to produce disease, but they belong to the great and useful species of the order. They are found primarily in the air and in the ground, and their presence is indispensable to the reduction of waste organic matters to the inorganic elements from which they are made up. Along with the pollen, the soot, and the fine particles of animal and vegetable matters in the air, these bacteria are collected by the rain falling to the earth. When they are brought to the earth in rainfall they immediately begin the work of changing the organic matter, and they are at once reenforced by the myriads which are always present in the ground. The greater the amount of organic matter carried along by the water, the greater the number of bacteria that gather to reduce it, so that the number of bacteria found in a water is an accurate measure of the amount of organic matter it contains. Their presence in large amount does not necessarily signify that the organic matter is dangerous, but the very fact that there is sufficient food to sustain great numbers of bacteria is sufficient indication that putrefactive processes are going on in the water, the true significance of which must be ascertained before the water should be accepted for domestic use. Animal matter is more highly putrefactive than vegetable matter, and, except under extraordinary conditions, a high number of bacteria is indicative of animal pollution.

Algæ.—There is another great branch of the plant kingdom which exerts a powerful influence upon the purification of surface waters: This is the group Algæ. These are the minute green plants which, in stagnant pools, grow in such large numbers as to occasionally form what is popularly known as a "scum" over the surface. These plants subsist upon the products of decomposition of organic matter. As soon as the bacteria succeed in breaking down the complex organic combination as above described, these algæ grow abundantly and feed upon the products of decomposition. As the change from ammonia to nitrites and nitrates is made, they continue to consume the débris, so that the tendency is to clear the water of such matter. If such a water were placed in a glass and no further pollution were allowed to enter, it would be found that after a short period the ammonia, nitrites, and nitrates would be greatly reduced. It is also true that the algæ themselves live to maturity and die, contributing more organic matter to the water. But, unless the conditions are such that an overabundant growth is induced, and the living algæ can not consume the débris of their dead ancestors, the supply of organic matter from this source is not such as to materially affect the condition of the water from the standpoint of total organic nitrogen.

These algæ ofttimes contribute odors, tastes, and color to the water as a result of their life processes and their decay, so that in all cases their presence is not wholly beneficial from a sanitary standpoint. Such odors and tastes are characteristic and can be readily detected. The action of algæ described above is not fully exerted unless the water is quiet, or practically so, for a short time, although there is no doubt that some action takes place in running streams.

Algæ also feed upon carbon dioxide set free by the action of bacteria upon organic matter. The recent studies along this line are very instructive, and seem to clear up an important point which has, for a long time, not been fully understood. The purifying process which has been supposed to exist in the extensive aeration of water, like that tumbling down over a cataract, has been found to have very little effect upon the state of organic matter in the water. Dr. Thomas M. Drown, in a memorable experiment, found that after air had been blown through water for an extended period very little change had resulted in the condition of the organic matter. The work served to emphasize the fact that bacteria are all important in the oxidation of organic matter, and that the process is distinctly different from the oxidation of an inert mineral substance. It was therefore believed that the splashing of a brook down the side of a mountain had no purifying effect. Recent work has shown, however, that this process is beneficial, not on account of the absorption of oxygen in the water, but by reason of the expulsion of the carbon dioxide from it, so that the algæ, deprived of a large part of their food, would not be likely to grow to an extent that would make their presence objectionable.

Disease germs.—There is one other requirement demanded of a drinking water which, although inseparably linked with much that has gone before, must nevertheless be treated by itself. This requirement is, that a water used for domestic purposes shall not contain the specific germs or bacteria of ground-borne diseases, such as typhoid fever and cholera. It has been stated that in all waters in which the decomposition of organic matter is going on there are bacteria, which are requisite to the furtherance of this decomposition. It has also been shown that, although these bacteria are not productive of any specific disease, their presence in large numbers in a given water is a satisfactory indication that there must be a correspondingly large amount of decaying matter in the water to provide them sustenance. Experience has shown that a water which during a long series of examinations shows an average of more than 150 to 200 bacteria per cubic centimeter merits careful investigation. The presence of disease-producing bacteria is a matter which requires special consideration.

The bacterium commonly occurring in the United States is the bacillus of typhoid fever. This disease has its seat in the human intestine, and the infective material is naturally ejected during the course of the disease, and is carried along through sewers to the place of disposal. If this is a river the water therein becomes infected with germs of this disease, and the infection is communicated to persons drinking the water farther down the course. It is well known that the natural habitat of these bacteria is not in water, and therefore their life is not continued for a long period. Just how long this period is, however, is very uncertain; it surely has no connection with the period required to mineralize organic matter. Therefore the absence of the latter in its unoxidized state is no guaranty that dangerous bacteria are not absent. Their term of life probably varies widely, depending upon the local conditions, temporary or permanent.

UNDERGROUND WATERS.

Heretofore we have considered only that part of the water of precipitation which, upon striking the earth, flows directly off the surface into streams. That part which sinks into the ground is of equal importance, for it constitutes the reserve supply from which streams are replenished after the influx due to a rainfall has spent itself. All ground waters must at some time issue from the ground in the form of springs, wells, etc., and, flowing along in courses, become surface waters.

Basis of interpretation.—The fitness of ground water for public supply must be determined in ways very different from those used in determining the potability of surface waters. When rain water sinks into the earth it meets conditions which are highly favorable to the oxidation of the organic matter it contains. The water sinks slowly down through the particles of sand, the faces of which are covered

with the bacteria that bring about oxidation. Under such conditions an enormous extent of bacterial surface is exposed to the water, and the change of the organic matter from albuminoid ammonia to nitrates is exceedingly rapid and complete. Consequently, when such water emerges from the ground it is to be expected that the amount of ammonia and nitrates will be exceedingly small or absolutely wanting. When a spring water is found which possesses these ingredients, it is practically certain either that the water was originally a surface water which, upon entering the earth, has quickly passed below the layer of available oxygen in the ground, so that the normal process of decay has been retarded, or, having been once freed from its organic matter, has become contaminated with the contents of some sewer, cesspool, drain, or other source of waste matter. It is not an easy task to discriminate between these two possibilities unless there is at the disposal of the investigator a table or chart showing the amount of normal chlorine of the water of the locality within which the spring is located. With such information at hand, it is necessary only to compare the amount of chlorine found with the normal amount for the locality to ascertain whether the contamination is local or arises from natural phenomena. It has therefore become the practice of sanitarians to demand that a ground water shall contain little or no unoxidized organic matter. The amount of nitrates found in such a water is nearly always large, sometimes rising, in perfectly safe waters, to a very high proportion. Such results indicate an extensive previous pollution, which has been thoroughly cleared up. The element of danger in waters of this kind is the possibility that there might at some time be such a change in conditions controlling this oxidation that the process would fail of completeness.

Storage of ground waters.—When ground waters are stored in reservoirs in the presence of sunlight there is a quick and profuse growth of algæ in the basin, due to the abundant presence of nitrates which serve for food. Under such circumstances it is necessary to cover the reservoirs when it is desired to preserve ground waters in their original state.

SANITARY ANALYSES.

It will now be instructive to consider sanitary analyses and their significance. A sanitary analysis of water is not the determination of its mineral constituents and the quantity of each, but consists of the observation of a few physical characteristics, such as color, turbidity, odor, etc., and a determination of the different forms of nitrogen it contains, the amount of which, as has been remarked, is a faithful representative of the character of the organic matter in the water. It should be distinctly borne in mind that the ingredients which are determined in such an analysis are not harmful of themselves, and, as such, have no significance whatever. They are simply

guideboards which point out the way to a knowledge of the true condition of the water.

In Table 1 is given an analysis of a normal water in the State of Massachusetts.

TABLE 1.—*Analysis of a normal water from Massachusetts.*

[Parts per million.]

Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
Decided	6.0	1.252	0.000	0.000	0.000	1.1	51.5

Turbidity.—The term "turbidity," in the first column, defines itself, and in the analysis above set forth the degree of turbidity is expressed by the word "decided." The terms here used to express various degrees of turbidity, from lowest to highest, are as follows: "Very slight," "slight," "distinct," and "decided." This nomenclature is now used in only a few laboratories. In more recent analytical procedure turbidity is expressed according to a standard scale, the details of which are described in Circular No. 8 of the Division of Hydrography of the United States Geological Survey.

There are several highly important reasons for knowing turbidity, which make necessary the fine adjustment of an apparatus for its determination. Turbidity is a physical condition of water which must be measured by comparison with standards which are arbitrarily adopted. A clear water is most acceptable as a beverage. The most slovenly of mankind have an inherent dislike for a turbid draft, and even horses refuse to drink a water of doubtful appearance. Turbidity is the result of various causes, and a trained observer can infer a surprising number of facts concerning the history of a water and the condition of the area from which it comes by a superficial survey of the visible foreign matter held in suspension. A highly turbid water is unsuitable for many domestic and manufacturing purposes, and therefore the accurate determination of the degree of turbidity at the beginning of an investigation in some cases obviates the necessity of further work.

Odor.—The determination of the odor of waters is important, as from it we can sometimes determine the origin of the water or the pollution which it contains. Odors are often imparted to water by the green plants which grow in it, sometimes to a disagreeable extent. For a description of the method of describing odor, reference should be made to Circular 9 of the Division of Hydrography.

Color.—Returning to the analysis above set forth, the color denoted as 6.0 means that, compared with an arbitrary standard, prepared

and adopted as such, this sample bears the relation of 6 to 1,000,000; that is, a standard brown color having been determined upon, the sample under investigation is compared with known dilutions of the standard, and the dilution having the tint nearest to the sample is the one which designates the color of the water.

Nitrogen.—The next division of the analysis is entitled "nitrogen," and is subdivided into "albuminoid ammonia," "free ammonia," "nitrites," and "nitrates."

Albuminoid ammonia.—Albuminoid ammonia represents the nitrogen in the original combination referred to above; that is, before decomposition has set in. From the results of the determination of the amount of albuminoid ammonia in a sample of water we can infer with a fair degree of accuracy the amount of organic matter it contains. This does not, however, give any clue as to the character of the organic matter, whether animal or vegetable. We may find in a polluted water a smaller amount of this ingredient than may exist in a normal water perfectly acceptable for drinking purposes. In the analysis reported above is set down a comparatively large amount of albuminoid ammonia, 1.252 parts per million; this water, however, is unpolluted by dangerous wastes. On the other hand, in several waters the nature of which is known to be very dangerous, there were found only 0.284, 0.196, 0.198, 0.262, and 0.263 parts per million. The determination reveals, then, only the quantity of organic matter present, and in order to decide whether it is of a dangerous nature or not we must look further. If it is found that the organic material is principally vegetable matter, which is far less susceptible to decay than animal matter, the water which contains it may be fit for household purposes if the taste, color, odor, etc., are acceptable. This, however, can not be determined by analysis, but must be the result of inspection of the water course.

Free ammonia.—Free ammonia is the product of the first process of decay of organic matter. Its presence, as such, in a water is not more harmful than that of albuminoid ammonia. It denotes that decomposition is incomplete; that it has been arrested or retarded. It is not necessary, nor, indeed, natural, that any considerable inhibition of the process of decay should take place, and when such retardation occurs, as is shown by a high proportion of free ammonia, there must be some cause for it. We have said that a controlling factor in this process of oxidation is the presence of oxygen. Now, if a water contain a large amount of organic matter in a putrescible state, its breaking down into carbon dioxide and ammonia may go on so rapidly that it consumes all or nearly all of the available oxygen. This is certainly the case with sewage, in which there is a large amount of organic matter undergoing rapid decomposition. In the following reports of analyses this is well illustrated. The first is a repetition of what is found on page 23, while the second is that of a polluted water.

TABLE 2.—*Analyses of a normal and a polluted water from Massachusetts.*

[Parts per million.]

Character of water.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
Normal	Decided	6.0	1.252	0.000	0.000	0.000	1.1	51.5
Polluted	Slight	1.5	.263	.664	.025	.800	24.1	127.0

It will be seen upon examination of the above that in the polluted water the turbidity is less than in the normal water, the color considerably less, the total residue smaller in amount, and the albuminoid ammonia only 22 per cent of that in the normal water. When, however, we observe the comparative amounts of free ammonia, we find that in the unpolluted water there is none, while in the other there are 0.664 parts per million. This satisfactorily bears out the statements made in the preceding paragraph. It is evident that although the albuminoid ammonia in the polluted water has been so oxidized that the amount remaining can not be regarded as high, the free ammonia has not decreased in proportion. The cause of this must therefore be that the organic matter in the polluted water is so readily decomposed that it has consumed or was consuming all the available oxygen at the time the analysis was made. The fact that in the normal water there is reported no free ammonia indicates one of two conditions: (1) Either that algæ have consumed, as food, all the free ammonia as fast as it has been made, or (2) that the organic matter is not readily oxidized. We shall consider further on just which is the most likely deduction. High free ammonia may therefore be an indication of sewage pollution; at any rate it implies a rapid decomposition of organic matter.

Nitrites.—The presence of nitrites in a water is another indication of the incomplete oxidation of organic matter. It is only one step further in the process of oxidation, and as such, it must bear much the same significance as the presence of free ammonia. A nitrite is an even less stable condition of nitrogen than free ammonia; in fact, it represents nothing more than a short period of transition between free ammonia and the nitrates. Even in sewage-polluted waters it does not occur in so large a proportion as do the other forms of nitrogen. Rapid indeed must be the initial stage of oxidation of organic matter in order to allow the accumulation of nitrites. According to the analyses reported in Table 2 there are no nitrites contained in the normal water, but there are 0.025 parts per million in the polluted sample. The latter amount may be regarded as extremely high, and, taken with the high free ammonia, is almost certainly due to sewage pollution.

Nitrates.—The nitrates found in a water represent the complete mineralization of organic matter. When such matter, from whatever source derived, has reached this state it is entirely harmless. This is by no means equivalent to saying that a water with a high amount of nitrates and an insignificant quantity of the other forms of nitrogen is safe for drinking. There is no necessary connection between the amount of nitrates and the good or bad qualities of the water for public use. The question of the presence of the specific germs of disease is all-important and will be hereinafter considered. The presence of nitrates in a water, therefore, indicates nothing more than "previous sewage contamination." Of itself it is quite insignificant, but, taken into consideration with the determinations heretofore discussed, forms the final link in the chain which secures for us a knowledge of the history of a water under examination.

On referring again to the two analyses in Table 2 it will be noted that the amount of nitrates in the polluted water is large, indicating previous pollution. Yet it does not in any sense indicate that that pollution was dangerous. The report of analysis of the normal water shows that there are no nitrates. This is both uncommon and interesting. The amount of albuminoid ammonia in this sample is large, and under ordinary circumstances we might reasonably expect that there would appear at least a characteristic amount of the end product—nitrates. But as none appears we must conclude from the analysis that the organic matter in the water is of a kind that resists decomposition, and that as fast as the process is accomplished the algæ consume the ammonia, so that none appears in the various stages of oxidation.

Chlorine.—Little or no mention has been made of this substance in the previous pages in order that the discussion of the changes which take place in organic matter might not be complicated by other considerations. Few if any determinations in the whole range of water analysis are as important as that of chlorine. It bears absolute testimony concerning the history of the water, and its interpretation is dependent upon none of the other determinations. It may be under certain circumstances the crucial test by which a water may be accepted or rejected for potable use.

It is well known that chloride—that is, a chemical combination of chlorine with another element of a certain class, such as silver, magnesium, potassium, or sodium—are found in the earth in quantities varying according to the chemical nature of the geological formations. The most common of these is sodium chloride, familiarly known as common salt. These substances dissolve in water, some readily, others slowly, so that water that has passed through or over the ground is nearly always found to contain chlorides, generally common salt. Salt is found in the air, especially near the seacoast, and is one of the component parts of organic matter. The water

which flows over the surface of the land bears onward to the ocean an appreciable amount of salt in solution, a fact which is attested in a familiar manner by the saltness of the ocean and some of our great lakes which have no outlet. The wind blowing over the sea, driving it into spray, raises fine particles of salt, which are carried through the air over the land. These particles, being brought down by the rain, influence the amount of salt which is found in normal waters.

The work of the Massachusetts State Board of Health in the determination of the amount of common salt in normal waters has become classical. In a long series of analyses of normal waters selected in every part of the State it was found that there are distinct regions in which the amount of salt does not vary, except within very narrow limits, and that areas of equal normal chlorine may be defined upon a map of the State. It was found that the boundary lines of such districts follow roughly the coast line, and as the coast is receded from the amount of salt in normal waters grows less. This work has been taken up in Connecticut, Vermont, New Jersey, Ohio, and various other States. (See fig. 1.) How is such a map to be put to practical use? Before considering this question it will be necessary to take up the matter of significance of common salt in surface waters.

Common salt is composed of sodium and chlorine in equal proportions. Therefore, if it is desired to determine the amount of salt in a given water, it is only necessary to isolate one of these elements and the amount found will represent the whole. It is, for known chemical reasons, better to determine the chlorine, and therefore in an analysis of water like that in Table 1 the column "chlorine" represents the amount of chlorides, usually common salt.

We have said that salt is one of the component parts of both animal and vegetable matter. When a surface water is collected into a stream it contains chlorine that has been derived from vegetation as well as from the air and earth. Now, the amount of chlorine to be gathered from the vegetation of a district is as constant as that derived from the air or ground. When, however, animal matter is poured into the water there is an immediate rise in the amount of chlorine, which, obviously, can not be accounted for by any change in the natural conditions of the drainage area. It is clearly a contribution from sources other than those normally existing. The waste products of man, such as urine and fæces, and of the household, such as garbage and wash water, contain large amounts of salt, and when such waste is turned into a river its presence is easily detected. Now, the use of a normal chlorine map becomes apparent; whenever the water from any district is analyzed it is only necessary to compare the content of chlorine found with the normal content for that district, as shown on the map, and if the analysis shows a higher amount there is only one deduction to be made—that is, the water is or has been polluted with sewage.

When chlorine is once introduced into a water it remains there throughout the journey to the sea, accumulating according to the normal content of the country or the pollution introduced. The organic matter may be completely oxidized, generations of algæ may mature and die, color, hardness, turbidity, odor, and all else may change, but chlorine remains fast. Public sewers may be introduced into a river and change it to a stream of reeking filth; miles may afterwards be traversed; sedimentation, oxidation, and the most subtle filtration may take place, and the water may again be suitable for drinking, yet the actual amount of chlorine carried along by the stream does not, under usual circumstances, decrease appreciably. It may appear in smaller proportion at one point than at another, but

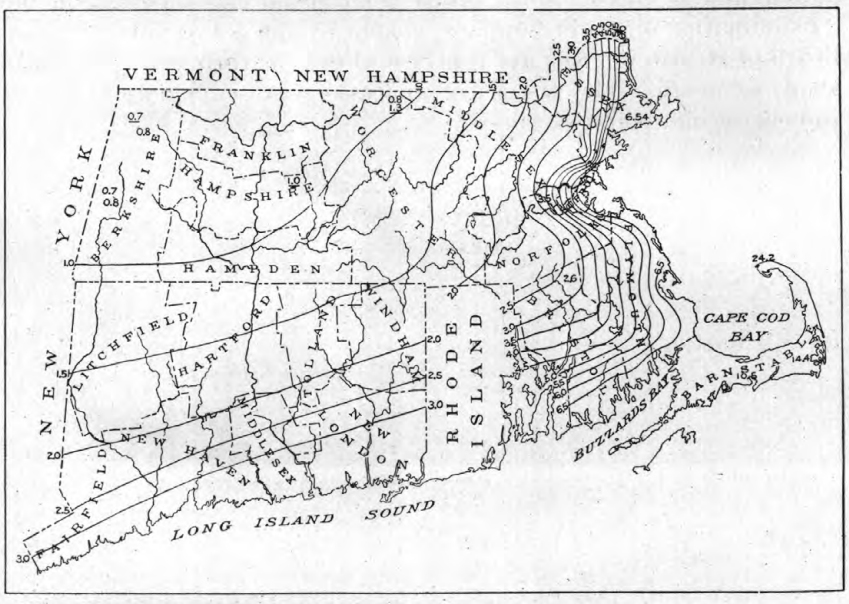

FIG. 1.—Normal chlorine map of Massachusetts and Connecticut.

not by reason of any reduction of the actual amount of chlorine. To illustrate, the water of the Blackstone River just below the Worcester precipitation works contained in the year 1900 an average of 15.7 parts of chlorine per million; after flowing a few miles to Uxbridge it contained 13.8 parts, and finally at Millville, a short distance above the State line, it contained only 9.3 parts. The river in its progress from Worcester to Millville receives a comparatively large amount of pure water from its tributaries, also a large amount of pollution from different establishments along its course, but the amount of sewage added is in no way proportional to the amount of pure water contributed. Therefore the proportion of chlorine to water must grow less all along the course from Worcester to Millville. It is obvious that the

proportion of chlorine is never reduced to an amount equal to the normal, and therefore must bear evidence of former abuse. The abnormal chlorine in a water may be likened to the scar left from some ugly wound; although the parts may be united and the surrounding tissues be healthy, yet the mark of former injury can never be effaced.

Total residue.—Under "Total residue" are included all matters, organic or mineral, which serve to pollute the water. In the above analysis it means that if 1,000,000 parts of water were evaporated there would remain in the container 51.5 parts of residue, which would represent practically the weight of the total impurity.

Analyses of normal and polluted waters.—The following analyses of normal and polluted waters, taken from the special report upon the "Examination of water supplies," made by the Massachusetts State Board of Health in 1890, are very useful in illustrating the principles above set forth. The first set of analyses represents normal waters and the second polluted waters.

TABLE 3.—*Analyses of normal and polluted waters.*

[Parts per million.]

NORMAL WATER.

No.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
1	None	0	0.022	0.000	0.000	0.060	0.8	50.0
2	Decided	1	.702	.000	.006	.030	1.0	25.0
3	do	6	1.252	.000	.000	.000	1.1	51.5
4	Slight	4	.333	.130	.001	.250	1.6	36.5
5	do	3	.136	.000	.000	.050	6.3	32.5
6	do	0	.152	.000	.000	.060	21.0	59.5

POLLUTED WATER.

7	Distinct	1	0.284	0.124	0.009	0.150	1.9	107.5
8	Very slight	5.5	.196	.000	.004	.550	5.4	51.5
9	Distinct	1.0	.198	.016	.004	.200	5.8	50.0
10	Slight	1.5	.262	.000	.010	.170	20.9	102.5
11	do	1.5	.263	.664	.025	.800	24.1	127.0

Careful examination of the above table shows that chemical analyses alone may furnish very little information concerning the healthfulness of a water unless certain matters determined are in exceedingly high

proportion. Analysis 11, in Table 3, for instance, is such that a person could, with a fair degree of safety, condemn the water. The free ammonia, nitrites, and chlorine are high, giving evidence which is unmistakable. Sewage is poured into the body of water from which this sample is taken.

Supposing, however, this series of analyses was not divided into "normal" and "polluted," how would we be able to place 8 in its proper position under "polluted waters?" The results of the determinations in this analysis appear lower than some of those in the normal list. On comparing it with 4, for instance, it will be seen that in the polluted water the turbidity is less, the color not much more, the total amount of organic matter not greatly different. The free and albuminoid ammonia are much less in the polluted water; the nitrites are considerably more, but not so great as in normal water 2. The nitrates are higher, but this, as has been explained, means little so far as the healthfulness of the water is concerned. The marked difference in the two seems to be in the amount of chlorine, but if we glance at the normal chlorine map (fig. 1) it will be seen that if 8 were collected in the region of Boston and 4 were collected farther west, these amounts of chlorine would both be normal. If we do not know where they were collected or whether the nitrogen compounds are the result of decomposition of harmless vegetable matter or dangerous animal waste, the bare water analyses are nearly worthless; but taken in connection with a knowledge of the locality, population, and sewerage conditions within the drainage area, the analyses are preeminently useful in determining the conditions of the water.

Hardness.—Some of the damages done by the use of hard water have already been referred to under the title "Use in boilers" (p. 14). In a public supply a hard water is troublesome and expensive by reason of the fact that when it is used for household washing it requires a larger amount of soap to produce the desired result. The fatty acids in the soap must first neutralize the calcareous matter in the water before it can be used for washing. A uniform scale for the determination of hardness is at present the subject of considerable thought among water analysts. The present methods, however, are efficient to a certain degree of accuracy and enable us to distinguish a soft water from a hard one.

There are two grades or kinds of hardness which will, wherever possible, be distinguished in the following pages. The first is due to the presence of alkaline carbonates, such as calcium, sodium, and magnesium carbonates. When water containing these compounds is boiled their effect quickly passes off; consequently it is designated as "temporary hardness," or, as it will be termed in this review, "alkalinity." The second grade of hardness is due to the presence of alkaline sulphates, chlorides, and nitrates. They do not disappear upon

boiling, and therefore maintain a "permanent hardness" or "normal hardness."

In the succeeding pages, in the case of New England, where the total hardness—that is, both temporary and permanent together—has been determined, the amounts indicating the degree of hardness are the result of a reduction of the amounts of all alkaline earth salts to terms of an equivalent amount of carbonate of lime. In other words, in Table 7 the statement of the hardness as 11 means that the water contains an amount of alkaline salts which make it as hard as would have been produced by 11 parts of carbonate of lime per million. In the statement of the hardness in the case of waters in the Ohio Basin, on the other hand, where the hardness is divided into "temporary" and "permanent," the temporary hardness indicates the amount of alkaline carbonates reduced to an equivalent of calcium carbonate; and in the case of permanent hardness, the amounts include the alkaline sulphates, chlorides, and nitrates reduced to an equivalent of calcium carbonate.

Summary.—In the preceding pages an attempt has been made to briefly and plainly state the characteristics demanded of a water required for public and household uses. Many details have been purposely omitted, but it is believed that enough has been said to enable the reader to comprehend the changes that take place in the dangerous or undesirable ingredients common to water supplies, a knowledge of which is necessary to a proper understanding of the contents of the following pages.

POLLUTION OF NATURAL WATERS.

The pollution of natural waters, though it may be sometimes unavoidable, is usually highly damaging to the resources of the country in which it takes place. The matter is a troublesome one in populous countries and has occupied the attention of chemists, engineers, land promoters, and others, as well as of courts of law, having been a fruitful source of litigation. The basis of action in all cases of this character is founded on the principles of common law in respect of the ownership of real property. The title of a land owner presumptively extends upward to the clouds and downward to the earth's center, embracing everything upon the surface and beneath it. This includes the mineral wealth in the ground and arising out of it, such as coal, iron, copper, oil, water, and even gas. The water flowing from a spring situated upon a certain piece of property belongs to the owner of the land as truly as do the blades of grass that grow upon it. A water right, whether it be vested in a spring, well, or river, is appurtenant to the land and passes with it by conveyance. The ownership so secured carries with it the assurance that all water passing out of or over the property shall be normal, and that any pollution

other than that caused by the natural drainage of occupied land lying above is actionable in law.

The situation is well summed up in a few paragraphs from the American and English Encyclopedia of Law, volume 28, under the heading "Water courses:"

Riparian rights are the correlative rights of adjoining proprietors upon the banks of water courses with respect to the water thereof. * * * The property in the water is indivisible, and all proprietors are entitled to an equality of rights therein.

In consequence of the common right of riparian proprietors to the benefits of water flowing through their land the general rule is that no proprietor has the right to use the water to the prejudice of another. This principle, however, does not restrain the use of the waters, so that there can be no diminution or impediment whatever, but the true measure and standard of the use which a riparian owner may make of his right is the reasonableness thereof. Each is entitled to a reasonable use for domestic, agricultural, and manufacturing purposes, * * * reasonable with respect to the rights of others.

A right to a reasonable use includes the right to release, let down, and discharge waters in order beneficially to employ them; and the exercise of the right entails no liability for injuries necessarily caused thereby to others in regard to the rise of the stream; yet if the discharge withdraws from another the use of the waters to which he is entitled, or if it needlessly deprives another of his beneficial use, or injures or destroys another's property, a case for damages is presented.

The right to the reasonable use of the water of a stream not navigable that flows through ones land includes the right to confine and obstruct its flow with dams in order to utilize the water power, or, for other beneficial purposes, to detain the water for such a length of time as it may be reasonably necessary for such use, notwithstanding the detention injuriously interferes with another's exercise of his right to the reasonable use of the stream in its natural state.

The right of every owner of land through which a stream of water flows to have the same flow in its natural state extends to the quality as well as the quantity of water, and therefore one who pollutes or contaminates water may be liable to those injured thereby, and a court of equity will interfere by injunction to restrain such use as will cause an irreparable damage or endanger the complainant's rights by adverse possession if continued.

A frequent ground of action arises from the operation of mills and factories, the refuse from which poisons, corrupts, and renders unwholesome the waters of a stream, or in some other way impairs it usefulness. The deposit of dyestuffs, whereby a stream is polluted or discolored; the discharge of poisonous or corrosive substances into a stream, whereby the machinery of lower riparian owners has been injured; emptying offensive matters from tanyards, and deposits of sawdust waste or refuse of mills to the injury of lower proprietors, have been held to be actionable and proper grounds for injunction.

A riparian proprietor who pollutes a stream by an unreasonable discharge of sewage, to the injury and inconvenience of lower riparian owners, is liable for damages therefor. If a muncipal corporation causes sewage to pollute a water course, to the use of which a lower landowner through whose premises it passes is entitled, it is guilty of a nuisance, for which damages may be recovered.

It appears, then, that there is no legal justification for the pollution of water, yet so universal is the practice that it has come to receive moral justification at the hands of society and meets no general con-

demnation except in cases where it goes beyond the bounds of human endurance. A few States in the Union have recognized the damage arising from water pollution and have made intelligent investigations for the purpose of correcting the evil. The results of some of these investigations will be presented in the following pages, together with the results of examinations made by several towns and cities as a consequence of local necessities. The data are arranged according to drainage areas, and in the case of interstate rivers, where the work has occurred in several States, the results obtained for a particular stream will be combined.

MERRIMAC RIVER BASIN.

GENERAL FEATURES AND METHODS OF UTILIZATION.

Course and drainage area.—The Merrimac drainage basin is 4,553 square miles in extent. (See fig. 2.) It is situated in New Hampshire and Massachusetts, occupying in the latter State 1,136 square miles. The Merrimac River proper is formed by the junction of the Winnepesaukee and Pemigewasset rivers at Franklin, N. H., from which place to its mouth, at Newburyport, Mass., it is about 110 miles long. From Franklin it takes a south-southeasterly course until it passes for a short distance into Massachusetts, when it abruptly turns northeastward and enters the Atlantic Ocean.

There is a wide variation in the physical characters of the Merrimac Basin. A large part of it is highly cultivated and fertile, but at the headwaters of the different tributaries the country is exceedingly rough and rugged. A small part of the area is low and swampy. Forests worthy of the name are almost entirely wanting in large parts of the basin, their absence causing a certain inconstancy in the flow of the river, but this has been in a measure corrected by a thorough system of storage, natural and artificial.

Throughout the basin the underlying rock is largely granite, which furnishes a valuable source of supply for building materials.

Storage.—Within the drainage area of the Merrimac are many lakes, ponds, and artificial reservoirs which afford excellent storage, and, as has been stated, compensate in a measure for the effects of extensive deforestation. The most important of these are Lake Winnepesaukee and Long Bay, covering 71.75 square miles; Squam, New Found, Belmont, and Massabesic lakes, Smiths and Suncook ponds, and a long chain of reservoirs in Massachusetts, which conserve a water supply for the "Metropolitan district."

Transportation.—The river is not important as a means of transportation. Small coastwise vessels may ascend as far as Haverhill only, and the amount of traffic is not large.

Power.—As a source of water power the Merrimac throughout its

whole extent is justly famous. In the main river there is a total fall of 269 feet in 110 miles, an average of 2.45 feet per mile. This fall, however, is concentrated at six principal points, giving most advan-

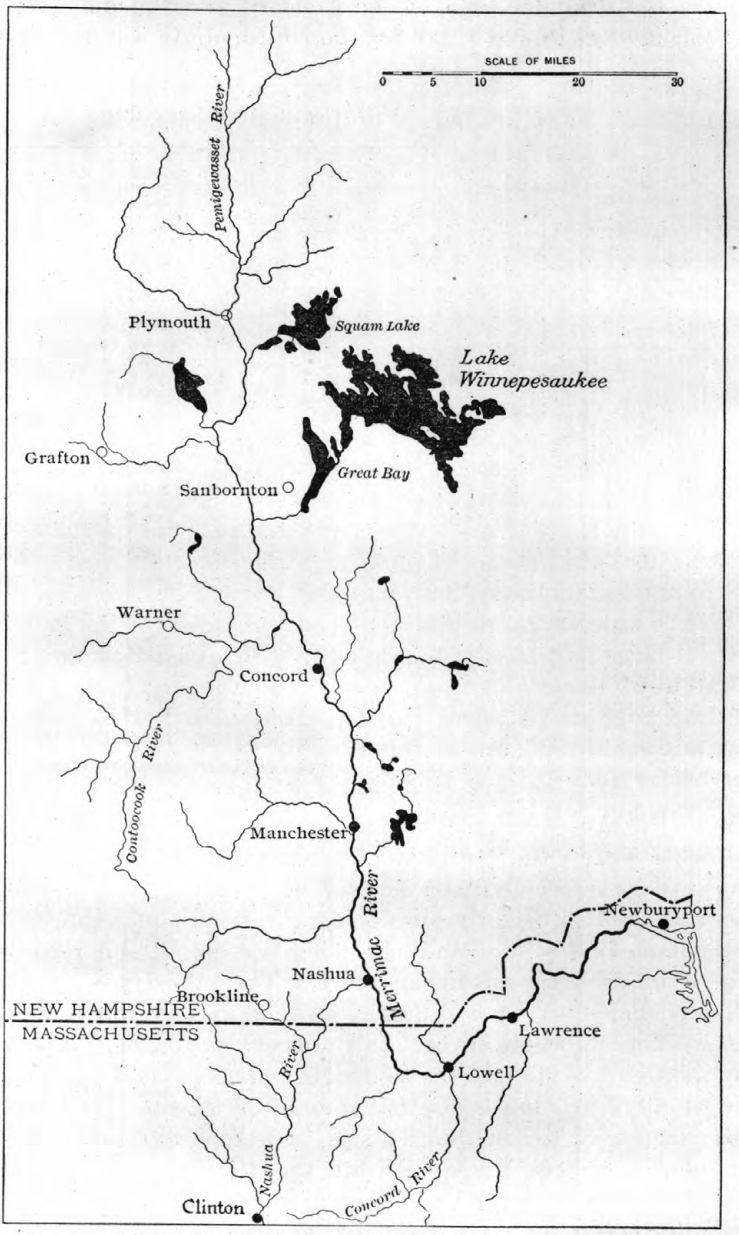

FIG. 2.—Merrimac River drainage basin.

tageous power facilities. Up to the present time there have been utilized over 40,000 horsepower at Lowell, Lawrence, and Manchester.

On the tributaries, too, there are a large number of power sites, which have been utilized extensively. In Table 4 is given the total utilized horsepower on each important tributary. Some of these, especially in the drainage area of the Concord and Nashua rivers, have been abandoned to make way for the metropolitan water-supply system.

TABLE 4.—*Utilized horsepower of tributaries of Merrimac River.*

Branch.	Total utilized horsepower.	Drainage area (square miles).
Powwow River	1,850	50
Shawsheen River	645	72
Spickett River	701	79
Beaver Brook	687	92
Concord River	4,962	380
Stony Brook	904	35
Nashua River	11,762	516
Souhegan River	2,451	224
Cohas Brook	170	44
Piscataquog River	1,250	214
Suncook River	2,881	264
Soucook River	72	90
Contoocook River	6,360	766
Winnepesaukee River	6,503	480
Pemigewasset River	4,114	1,013
Total	45,312	----------

Ice.—With the exception of Lake Winnepesaukee there are no very large ice fields within the Merrimac drainage area. Taken collectively, however, the ice industry is very large, each pond or lake which has remained sufficiently pure being the source of supply for the country immediately surrounding. There are no reliable records of the size of the ice crop within this basin. The industry is largely localized, each field having a different ownership, and the returns made by the different owners are certainly not correct, for the endeavor to escape taxation has induced the several companies to make returns which are usually far below the actual amount of ice cut. The common measurement of ice in the fields is 1,000 tons to the acre, the ice being about 12 inches thick. Within the Merrimac Basin it is possible to cut two or three crops. According to the Tenth Census report on water power there are about 100 square miles of pondage in this basin, equal to 64,000 acres. Assuming that 25 per cent of this area is available for ice cutting and allowing for only one crop during the season, which is certainly a low average, there would be available

160,000 tons on the lakes alone. Allowing for a large crop on the rivers, it appears that 1,000,000 tons a season is a conservative estimate, and the total amount cut is probably far more than this. At all events, the value of this system as a source of ice supply is very great.

FLOW MEASUREMENTS.

During a series of years the flow of the Merrimac has been carefully measured at Lawrence, and the discharge is given in the following table:

TABLE 5.—*Estimated annual discharge of Merrimac River at Lawrence, Mass.*

[Drainage area, 4,553 square miles.]

Year.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1890	31,560	590	9,373	6,785,786	27.93	2.06
1891	39,000	280	8,370	6,033,916	24.84	1.48
1892	24,800	225	5,869	4,264,911	17.58	1.29
1893	44,800	286	4,850	4,726,807	19.47	1.43
1894	27,900	104	5,035	3,645,052	15.03	1.11
1895	65,300	71	5,799	4,196,973	17.25	1.27
1896	82,150	183	7,187	5,203,029	21.40	1.58
1897	41,499	176	8,002	5,800,105	23.90	1.76
1898	36,000	372	8,413	5,092,341	25.05	1.85
1899	38,200	50	6,464	4,672,824	1.42	19.20

On the Sudbury River, tributary to the Concord, measurements of flow have been regularly made since the year 1875, and are set forth in the following table:

TABLE 6.—*Mean flow of Sudbury River in cubic feet per second, 1875–1900.*

[Drainage area, 75.2 square miles.]

Year.	Second-feet	Year.	Second-feet.	Year.	Second-feet.
1875	111	1885	105	1895	134
1876	118	1886	126	1896	119
1877	141	1887	134	1897	114
1878	169	1888	197	1898	153
1879	104	1889	176	1899	113
1880	67	1890	149	1900	126
1881	114	1891	150	Mean	124
1882	100	1892	90		
1883	62	1893	120		
1884	131	1894	89		

CHARACTER OF NORMAL WATER IN THE MERRIMAC BASIN.

The waters of the Merrimac have been studied more carefully, probably, than those of any other river in the world. The Massachusetts State Board of Health, famous for its pioneer work in modern river survey, has determined very closely the character of the water in that part of the drainage area that lies within the State. No work of importance has been done by the State of New Hampshire, but the waters of the Winnepesaukee have been carefully analyzed by the Commonwealth of Massachusetts. The natural conditions in the drainage area are, however, sufficiently uniform to warrant the assumption that the normal characteristics of the headwaters in Massachusetts are representative for the whole area.

Tables 7 and 8, the first consisting of analyses of practically normal surface waters and the second consisting of analyses of normal ground waters, will fairly serve as an index of the character of unpolluted water in the Merrimac Basin. The last column in these tables shows the number of analyses on which the averages stated were based.

TABLE 7.—*Analyses of normal surface waters in Merrimac Basin.*

[Parts per million.]

Place of collection.	Turbidity.	Color.[a]	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Number of analyses made.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
Sudbury reservoir	.....	2.2	0.175	0.030	0.001	0.054	2.2	36.2	11	52
Framingham reservoir.	Slight to decided	1.9	.170	.022	.001	.037	2.3	36.3	12	12
Ashland reservoir	do	6.8	.223	.012	.001	.047	2.4	37.2	11	([b])
Nagog Pond, Acton	None to slight	.5	.170	.005	.000	.011	2.4	20.9	2	11
Scott reservoir, Fitchburg.	Slight to decided	1.6	.227	.068	.001	.020	1.4	26.1	2	4
Haynes reservoir, Leominster.	do	1.6	.304	.016	.000	.020	1.0	18.7	1	4
Morse reservoir, Leominster.	Very slight to slight.	2.3	.198	.007	.000	.030	1.2	21.0	2	4
Sandy Pond, Concord.	.....	.3	.129	.001	.001	.041	2.5	26.6	.....	.....
Crystal Lake, Haverhill.	.....	1.3	.166	.009	.....	.030	3.0	32.2	.....	.....
Lake Winnepesaukee.	.....	1.0	.093	.002	.000	.038	[c]1.2	20.9	.....	24
Penacook Lake, New Hampshire.[d]	.....	1.0	.138	.020	.000	.000	1.4	32.0	11	1

[a] Nessler scale.
[b] Over 80, extending over 13 years.
[c] Excess of chlorine, 0.2.
[d] Furnished by H. E. Barnard, New Hampshire State Laboratory of Hygiene.

TABLE 8.—*Analyses of normal ground waters in Merrimac Basin.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Number of analyses made.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
El-Hazar, Lowell	2	0.012	0.004	0.000	0.025	1.0	24.0	5	2
Ballardvale, Andover	3	.012	.003	.000	.035	2.4	23.5	4	2
Framingham	1	.025	.000	.000	.065	2.2	38.0	17	2
Pepperell	1	.006	.003	.000	.065	1.5	53.0	24.5	2
Concord	0	.025	.006	.000	.260	2.6	26.5	4	3
Methuen	0	.012	.003	.000	.150	2.0	85.0	21	2
Chelmsford	2	.022	.006	.000	.510	2.8	27.0	6	1
Dracut	2	.077	.008	.000	.040	2.7	33.5	6.5	2
Well in Sandbarton	0	.000	.000	.000	.300	1.76	55.0	2.0	1

POLLUTION IN THE MERRIMAC BASIN.

The country drained by the Merrimac River system contains a population of about 632,560, according to the national census of 1900. Of this number, 414,040 dwell in Massachusetts. The population per square mile within the whole area is therefore 151; that in New Hampshire is 71.4; that in Massachusetts is 364.4. A large proportion of this population is concentrated within cities and large towns, so that the above figures do not, even approximately, represent the actual conditions in the drainage area.

Pollution exists in the basin to an extent that has made the waters a fruitful source of study. On the main river, between Newburyport, Mass., and Concord, N. H., there is a large civic population supplied with sewerage systems, from which large volumes of crude sewage are daily poured. Some of the tributaries also receive a damaging amount of pollution. The latter will first receive attention, and their effects will be gathered together and summed up in connection with the pollution in the Merrimac proper.

SHAWSHEEN RIVER.

Rising in the historic town of Lexington, Mass., the Shawsheen runs in a northerly direction and enters the Merrimac at Lawrence. It is a somewhat unimportant stream from the standpoint of natural resource; the flow is unsteady and the power values poor. As a source of water supply it would furnish in the driest year about 20,000,000 gallons of bad water daily from the 34.1 square miles on the upper end of the drainage basin.

The population of the portion of the area above mentioned is about 125 per square mile, and appears to be growing rapidly. Few precau-

tions have been taken to keep the waste from this number of people out of the river, and the country is highly fertile and swampy to a large degree, so that the water of the river contains an abundance of organic matter and has a high color.

Analyses of the water of the river have been made by the State Board of Health, as follows:

TABLE 9.—*Analyses of water from Shawsheen River.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Number of analyses made.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
Bedford	Slight	15	0.311	0.000	0.002	0.035	5.9	76.7	22	2
Wilmington	None to distinct.	9.6	.272	.018	.001	.085	3.5	56.3	------	24
Andover	Slight to decided	5.1	.385	.074	.001	.047	4.2	55.7	13	3
North Andover	Slight	8.5	.306	.106	.005	.250	3.6	53.5	13	1

The special report of the State Board of Health of Massachusetts, made in 1895, upon the metropolitan water supply has the following:

It was the general opinion from 1874 to 1887 that the water of the Shawsheen River was of satisfactory quality for the purposes of a public water supply; but the investigations of the State board of health since the latter year have shown that this is not the case. The population upon the watershed (123 per square mile) is not very large, but the headwaters of the stream are in the town of Lexington, within 10 miles of the statehouse, where there is likely to be a large growth in the future, and the territory in and beyond Lexington is used to an increasing extent for market gardening. The watershed also contains many swamps, from which the water acquires a high color and takes up much nitrogenous organic matter.[a]

CONCORD RIVER.

Sudbury and Assabet rivers join at Concord, Mass., to form the Concord, which from this point flows in a northerly direction to join the Merrimac at Lowell. (See fig. 3.) The country drained by the system varies in character, a part being extremely flat meadow land, through which the river winds sluggishly, while the remainder is of the hilly, rolling character common to Massachusetts. The Assabet Basin and the upper part of the Sudbury are of the latter character, but the Lower Sudbury and the Concord, from the town of Concord to Billerica, are very flat. Two miles from its junction with the Merrimac there is a fall of 40 feet in the Concord, corresponding to the fall in the Merrimac at Lowell.

[a] Report Massachusetts State Board of Health upon a Metropolitan Water Supply, p. 114.

Pollution in the Concord system has been accurately determined. The Upper Sudbury is set apart as a drainage area for a part of the supply of the Massachusetts metropolitan district, and for years

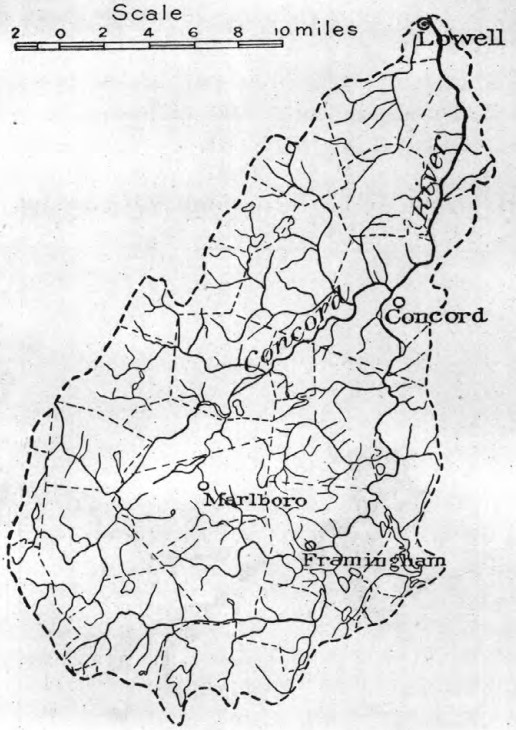

FIG. 3.—Concord River drainage basin.

accurate analyses have been made. The Assabet has been examined with reference to its use as a future source of supply, and the Concord has received attention all along its course.

SUDBURY RIVER.

Drainage area.—In the Sudbury area the city of Boston had six reservoirs built or started, utilizing the water from Farm Pond and Lake Cochituate, when the control was put into the hands of the Metropolitan Water Board. The drainage area here included is as follows:

	Sq. miles.
Reservoirs 1 to 6	74.656
Farm Pond	.543
Lake Cochituate	18.87
Total	94.069

Within this area are Marlboro, Southboro, Westboro, Hopkinton, Ashland, and the largest populated portions of Natick, Framingham,

Sherborn, and Wayland, all representing a population of about 45,300, or 482 per square mile.

Conditions in the area.—That waters can be conserved in so populous an area and delivered in good condition to the citizens of Boston without any purification save that occasioned by storage may be considered remarkable. It is commonly found that a river running out of a valley having so many persons per square mile as live in the basin of the Sudbury is so polluted that its use in the raw state is dangerous. The examination of the condition of the Shawsheen showed what may be expected even in a country with a population of 125 per square mile. It will therefore be profitable to consider the conditions

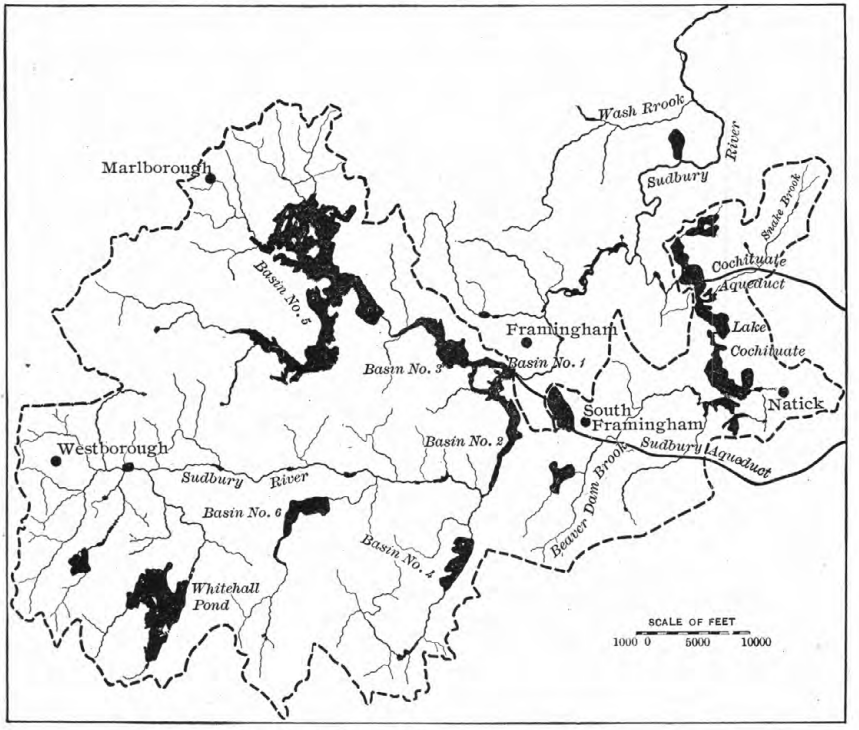

FIG. 4.—Sudbury River drainage basin.

within the Sudbury area and show how it is possible to maintain the run-off water in a normal state.

Examination of the accompanying map of the area (see fig. 4) will show that Westboro is situated on the western divide of the Sudbury, and just beyond the divide is the sewage-disposal work for the town. On the northern boundary is Marlboro, a city of importance, and to the east, over the divide, is another disposal works. In the stream known as Walker Brook, running through Marlboro to the great Sudbury reservoir, has been placed a filter, and all of the water from the

city of Marlboro, which, as shown by analysis, is extensively polluted, is purified before being mingled with the pure water in the reservoir. Within the Cochituate Basin are South Framingham and Natick, both with sewerage systems and sewage-disposal works the latter situated outside of the drainage area. In addition to this, a filtration system has been established at the Reformatory Prison for Women, while the water of Pegan Brook, running from Natick into Lake Cochituate, is filtered like that of Walker Brook in Marlboro. The differences between the waters of this area and those of others having an equal population are due entirely to these precautions.

Out of the Sudbury and Cochituate basins there were daily drawn in the year 1902 about 41 million gallons of water. If it were not for the filtration of polluted water described in the foregoing paragraph, the water from this area would be quite unfit for domestic use, and this large investment would diminish in value or would fail completely. It would be necessary to filter the entire output, which would cost at least $5 per 1,000,000 gallons, or, at the present rate of consumption, $74,800 annually. Under the present conditions the expense of sewage purification in the Sudbury and Cochituate basins amounts to a small fraction of this sum annually. Thus by an expenditure of a small amount of money for the construction of disposal works and a comparatively insignificant amount for maintenance the value of the Sudbury resource is preserved. This is a typical case, illustrating what may be done in the way of preserving in its normal state the water of a populous district. It stands forth in contrast to the many cases hereinafter taken up, in which all thought of preservation of values undamaged is thrown to the winds.

Character of water.—The character of the water in the Upper Sudbury Basin is well set forth in the first three analyses in Table 7, page 37. It will be seen that from all evidences the precautions taken are successful, for the waters are practically normal. The Cochituate water is also nearly normal and is similar in many respects to that of the Sudbury, possessing, however, a much lighter color. The color of the Sudbury water has been improved during recent years by the drainage of swamp lands in the watershed.

Passing out of the hilly region, the Sudbury winds along the plain through the towns of Sudbury, Wayland, and Lincoln, carrying along the incidental pollution from these places as well as that from Framingham Center and the effluent from the Natick, Marlboro, and Framingham filter beds. This pollution has its effect upon the river, as is shown by the marked change in the character of the water. The following analyses of waters, taken along the Sudbury, Assabet, and Concord at different points, are reproduced from the report of the Massachusetts State Board of Health for 1900.

TABLE 10.—*Analyses of water from Sudbury River between Saxonville and Wayland (Farm Bridge).*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness.	No.	Place of collection.
Aug. 15, 1900	Veryslight	3.4	0.216	0.040	0.002	0.000	3.6	40.0	16	1	Dam above Saxonville Mills.
Aug. 29, 1900	do	2.2	.244	.012	.000	.030	3.6	40.0	16	2	Do.
Do	Decided	8.0	1.500	.390	.000	.020	9.0	118.0	22	3	3,000 feet below Saxonville dam.
Feb. 27, 1901	do		2.720	5.040	.013	.200	11.1	162.5	27	4	4,000 feet below Saxonville dam.
Aug. 15, 1900	do	6.1	1.000	.110	.007	.010	7.3	90.5	20	5	1 mile below Saxonville dam.
Do	do	6.1	.850	.140	.004	.010	6.9	103.0	22	6	2.7 miles below dam.
Aug. 29, 1900	do	3.3	.600	.300	.004	.020	8.7	92.5	26	7	Do.
Feb. 27, 1901	do	6.0	.940	.940	.070	1.020	16.8	153.0	29	8	Do.
Aug. 29, 1900	Slight	3.0	.336	.136	.000	.020	8.0	69.5	26	9	4.1 miles below dam.
Aug. 15, 1900	do	3.0	.292	.136	.004	.010	6.3	74.5	25	10	6 miles below dam.
Aug. 29, 1900	do	2.9	.376	.032	.003	.010	8.3	80.0	26	11	Do.
Feb. 27, 1901	do	2.7	.206	.172	.018	.420	6.8	71.5	25	12	Do.

TABLE 11.—*Analyses of water from Sudbury River between Wayland and Concord.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness.	No.	Place of collection.
Aug. 11, 1900	Slight	2.9	0.246	0.072	0.005	0.030	6.6	61.5	22	13	Canal bridge.
Aug. 29, 1900	Veryslight	3.6	.258	.046	.002	.020	6.3	62.5	23	14	Do.
Feb. 27, 1901	do	2.9	.214	.244	.010	.410	6.5	64.5	22	15	Do.
Average		3.1	.239	.121	.006	.153	6.5	62.8	22		
Aug. 15, 1900	Veryslight	3.0	.260	.022	.004	.000	5.6	56.0	23	16	Lee's bridge.
Aug. 29, 1900	do	2.3	.244	.030	.000	.020	6.8	58.0	20	17	Do.
Average		2.6	.252	.026	.002	.010	6.2	57.0	21		
Aug. 15, 1900	Veryslight	3.0	.226	.026	.001	.000	6.0	54.0	20	18	Heath's bridge.
Aug. 29, 1900	do	1.9	.222	.024	.000	.030	5.8	58.5	18	19	Do.
Feb. 27, 1901	Slight	3.6	.250	.142	.006	.380	6.2	71.5	20	20	Do.
Average		2.8	.233	.064	.002	.137	6.0	61.3	19		
Aug. 15, 1900	Veryslight	3.0	.262	.044	.002	.000	5.8	55.0	22	21	Near mouth Concord.
Aug. 29, 1900	do	2.2	.222	.034	.000	.010	5.5	59.0	21	22	Do.
Feb. 26, 1901	Slight	3.2	.274	.122	.005	.290	6.0	64.5	21	23	Do.
Feb. 27, 1901	do	3.7	.284	.144	.005	.380	5.9	65.0	21	24	Do.
Average		3.0	.260	.086	.003	.170	5.8	60.9	21		

Findings.—The dates of collection of the samples reported in Tables 10 and 11 are well selected to show the character of the water in Sudbury River in midsummer and midwinter seasons. The analyses given show clearly the effects of pollution on the river along the entire course, from the borders of the restricted area to the mouth of the Assabet, in Concord. Samples 1 and 2, taken from the dam above Saxonville mills, show the effects of contamination from Framingham Center in the content of chlorine. The normal chlorine map shows that the proper amount for this area is about 2.5 parts per million, while that in the samples indicated is 3.6. The amount of nitrogen in the two determinations is noticeably low. This may be due in part to the short term of storage afforded in the mill pond above Saxonville dam, but the more correct explanation is probably that the water which runs out of the restricted area below the reservoirs has little polluting material turned into it, except that of an indirect nature, and the only testimony which remains is the abnormal amount of chlorine. As far as the analyses show, the water from above Saxonville dam may be taken to represent roughly the character of the unpolluted Sudbury water. A comparison with the analyses of the water taken from points below may be fairly made upon this basis. Nos. 3 and 4 show clearly the effects of pollution from Saxonville, while 5, 6, 7, and 8 well represent the effects of oxidation, sedimentation, and dilution with fairly pure water from small tributaries. No. 8 shows in an instructive way the difference in the purifying action of those three agents during the cold season. Nos. 9–12 in Table 10 and 13–24 in Table 11 present no remarkable features, and merely indicate the continued effects of self-purification in a river which runs through a district sparsely populated. It is interesting to note that the amount of chlorine remains high, increasing as the points of pollution are passed, and thereafter being reduced in proportion to the dilution from tributary streams.

ASSABET RIVER.

The drainage area of this river is a narrow one, lying between the drainage basin of the Sudbury and that of the Nashua. The country is fertile and the affluent from sewage-disposal works at Westboro and the pollution at the village of Northboro all assist in contaminating the stream. The special report of the State Board of Health in 1895, in considering future sources of supply for the metropolitan district, contains the following statement:

> Owing to the polluting matters which enter the streams at Northboro, to the very large area of swampy land along the river between Northboro and the Boston and Albany Railroad, and to the disposal of the sewage of Westboro upon the banks of this section of the river (Assabet), it is not of suitable quality for water-supply purposes.

The analyses published at that time fully bore out this statement,

but since then the river has become more polluted. The annual report of the State board for the year 1900 contains the following analyses:

TABLE 12.—*Analyses of water from Assabet River.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness.	Place of collection.
Feb. 27, 1901	Decided	5.0	0.520	0.204	0.002	0.280	4.3	60.0	16	2 miles above Northboro.
Aug. 15, 1900	Slight	5.4	.392	.100	.003	.000	5.2	53.0	18	Below Hudson.
Aug. 29, 1900	Decided	7.0	.110	.640	.001	.020	24.9	124.5	23	Do.
Feb. 27, 1901	do	3.3	.416	.256	.005	.300	15.9	80.5	18	Do.
Do	do	4.0	.336	.188	.005	.230	7.1	66.0	14	Below Gleasondale.
Aug. 15, 1900	do	3.0	.376	.140	.002	.000	6.7	53.5	11	Below Maynard.
Aug. 29, 1900	do	3.4	.425	.090	.003	.010	7.6	61.5	11	Do.
Feb. 27, 1901	do	3.5	.480	.288	.004	.200	7.1	70.5	16	Do.
Aug. 15, 1900	Slight	3.2	.388	.216	.007	.070	6.5	50.5	13	Near mouth.
Aug. 29, 1900	Very slight	2.4	.278	.138	.005	.040	7.8	57.5	13	Do.
Feb. 26, 1901	Slight	3.5	.308	.164	.004	.260	6.6	57.0	18	Do.
Feb. 27, 1901	do	3.5	.296	.230	.005	.280	5.9	63.0	16	Do.

CONCORD RIVER, BETWEEN CONCORD AND LOWELL.

Below Concord, the river slowly winds through a country of scanty population, without materially adding to the pollution which it bears along. The water perceptibly improves through the same agencies as are above noted in the case of the Sudbury, until it comes within the polluting influence of Lowell.

TABLE 13.—*Analyses of water taken at different points along Concord River.*

[Parts per million.]

Turbidity.	Color.	Ammonia. Albuminoid.	Free.	Nitrogen as— Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness.	Place of collection.
Very slight	3.2	0.286	0.102	0.004	0.030	6.4	53.5	16	Below North Bridge, in Concord.
Do	3.0	.250	.080	.003	.040	6.7	55.0	17	At Flint's bridge, in Concord.
Slight	3.4	.278	.158	.005	.330	6.3	63.5	17	Junction Sudbury and Assabet.
Very slight	11.0	.352	.030	.002	.130	5.2	59.0	16	Billerica.
Do	2.6	.224	.044	.001	.010	9.4	61.0	25	Above Billerica waterworks.
Do	2.0	.222	.040	.000	.010	5.9	54.0	14	North Billerica.
Do	2.0	.220	.018	.000	.010	5.9	52.0	14	Above Talbot's mill, Billerica.

NASHUA RIVER.

Nashua River rises in Worcester County, Mass., and flows in a northeasterly direction into New Hampshire, where it joins the Merrimac at Nashua. Above Lancaster, Mass., the river divides into the North and South branches, the former coming down from the northwest, the latter having traced a circuitous course in a general northeasterly direction. (See fig. 5.)

FIG. 5.—Nashua River drainage basin.

There are situated within the Nashua Basin 23 municipalities, exclusive of Nashua, at the mouth, some of which extend over across the divide into other watersheds. The total population, according to the Twelfth Census, is about 83,200, or neary 161 per square mile. This, however, does not fairly represent the conditions upon the river system, for upon many branches the country is sparsely settled. Large settlements are not numerous, and only three are of important size. Fitchburg, on the North Branch, has a population of 31,531; Leominster, a short distance below, is reported to have 12,393; and Clinton, the only important center on the South Branch, has 10,251 inhabitants.

SOUTH BRANCH OF NASHUA RIVER.

The South Branch of the Nashua has a drainage area of 129 square miles, the topography being hilly and steep, affording admirable opportunities for storage. The upland branches, Quinepoxet and Stillwater, join to form the South Branch, bringing in the waters of a country of small population and affording a supply of excellent quality. Practically all of this upland area has been set aside by the Metropolitan Water Board for the conservation of a supply for Boston and vicinity. The river is intercepted by a mammoth dam, which will hold back the waters of one of the largest reservoirs ever constructed, at a point just above Clinton.

The waters of the reservoir will cover the present villages of Boyleston, West Boyleston, and Harrisville, and the work of effacing these places has already been carried forward. At the time of the first report on the project, in the year 1895, the population of the proposed restricted area of 118.23 miles was 61 per square mile. Since that time there has been practically no increase over the whole country, and recently the destruction of the villages above mentioned has caused a marked decrease. The completion of this work will effect a change in the quality of the water taken from this basin. The few points of pollution now existing there will be removed and storage in the new reservoir will improve the character of the water. Yet even now the supply which is taken from the river and carried through the aqueduct constructed across the eastern watershed to the Sudbury Basin is of excellent quality and will serve as a normal from which to consider the pollution in the lower reaches of the river. Reference to the map of normal chlorine, page 28, will show that the proportion for this country is 1.6 parts per million.

Quinepoxet and Stillwater rivers.—From the Massachusetts reports have been taken the following statements of analyses of waters gathered from the Quinepoxet and Stillwater rivers, the one at Holden and the other at Sterling:

TABLE 14.—*Analyses of water from Quinepoxet and Stillwater rivers.*

QUINEPOXET RIVER AT HOLDEN.

[Parts per million. Averages by years.]

Year.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1892	Slight	6.2	0.194	0.014	0.001	0.088	1.9	37.0	9
1893	do	7.2	.192	.004	.001	.044	2.6	37.5	9
1894	do	6.1	.214	.041	.001	.027	2.9	38.5	7
1895	Very slight to distinct.	7.7	.289	.020	.003	.090	2.6	44.7	9
1896	do	6.4	.250	.012	.000	.045	1.9	37.4	4
1897	Very slight to decided.	7.7	.275	.032	.001	.055	2.1	38.8	8
1898	Slight	6.2	.248	.030	.001	.037	2.1	34.7	8
1899	Very slight to decided.	4.8	.261	.028	.001	.046	1.9	36.5	5
1900	do	5.1	.277	.036	.002	.047	2.1	38.8	5

STILLWATER RIVER AT STERLING.

1892	None to slight	4.4	0.131	0.001	0.000	0.072	1.3	33.8	9
1893	do	5.0	.147	.006	.001	.002	1.8	34.5	7
1894	do	4.5	.137	.008	.000	.017	1.8	32.0	8
1895	do	5.2	.179	.008	.000	.051	1.9	34.8	9
1896	Very slight to distinct.	5.0	.229	.016	.000	.035	1.6	33.2	7
1897	None to very slight.	6.6	.199	.013	.000	.037	1.7	34.7	8
1898	do	5.1	.158	.008	.001	.026	1.6	30.2	8
1899	Very slight	3.1	.177	.020	.000	.050	1.7	32.4	5
1900	None to very slight.	3.3	.156	.025	.001	.025	1.5	30.7	7

South Branch of Nashua River at Clinton.—Just below the dam which marks the beginning of the restricted area above described the South Branch passes the town of Clinton, and there meets with its first important pollution. Flowing through Clinton from the west, Coachlace Brook enters the main stream. The large plant of the Lancaster Woolen Company, employing over 2,000 hands, contributes sewage and manufacturing refuse into the South Branch, and a small portion of the town also drains into this stream. Until September 15, 1899, the sewage of Clinton and an enormous quantity of wool-washing waste and other refuse from the extensive works of the Bigelow Carpet Company were discharged into Coachlace Brook.

In Table 15 is set forth results of four analyses of water from Coachlace Brook, which was at that time the foulest stream in the Nashua Basin.

TABLE 15.—*Analyses of water from Coachlace Brook.*

[Parts per million.]

Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
Slight	3.5	0.620	2.280	0.056	0.180	10.0	96.5
Do	2.3	.520	2.200	.033	.330	9.5	89.0
Distinct	2.0	.710	1.720	.044	.200	9.9	94.5
Decided	4.0	.786	1.620	.200	.050	9.7	110.0
Average	2.9	.659	1.955	.083	.190	9.8	97.5

Character of water at Lancaster.—A short distance below this point is Lancaster, the place at which the North Branch enters. The quality of the water has been determined by a long series of analyses of samples taken at a point on the South Branch just above the confluence of the two rivers. The place was well chosen, for the water taken there shows the effect of the mixture of the water from Coachlace Brook and that running past the Lancaster mills, as above described.

TABLE 16.—*Analyses of water from South Branch of Nashua River above its confluence with North Branch at Lancaster.*

[Parts per million.]

Year.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Number of analyses made.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
1895	Very slight to distinct.	5.3	0.238	0.167	0.008	0.114	3.4	46.6	14	16
1896	Distinct	4.5	.216	.094	.006	.134	3.5	47.2	16	12
1897	Very slight to distinct.	6.0	.257	.092	.004	.110	3.2	44.7	13	12
1898	Very slight to decided.	5.0	.269	.327	.010	.098	3.3	47.7	13	12
1899	Very slight to distinct.	4.5	.415	1.026	.018	.087	7.5	73.4	17	12
1900	Very slight to decided.	3.3	.346	.537	.020	.392	10.0	77.3	19	12
1901	Decided	3.3	.331	.314	.012	.405	8.1	78.4	19	12

NORTH BRANCH OF NASHUA RIVER.

The North Branch of the Nashua is a good power stream and has been utilized extensively. Its flow is regulated to some extent by a series of reservoirs, but in spite of this the flow is variable. The total area of the basin is 127 miles, and the population is greater than that on the South Branch. The communities of Leominster and Fitchburg contain 44,000 inhabitants; both places support extensive manufacturing industries, and the pollution from household sewage and factory wastes is extensive. There are, nevertheless, many points in the watershed above these towns where the water is of excellent quality. Among these are Scott reservoir, which supplies Fitchburg, and Morse and Haynes reservoirs above Leominster, analyses of which are recorded in Table 7.

Normal water.—Still farther up in the drainage area is the Ashburnham storage reservoir, which conserves a normal water of a character indicated in the following report of analysis, it being the average of nine samples:

TABLE 17.—*Analysis of water from Ashburnham storage reservoir.*

[Parts per million.]

Turbidity	"None" to "distinct."
Color	None.
Residue on evaporation	25.2
Free ammonia	.003
Albuminoid ammonia	.077
Chlorine	[a]1.3
Nitrates	.191
Nitrites	.001

Above Fitchburg.—Taking the waters of Scott, Haynes, Morse, and Ashburnham reservoirs as normal, let us descend to a point a short distance above Fitchburg, where the pollution is merely that from a few factories in the vicinity of West Fitchburg.

TABLE 18.—*Analyses of water from North Branch of Nashua River above Fitchburg.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
June 19	Very slight	3.8	0.170	0.002	0.001	0.050	1.4	33.5	5
August 1	do	4.5	.182	.008	.000	.010	1.6	32.5	5
August 29	None	3.9	.170	.010	.000	.050	1.8	31.5	5
September 26	Slight	3.8	.216	.008	.001	.030	2.3	26.5	5
October 23	None	4.2	.192	.012	.000	.020	2.3	42.5	8
November 28	do	6.0	.178	.022	.000	.070	1.8	35.0	10
December 26	Very slight	4.5	.130	.012	.001	.130	1.8	36.0	8
Average		4.4	.177	.011	.000	.051	1.9	33.9	7

[a] Normal.

Except for a slight increase in the amount of chlorine the above analyses do not differ significantly from those in the normal reservoirs above noted. This difference is, however, an important one and bears unmistakable evidence of the pollution above noted.

Below Fitchburg.—Below Fitchburg the character of the water undergoes a marked change, as is indicated by the following series of analyses of samples taken at a point just below the city. It will be observed that, although the evidences of pollution are clear, they do not indicate the extremely foul character which was apparent in the waters of Coachlace Brook, on the South Branch.

TABLE 19.—*Analyses of water from North Branch of Nashua River below Fitchburg.*

[Parts per million.]

Date of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1893	5.7	0.360	0.461	0.018	0.118	6.9	74.6	20
1894	5.6	.346	.634	.020	.152	7.5	73.9	19
1895	5.9	.423	.832	.010	.134	7.5	81.0	22
1896	4.8	.499	.677	.017	.151	7.4	81.5	20
1897	6.1	.420	.370	.007	.120	6.1	68.2	18
1898	5.1	.467	.435	.009	.117	4.8	60.0	16
1899	4.3	.657	.967	.009	.069	7.2	76.2	18
1900	3.9	.660	1.011	.010	.072	9.7	81.0	20

Below Leominster.—Descending farther we come to Leominster, at which place enters a polluted stream known as Monoosnoc Brook, the characters of which are shown by the following statement, which is the average of ten analyses made in 1899 and 1900.

TABLE 20.—*Average of ten analyses of water from Monoosnoc Brook.*

[Parts per million.]

Turbidity	Decided.
Color	7.5
Residue on evaporation	49.9
Free ammonia	.280
Albuminoid ammonia	.444
Chlorine	4.3
Nitrates	.071
Nitrites	.0075
Hardness	12

At Lancaster.—Another series of analyses appears to have been made, the water being taken from the North Branch at a point just above its confluence with the South Branch. This point is also well chosen, as the river carries all the pollution which has entered above save that which has been oxidized or deposited in the course of the stream. Analyses of the water here show just what is contributed by the North Branch to the Nashua River system.

The following record covers six years, and can therefore be accepted as indicative of the true character of the water:

TABLE 21.—*Analyses of water from North Branch of Nashua River, just above its confluence with the South Branch at Lancaster.*

[Parts per million.]

Date of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1895	5.1	0.269	0.282	0.019	0.236	7.7	69.6	19
1896	4.7	.293	.217	.019	.155	5.5	61.6	18
1897	5.4	.290	.285	.008	.150	4.2	52.9	15
1898	4.5	.268	.222	.013	.168	4.4	50.7	15
1899	3.6	.316	.540	.016	.132	6.0	63.8	16
1900	3.1	.322	.501	.022	.152	6.6	63.4	18

A comparison of the results in Table 21 with the analyses of water from the South Branch, Table 16, shows that until 1899 North Branch was the more highly polluted.

During the years 1895–1898, inclusive, the amounts of free ammonia, nitrates, and chlorine in South Branch water were approximately 50 per cent of those in North Branch. After 1898 there appears to be a decided change in the character of the water in South Branch; organic ingredients increased remarkably and reached a maximum in the year 1900. It is evident that unusual conditions arose to produce this result. A history of the work of the Metropolitan Water Board of Massachusetts upon the South Branch of Nashua River shows that in March, 1898, a large proportion of the run-off water in the basin of South Branch above Clinton was diverted for use in the metropolitan district. This water had, up to this time, been efficient in diluting the refuse and sewage discharged from Clinton, and its withdrawal was immediately apparent in the condition of the stream below. Coincident with this diversion there was in progress the preparation of Wachusett reservoir; old dams were removed, the surface of the country was stripped of vegetation, and large amounts of water were

turned into the stream from foundation-wall excavations. The result was that the water which flowed past Clinton was made extremely turbid, and must have carried along in solution, as well as in suspension, great quantities of organic matter. These conditions are entirely sufficient to account for the change in the character of South Branch water above its confluence with North Branch.

The unfavorable change in the character of the water in South Branch is only temporary. The beginning of an improvement took place late in the fall of the year 1899, when the sewage of Clinton and the manufacturing wastes of the Bigelow Carpet Company were diverted into newly constructed purification works. The completion of Wachusett reservoir will mark the end of the operations which have increased the organic constituents in the river water and South Branch will be restored to its former condition, or be greatly improved. Mr. F. P. Stearns, chief engineer of the Metropolitan Sewerage and Water Board, has expressed the belief that the above result will be reached in the fall of the year 1903, or early in the spring of 1904.

From Lancaster to Nashua, N. H.—We have now traced the pollution in the headwaters of the Nashua branches down to a point at which the main river takes its origin. From this point to Groton the river flows very sluggishly, and from Groton to a point 3 miles from its confluence with the Merrimac its fall is more rapid, becoming quite steep for the remainder of the course. From Lancaster to Nashua there is no settlement contributing important pollution. As the river sluggishly winds along its course it is increased in flow by other streams, notably the Squannacook at Ayer and the Nissitisset at Pepperell, so that when it reaches the latter place dilution, sedimentation, and oxidation have had an effect which may be readily seen by examining the following reports of analyses:

TABLE 22.—*Analyses of water from Nashua River at Groton and Pepperell.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Place of collection.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
May 22, 1895	Decided	4.0	0.164	0.014	0.003	0.170	4.0	48.5	16	Groton.
Aug. 16, 1899	Slight	2.0	.264	.116	.014	.230	7.0	65.0	17	Pepperell.
Sept. 21, 1899	Very slight	2.7	.230	.054	.012	.150	8.2	67.5	20	Do.
Oct. 14, 1899	do	2.4	.236	.168	.004	.060	9.7	75.5	23	Do.
Mar. 15, 1899	Decided	4.2	.264	.332	.003	.110	6.4	68.5	23	Do.
July 16, 1900	Very slight	1.5	.200	.100	.005	.050	7.0	60.0	20	Do.
Aug. 21, 1900	Slight	2.3	.258	.234	.018	.100	9.2	65.0	20	Do.

Flowing ever more swiftly it passes into the State of New Hampshire and emerges at Nashua in the Merrimac. The average of 19 analyses made during the years 1887–88 appear below. The samples were taken at Mine Falls, above Nashua pollution.

TABLE 23.—*Average of nineteen analyses of water from Nashua River at Mine Falls.*

[Parts per million.]

Turbidity	Slight to decided.
Color	3.8
Residue on evaporation	45.8
Free ammonia	.029
Albuminoid ammonia	.187
Chlorine	[a] 2.9
Nitrates	.102
Nitrites	.003

OTHER TRIBUTARIES OF THE MERRIMAC.

Outside of the State of Massachusetts the character of the waters of the Merrimac drainage area is almost unknown. The New Hampshire laboratory of hygiene has not yet been established for a time sufficient to allow extensive investigations. It is probable that in due time this laboratory will complete the work which has been carried on by the State Board of Health of Massachusetts.

Piscataquog and Contotook rivers.—No analyses are available of the water of the Piscataquog or Contotook. It is safe to assert that neither stream is polluted to any extent, for there are no important settlements in the valleys. The population in the basin of the Contotook is only 31.4 per square mile.

Lake Winnepesaukee.—The water of Lake Winnepesaukee has been analyzed by the Massachusetts State Board of Health for the purpose of determining its fitness as a source of supply for the metropolitan district. The average is included in Table 7.

Pemigewasset River.—The Pemigewasset Valley, which lies at the head of the Merrimac system, has a population of 17 per square mile. No sewerage systems enter the river, nor are there any large centers of population. The supply of water to the Merrimac is therefore pure and abundant. The only available analysis has been kindly furnished by Mr. H. E. Barnard, chemist of the New Hampshire laboratory of hygiene. The place of collection was at Campton Village, at the extreme southern end of the basin. It therefore fairly represents the character of the water furnished by the Pemigewasset drainage area to the Merrimac.

[a] Chlorine 1.4 above normal.

TABLE 24.—*Analysis of water from Pemigewasset River at Campton, N. H.*

[Parts per million.]

Appearance.		Total residue on evaporation.	Ammonia.				Chlorine.	Nitrogen as—		Hardness.
				Albuminoid.						
Turbidity.	Color.		Free.	Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.	
None	4.0	34	0.016	0.094	.....	.....	0.637	0.100	0.100	.....

POLLUTION OF MERRIMAC RIVER AT MANCHESTER, NASHUA, LOWELL, LAWRENCE, AND HAVERHILL.

Having considered the characteristics of the water in the tributaries which have received attention from analyses, let us review the work which has been done in the Merrimac proper and show, as closely as possible with the data at hand, how each tributary affects the river; also the changes due to the extensive pollution which arises from the cities along the bank.

Manchester.—We have said that the upper part of the Merrimac area is sparsely settled, and that such analyses as are available show that the water is pure. From the Contotook, Pemigewasset, and Winnepesaukee drainage basins there is delivered into the Merrimac a great volume of water, which is increased by the numerous smaller tributaries which enter all along the course. It is not likely that it changes greatly in character until it reaches Manchester, N. H., an important manufacturing city of 56,987 inhabitants. Sewage and manufacturing wastes are poured directly into the river, and, although there are at hand no analyses to show the exact condition of the wate , it is certain that the change is marked.

Nashua.—Sixteen miles below, at the city of Nashua, a series of analyses has been furnished by Mr. Barnard which shows the effect of Manchester pollution after it has been carried along for the above distance. It is at this point that the abundant flow of Nashua River enters the Merrimac, dilutes still further the Manchester pollution, and renders the sewage from Nashua, a city of 23,898 inhabitants, less damaging than it would be under conditions not so favorable.

TABLE 25.—*Average of nineteen analyses of water from Merrimac River at Nashua.*

[Parts per million.]

Appearance.		Total residue on evaporation.	Ammonia.				Chlorine.	Nitrogen as—		Hardness.
				Albuminoid.						
Turbidity.	Color.		Free.	Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.	
Slight	3.4	50.1	0.014	0.153	.....	.....	1.5	0.074	0.002	6.0

Lowell.—Leaving Nashua, the river crosses the State line, and when it reaches a point opposite the old water intake at Lowell it is of a quality shown in the following analysis:

TABLE 26.—*Analyses of water from Merrimac River above Lowell.*

[Averages by years, monthly samples. Parts per milllon.]

Years.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1888	3.0	0.148	0.016	0.002	0.099	1.6	34.2	------
1889	2.8	.149	.018	.002	.071	1.4	29.5	------
1890	3.0	.128	.014	.001	.111	1.3	35.7	14
1891	2.9	.129	.017	.001	.137	1.3	34.3	12
1892	3.9	.141	.021	.001	.092	1.4	36.1	13
1893	3.3	.149	.026	.001	.082	1.0	33.9	11
1894	3.5	.135	.024	.001	.063	1.8	35.5	11
1895	4.1	.187	.029	.001	.066	2.1	38.4	12
1896	4.0	.167	.024	.001	.070	1.7	34.7	10
1897	5.1	.177	.030	.001	.067	1.5	35.4	10
1898	4.2	.173	.026	.001	.048	1.7	35.3	10
1899	2.7	.287	.050	.002	.060	1.8	36.0	9
1900	2.7	.297	.052	.002	.047	1.9	35.5	11

The water represented in the series of analyses above set forth was formerly used in its raw state as the principal water supply for the city of Lowell. The history of that municipality during this period furnishes to the world one of the clearest illustrations of the cost of water pollution extant, and it stands among epidemiologists as one of the classical examples of disease production through polluted water supply. No history of typhoid fever is complete without an account of the Lowell epidemic. For years the typhoid rate was abnormal, but little attention was given to it until the year 1890, when there occurred from September of that year to January, 1891, a series of 550 cases. Prof. William T. Sedgwick, in a remarkable investigation, traced the origin of the epidemic to a few individuals who, while in the prodromal stage of typhoid fever, had polluted a small brook which enters the Merrimac a short distance above Lowell.

The pecuniary damage caused by polluted water throughout all the years in which the Merrimac was used as a source of supply will never be even approximately estimated. In the epidemic of 1890 alone there was a loss of 92 lives. In addition to this there was the expense incident to the care of 550 cases of the disease and the temporary loss of productiveness of all those who escaped death. The greater part

of this drain upon the resources of the community was without a shade of justification; it might have been prevented by the exercise of municipal decency. After the lesson had been learned, the city of Lowell was obliged to add to the total expense by constructing a new supply, the cost of which will be borne by generations yet unborn.

As the Merrimac passes by Lowell its burden of sewage is increased by the addition of wastes from 95,000 persons and from enormous mills and factories.

Lawrence.—Flowing 9 miles farther the river reaches the city of Lawrence, and there, opposite the intake of the works, the water has a character denoted by the following series of annual averages, each average being the result of monthly analyses:

TABLE 27.—*Analyses of water from Merrimac River above Lawrence.*

[Parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1888	3.0	0.180	0.026	0.002	0.094	1.8	36.8	------
1889	3.0	.176	.030	.003	.072	1.7	30.9	------
1890	3.3	.166	.046	.001	.089	1.7	31.9	16
1891	2.7	.152	.040	.001	.110	1.8	37.9	13
1892	4.3	.181	.042	.001	.105	1.8	41.2	14
1893	4.2	.181	.057	.002	.081	2.0	38.6	11
1894	3.7	.167	.062	.001	.063	2.3	37.0	12
1895	5.1	.249	.064	.002	.071	2.8	43.4	14
1896	4.2	.220	.068	.003	.087	2.4	39.8	12
1897	5.6	.228	.049	.001	.067	2.0	38.4	11
1898	4.5	.212	.050	.003	.058	2.2	39.0	11
1899	2.9	.232	.088	.003	.056	2.4	39.9	10
1900	3.0	.224	.089	.002	.060	2.5	39.6	11

The history of the Lawrence water supply and the consequences of its use closely resemble those already described at Lowell, and, indeed, the account of the events in the two cities is generally combined. For years the raw water from the Merrimac was pumped into the Lawrence mains. Following the discharge of typhoid-infected stools from the sewers at Lowell there arose a widespread epidemic in the lower city. In Lawrence the source of supply was not changed, but the first sand filter in the country was established at a cost of $65,000. Through this filter the water of Lawrence is now drawn at an annual expense of $8,000 or $9,000, the result being that the typhoid-fever rate in the city has been considerably lowered.

A comparison of the water after it has been passed through this filter with that in the river is instructive. For this purpose the following analyses are presented, each being the average of 12 monthly samples:

TABLE 28.—*Analyses of the effluent of the Lawrence filter.*

[Parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1894	3.9	0.094	0.103	0.002	0.309	3.0	61.0	28
1895	5.0	.108	.146	.001	.274	3.1	59.5	27
1896	4.0	.099	.121	.004	.319	2.5	54.3	24
1897	5.6	.108	.123	.002	.317	2.5	51.7	20
1898	4.3	.090	.107	.001	.324	2.6	46.6	19
1899	2.7	.089	.087	.001	.205	2.8	44.4	16
1900	2.8	.108	.123	.001	.173	2.7	43.0	15

TABLE 29.—*Increase in amount of impurities in Merrimac River water from a point above Lowell to Lawrence, as determined by regular monthly examinations in different years.*

[Parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1887–1889	0.1	0.027	0.007	0.000	[a]0.003	0.026	2.3	.....
1890	.5	.023	.016	.000	[a].020	.280	6.2	2
1891	[a].2	.023	.021	.000	[a].030	.350	2.9	1
1892	.6	.027	.019	.000	[a].013	.390	4.8	0
1893	.9	.032	.031	.001	[a].002	.350	4.7	0
1894	.2	.032	.028	.000	.000	.490	1.5	1
1895	1.1	.063	.022	.001	.005	.630	5.2	1
1896	.2	.053	.034	.002	.017	.700	5.1	2
1897	.6	.051	.019	.000	.000	.500	3.0	1
1898	.3	.039	.024	.002	.010	.440	3.7	1
1899	.2	.045	.038	.001	[a].004	.590	3.9	1
1900	.3	.027	.037	.000	.011	.550	4.1	0

[a] Decrease.

At Lawrence the sewage from 63,000 persons and extensive manufacturing wastes are poured into the Merrimac. Thence the river flows 8 miles to Haverhill.

Haverhill.—Above Haverhill there were, from July to November, 1900, five samples taken, the reports of analyses being as follows:

TABLE 30.—*Analyses of Merrimac River water above Haverhill.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
July 17	Slight	2.3	0.288	0.192	0.004	0.010	3.9	46.5	13
Aug. 21	Decided	1.5	.316	.144	.008	.050	3.9	44.0	16
Sept. 18	Slight	1.5	.328	.272	.009	.020	4.8	50.0	13
Oct. 30	do	3.4	.360	.296	.010	.100	4.4	53.5	14
Nov. 20	Decided	6.5	.328	.144	.003	.080	3.3	53.0	16
Average		3.0	.324	.210	.007	.052	4.1	49.4	14

Haverhill sewage is discharged into the Merrimac. This city has a population of 31,175. Analyses of the water from the river, collected a short distance below the city, are reported by the State Board of Health as follows:

TABLE 31.—*Analyses of Merrimac River water below Haverhill.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
July 17	Slight	2.0	0.324	0.284	0.007	0.010	4.2	44.0	14
Aug. 21	Decided	1.5	.276	.220	.010	.020	3.7	45.0	17
Sept. 18	Slight	2.3	.375	.265	.017	.040	5.7	55.0	16
Oct. 13	Decided	3.5	.360	.264	.011	.090	4.4	54.0	11
Nov. 20	do	6.6	.340	.136	.004	.120	3.2	53.5	14
Average		3.2	.335	.311	.010	.050	4.2	50.3	12

BLACKSTONE RIVER.

COURSE, CHARACTER, AND UTILIZATION OF THE STREAM.

Blackstone River is a small stream which rises in Worcester County, Mass., and flows in a southeasterly direction, passing over the State line into Rhode Island and emptying into the Providence River at Providence. Its drainage area covers about 458 square miles. At the source the elevation is 438 feet above mean tide and as its course is about 43 miles long its fall must be somewhat more than 10 feet per mile. It is obvious that such a river, so accessible, and in the midst of a populous country, must have unusual value as a source of power. This fact has long been recognized and the stream has been thus utilized, the natural facilities being enhanced by the development of every accompaniment known to be of use in a river of this character. Probably no stream in the United States has been so effectively harnessed and brought into subjugation; milldams have been erected at favorable points, compensating reservoirs have been constructed, and ponds and lakes have been raised in order that the flow may be regulated to meet the demands of manufacturing. The result is that though the river is derived from a watershed which has been extensively deforested, and, under ordinary circumstances it would be subject to floods and variation in flow, its water is seldom allowed to fall below a certain minimum because of the judicious management of the conserved water during dry seasons. The great resource of this stream is, therefore, its water power, and it has been said with authority that the value of this interest is proportionately greater than that found in any other stream in the United States.

POPULATION OF THE BASIN.

Population.—The Blackstone River (see fig. 6) is formed by the junction of Kettle and Mill brooks in the southern part of the city of Worcester. These two brooks drain small parts of the towns of Holden and Leicester, as well as Worcester. The other Massachusetts towns in the basin are Auburn, Millbury, part of Shrewsbury, Grafton, Upton, Sutton, Northbridge, Hopedale, Mendon, Douglass, Uxbridge, and Blackstone, representing a population of about 157,000, or 604 per square mile. In the State of Rhode Island the river drains the municipalities of North Smithfield, Burrillville, Gloucester, Woonsocket, Lincoln, and Cumberland, having a combined population of 56,267.

This large population is mostly in the northern part of the drainage area, at Worcester, Mass., which has a population of 118,421. The population per square mile therefore decreases as the mouth of the river is approached. This fact was well expressed in the report of the Massachusetts Board of Health in 1890, as follows:

TABLE 32.—*Population in drainage basin of Blackstone River.*

	Locality.	Distance below discharge of Worcester sewage.	Drainage area (square miles.)	Population, estimated (1888).	Population per square mile.
		Miles.			
1	At the Quinsigamond Iron and Wire Works	0	63.0	----------	----------
2	At the first bridge below Quinsigamond village	1	63.9	77,500	1,213
3	At the dam of the Cordis Co., Millbury	5	77.9	----------	----------
4	At the upper dam of the Calumet Woolen Co., Uxbridge	17	145.9	90,900	623
5	At the Middleville dam, Blackstone	24	258.1	102,800	398
6	At the dam of the Blackstone Manufacturing Co., Blackstone	26	260.3	----------	----------

Since the collection of the facts in the table the city of Worcester has grown faster than the lower towns in the valley, making the conditions above set forth even more extreme.

FIG. 6.—Blackstone River drainage basin.

NORMAL WATER IN THE BASIN OF THE BLACKSTONE.

Normal water in the basin of the Blackstone has been found at the head of Kettle Brook, Paxton, Lynde Brook storage reservoir in Leicester, and Tatnuck Brook storage reservoir in Holden.

TABLE 33.—*Analyses of normal water in Blackstone Basin.*

LYNDE BROOK STORAGE RESERVOIR.

[Parts per million, averages by years.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1888	2.4	0.151	0.037	0.001	0.065	1.4	26.4	----
1889	2.4	.167	.030	.001	.053	1.5	25.4	----
1890	2.1	.132	.026	.001	.078	1.4	30.7	9
1891	2.4	.126	.045	.001	.074	1.2	28.3	7
1892	2.5	.139	.038	.000	.105	1.5	29.9	8
1893	2.6	.162	.036	.001	.066	1.5	26.6	6
1894	3.6	.139	.055	.000	.103	1.8	33.7	12
1895	3.2	.161	.033	.000	.116	2.0	36.3	12
1896	2.9	.158	.035	.000	.054	1.8	29.5	8
1897	4.4	.191	.068	.001	.087	1.8	33.1	8
1898	3.1	.156	.030	.001	.059	2.0	32.4	8
1899	2.0	.147	.030	.000	.031	1.2	24.9	4
1900	2.3	.176	.043	.000	.039	1.4	29.2	7
KENT RESERVOIR, KETTLE BROOK.								
1898	3.6	0.176	0.012	0.001	0.042	1.6	32.0	8
1899	2.7	.239	.047	.001	.037	1.3	32.5	7
1900	3.2	.213	.037	.001	.064	1.7	32.0	8
TATNUCK BROOK RESERVOIR.								
1888	1.7	0.157	0.012	0.001	0.043	1.2	22.3	----
1889	1.9	.143	.003	.001	.031	1.2	20.4	----
1890	1.7	.141	.007	.001	.078	1.3	26.8	9
1891	1.7	.143	.024	.001	.077	1.1	23.0	4
1892	2.0	.142	.012	.000	.067	1.2	25.2	5
1893	3.5	.182	.020	.000	.049	1.4	24.5	5
1894	2.0	.151	.010	.000	.032	1.6	22.7	4
1895	2.1	.173	.012	.000	.068	1.8	23.3	5
1896	1.7	.142	.008	.000	.034	1.5	20.0	4
1897	2.1	.155	.007	.000	.054	1.6	21.2	5
1898	2.2	.141	.006	.000	.020	1.6	22.4	5
1899	1.1	.136	.013	.000	.016	1.2	20.0	2
1900	1.5	.186	.026	.000	.023	1.2	22.7	3

POLLUTION IN BLACKSTONE RIVER.

The Blackstone is the most polluted river in New England; its name has become synonymous with filth. The headwaters of a river system are usually free from pollution, but in this case the opposite is true. The sewage from the city of Worcester befouls the river almost at its source, and thereafter throughout its whole extent the Blackstone is a damaged resource to the country. Such is the accumulation of filth in the mill ponds that from some of those near Worcester there arise odors that are detrimental to comfort and realty, if not to health. The use of its water in boilers has long been abandoned, and it can not be used in the manufacture of light-colored cloths.

Worcester sewage.—The sewage of Worcester, consisting of the usual city waste and an enormous amount of manufacturing refuse, a large part of which is acid from the steel manufactories, is turned from the sewers into Mill Brook. The quantity is sufficient at times to give to the waters of the Blackstone River an acid reaction.

The water of Mill Brook above the point of sewage discharge has not been regularly examined, but it is known to be of a quality characteristic of a stream flowing through a country of considerable population, and approaching in some degree the character of the normal waters above set forth. After being polluted with the Worcester sewage the water of Mill Brook is of a vile character, as is shown in the following table of averages of monthly analyses for the years 1888–1900.

TABLE 34.—*Analyses of water from Blackstone River below mouth of Mill Brook and above outlet of sewage works.*

[Parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1888	6.4	1.040	2.112	0.029	0.370	12.1	----	----
1889	7.6	1.198	2.841	.024	.235	10.6	----	----
1890	8.2	1.024	1.800	.014	.367	10.3	----	----
1891	8.0	1.563	3.340	.032	.333	17.3	135.4	46
1892	7.1	1.262	2.530	.061	.312	18.4	162.8	49
1893	6.8	.603	1.429	.012	.180	10.4	179.5	45
1894	8.6	.570	.739	.006	.195	8.8	171.7	37
1895	8.4	.374	.507	.007	.175	8.6	134.0	29
1896	7.5	.486	.759	.010	.187	10.1	126.9	29
1897	9.4	.533	.715	.015	.151	7.7	176.2	29
1898	5.0	.557	.762	.011	.167	8.3	135.2	35
1899	2.6	.751	1.921	.010	.109	12.0	253.3	97
1900	1.8	.602	1.141	.011	.102	8.3	194.9	62

For years the city of Worcester has converted Mill Brook into an open sewer, and up to June 25, 1890, the contents were discharged directly into Blackstone River. At that time, however, a chemical precipitation works was completed by the city, and by means of a diverting dam the whole flow of Mill Brook, except during seasons of freshet, was carried across to a series of tanks, six in number, each being 100 feet long, 66.76 feet wide, and 7 feet deep. The capacity of these tanks for the treatment of sewage, according to the process adopted, was 6,000,000 gallons daily. In the year 1883 ten more tanks were added to the original six, which gave to the disposal works a nominal capacity of 15,000,000 gallons per day.

The treatment of sewage was first as follows: After being screened it was mixed with chemicals, and, passing through a mixing channel, it fell into the precipitation tanks, discharging from the first to the second, and so on through the whole series, finally being poured into the Blackstone River. The chemicals used were lime and sulphate of alumina, the former being required in large quantities when the sewage was greatly impregnated with iron. After the enlargement of the works in 1893 the process was changed slightly, the object being to secure a more thorough mixture of chemicals with the sewage before it passed into the precipitation tanks. During the year ending November 30, 1901, 3,564.7 million gallons of sewage were received at the disposal works, of which 3,133.8 million gallons were treated chemically and the remainder used for experimental work in connection with new processes of sewage disposal. The total cost of this treatment was $12.20 per 1,000,000 gallons. The chemical precipitation of sewage at Worcester is not, however, successful from the standpoint of river purification, and very little if any benefit has been apparent in the river throughout all the years during which this great expenditure has been incurred by the city. Finally the legislature of the State enacted a law requiring the city to dispose of its sewage by some other method, and experiments are now being conducted to determine a method which will effect a more satisfactory purification of Blackstone River.

Below sewage-disposal outlet.—The next recorded point of examination of the Blackstone is below the sewage precipitation works. The point of collection of the samples is nearly a mile below the mouth of Mill Brook and a considerable distance below the outlet of the precipitation works, so that the effluent has had ample opportunity to become thoroughly mixed with the river water. The following is a list of annual averages of monthly examinations during the period 1888–1900.

TABLE 35.—*Analyses of water of Blackstone River below Worcester sewage-disposal outlet.*

[Parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1888	6.4	1.040	2.122	0.029	0.370	12.1	----	----
1889	7.6	1.198	2.894	.024	.235	10.6	----	----
1890	7.4	1.177	2.253	.016	.381	12.6	----	----
1891	8.0	1.303	4.080	.031	.358	19.1	156.2	46
1892	5.3	1.442	3.633	.033	.278	22.1	193.5	72
1893	7.4	1.447	3.757	.070	.369	19.8	256.5	74
1894	6.0	1.309	4.228	.047	.316	21.3	257.5	79
1895	7.9	.840	2.298	.040	.347	15.2	191.4	58
1896	4.0	.930	2.645	.071	.356	19.1	242.8	83
1897	7.5	.843	2.447	.047	.300	13.3	199.4	54
1898	4.9	.725	2.260	.072	.264	13.0	194.1	66
1899	3.0	1.337	3.908	.053	.176	23.7	324.8	120
1900	2.5	1.249	4.430	.145	.110	21.3	224.7	73

Comparison of the analyses in Tables 34 and 35 shows clearly that, in spite of the so-called sewage purification carried on at Worcester at so great an expense, Blackstone River is in far worse condition below the sewage outlet than above. The amounts of free ammonia, nitrites, and chlorine at the lower sampling point are considerably greater than above the outlet of the purification works. In addition to this there are unmistakable evidences that the amount of objectionable matter from the outlet is increasing from year to year, while the conditions above constantly improve.

Uxbridge.—Again there appears a record of examinations of samples taken from the river at the upper dam of the Calumet Woolen Company at Uxbridge, 17 miles below the city of Worcester. The analyses were made monthly during the period 1888–1900, but in Table 36 the results are made up into yearly averages, as in the preceding tables, 34 and 35.

TABLE 36.—*Analyses of water from Blackstone River at Uxbridge.*

[Parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1888	4.5	0.284	0.979	0.008	0.322	6.1	.....	....
1889	2.8	.300	.992	.009	.253	6.0	.....	....
1890	2.5	.214	1.168	.006	.272	6.6	.....	....
1891	2.7	.272	1.674	.008	.396	7.7	83.2	28
1892	2.1	.222	2.113	.007	.326	8.2	85.9	28
1893	4.0	.256	1.603	.029	.424	10.0	94.5	32
1894	5.1	.242	1.372	.032	.460	12.2	108.0	40
1895	6.4	.315	1.081	.037	.439	10.5	105.6	39
1896	4.2	.308	1.209	.054	.405	10.9	107.7	42
1897	5.9	.298	1.126	.035	.481	10.4	103.1	38
1898	5.8	.305	.818	.046	.360	8.4	87.2	32
1899	2.6	.374	2.298	.078	.331	15.9	140.6	56
1900	2.7	.351	2.122	.039	.359	13.8	114.3	42

It will be seen that sedimentation, dilution, and oxidation have worked improvement in the water by the time it has traversed the 17 miles, although the process during late years does not appear to be as effective as formerly. It requires only a glance to perceive that the pollution of the Blackstone is still enormous. Be it remembered, too, that, apart from the pollution at Worcester, the numerous mills along the course of the stream and the large number of employees there engaged contribute a great quantity of sewage and foul industrial waste, which of itself would be damaging to the river. Therefore the comparison of the two sets of analyses above given does not furnish an idea of the normal self-purifying ability of the river, for it is more than probable that there would appear a greater decrease in the amount of organic matter if it were not for the constant introduction of new pollution.

At Millville.—Down the river, nearly to the State line at Millville, town of Blackstone, a series of analyses similar to the one at Uxbridge has been carried on for thirteen years. This point is 24 miles from the Worcester outlet and the water is not objectionable in odor. Still, as the following analyses show, the water is polluted.

TABLE 37.—*Analyses of water from Blackstone River at Millville.*

[Average by years, in parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1888	4.7	0.253	0.444	0.005	0.242	4.4	.....	----
1889	3.8	.277	.450	.004	.160	4.3	.....	----
1890	3.4	.211	.587	.004	.240	4.6	.....	----
1891	3.2	.293	.807	.005	.275	5.5	60.5	19
1892	3.5	.249	.896	.004	.218	5.4	60.3	18
1893	4.0	.288	.899	.008	.289	6.6	62.3	20
1894	4.9	.219	.528	.008	.232	7.3	63.7	25
1895	5.8	.253	.501	.016	.278	7.4	74.7	27
1896	4.0	.248	.549	.018	.347	7.6	73.4	28
1897	5.3	.262	.528	.014	.332	7.3	70.7	26
1898	5.5	.256	.456	.016	.222	6.1	64.3	23
1899	2.8	.267	.985	.029	.220	8.8	89.5	32
1900	3.6	.288	1.194	.023	.272	9.3	83.2	29

In Rhode Island.—As Blackstone River passes out of the State of Massachusetts, it comes within the polluting influence of Woonsocket, R. I., a city of 28,000 inhabitants, situated a short distance south of the State line. From this point to its outlet in Providence it flows through a thickly settled country, which, while it contributes no large amount of raw sewage to the river, does not, nevertheless, permit so extensive a purification of its water as might be effected in a country having a smaller population.

The State of Rhode Island, through its board of health, has attempted to supplement the Massachusetts work by making periodical analyses of the water of the river at two different points—one at Albion, a short distance below Woonsocket, and the other at Valley Falls, nearer Providence. The results of these analyses are given in Table 38.

TABLE 38.—*Analyses of water from Blackstone River at Albion and Valley Falls, R. I.*

ALBION.

[Average by years, in parts per million.]

Year.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1894	0.235	0.156	0.040	0.800	11.0	75	21.7
1895	.260	.127	.....	.560	10.5	81	21.3
1896	.220	.204	.030	.780	.9	72	16.0
1897	.220	.223	.030	.650	7.7	75	14.0
VALLEY FALLS.							
1894	0.261	0.117	0.070	0.824	12.0	66.5	17.6
1895	.201	.139	.070	.500	10.8	69.0	22.4
1896	.200	.196	.070	.070	.9	85.0	16.0
1897	.220	.215	.040	.070	.8	74.0	15.0

The results expressed in Table 38 do not inspire confidence in their accuracy, and it is highly probable that the tables presented in the report of the State Board of Health for 1897 are typographically incorrect. On comparing the results with those taken from the Massachusetts reports it will be seen that the nitrites are enormously high, averaging greater than the amounts found below the Worcester sewage outlet. It is extremely unlikely that these results are correct, because of the fact that the water shows decided improvement as it flows from Worcester town to the Rhode Island line, and south of that there is no increment of sewage which would by any means give to the nitrites the enormous figure which appears in the above analyses. The chlorine determinations, too, show improbable fluctuations.

On the other hand, the amounts of free and albuminoid ammonia, which would necessarily fluctuate to some extent at least with the nitrites and nitrates, do not appear excessive.

CONNECTICUT RIVER BASIN.

NATURAL RESOURCES.

Course and drainage area.—The Connecticut is the largest river in New England. From its source in the Connecticut lakes in the extreme northern part of New Hampshire to its mouth in Long Island Sound the course of the river measures 375 miles. The drainage area is long and narrow, being from 40 to 60 miles in width and covering 10,924 square miles (see fig. 7). The character of the country

varies from the rolling surface common to Massachusetts to the hilly or mountainous country of New Hampshire and Vermont. The rocks are granite, gneiss, syenite, and mica, intersected by dikes of trap and red sandstone. Along the course of the river in Massachusetts and Connecticut there are rich alluvial deposits, but for the most part the basin of the Connecticut is covered by surface drift. Lakes are abundant on most of the branches, and the flow of the main river is fairly steady.

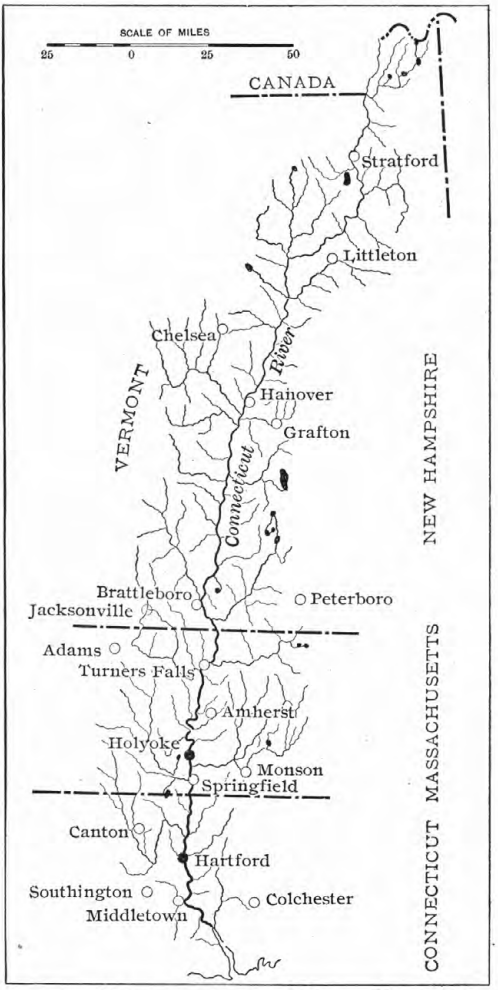

FIG. 7.—Connecticut River drainage basin.

The course of the Connecticut is varied. From its source for a distance of 200 miles downstream the river contains many falls and rapids, the last one being at Bellows Falls, Vt. Below this place the fall in the stream is much less, yet the pitch is sufficient to give the water a fairly good flow. Throughout the extent of the river below Bellows Falls the course of the river is broken by falls in three places, Turners Falls and Holyoke, Mass., and Windsor Locks, Conn. The power developed at Holyoke is the largest in the country, except that at Niagara.

Transportation. — The river has considerable importance in the lower end as a means of transportation. Navigation extends 30 miles from the mouth up to Hartford, and small boats may ascend, by means of Windsor Locks, as far as Holyoke. Travel, however, above Hartford is insignificant, while even in the lower stream large vessels have difficulty in low tide.

Power.—As a source of power the value of the Connecticut is enormous. The main river, with a total fall of 2,038 feet, has been largely utilized, but there remain possibilities for further development which,

if advantage were taken of them, would make the Connecticut one of the most valuable streams in the world. The tributaries have been developed extensively, and the possibilities for the future are promising.

In the following table, taken from Water-Supply and Irrigation Paper No. 44, there is presented a detailed statement of the altitude and fall per mile at different points along the river:

TABLE 39.—*Fall of Connecticut River.*

Locality.	Distance from mouth.	Height above sea.	Fall per mile.
	Miles.	*Feet.*	*Feet.*
Mouth	0	0	.....
Hartford	50	0	.....
Foot of Enfield Rapids	60	6	0.6
Top of Enfield dam	66	38	5.3
Top of Holyoke dam	84	98	3.3
Fitchburg Railroad crossing	115	109	.35
Top of Turners Falls dam	120	173	12.8
Mouth of Ashuelot River	136	206	2.1
Westmoreland	159	219	.6
Foot of Bellows Falls	170	234	1.4
Head of Bellows Falls	170	283	.....
Beaver Meadows, Charlestown	181	289	.5
Windsor	196	304	1.0
White River Junction	209	339	2.7
Ledyard bridge, Hanover	213	375	9.0
Oxford	230	380	.3
Wells River	255	407	1.1
Foot of McIndoes Falls	262	432	3.6
Lower Waterford	273	643	19.2
Head of Fifteenmile Falls	285	830	15.6
North Stratford	312	885	2.0
West Stewartstown	344	1,035	4.7
Connecticut Lake	361	1,618	34.3
Second Lake	369	1,882	15.5
Third Lake	375	2,038	26.0

The following table contains a statement of the total utilized horsepower and the drainage area of the most important tributaries of the Connecticut.

TABLE 40.—*Drainage area and utilized horsepower on the Connecticut River tributaries.*

Tributary.	Horse-power utilized.	Drainage area.	Tributary.	Horse-power utilized.	Drainage area.
		Sq. miles.			*Sq. miles.*
Salmon River	1,432	150	Ottaquechee River	1,723	192
Hockanum River	3,957	79	Mascomy River	1,576	190
Little River	555	76	White River	2,714	623
Farmington River	8,856	584	Ompomponoosuc River	493	123
Scantic River	1,122	118	Waits River	596	156
Westfield River	3,910	514	Lower Ammonoosuc River	2,526	388
Chicopee River	4,044	706	Wells River	628	94
Mill River	1,161	58	Passumsic River	4,724	435
Deerfield River	4,352	646	Johns River	168	86
Millers River	8,172	369	Israels River	974	129
Ashuelot River	3,964	422	Upper Ammonoosuc River	548	252
West River	1,947	363	Nulhegan River	240	132
Williams River	361	103			
Black River	2,132	152			
Sugar River	3,176	272			

FLOW.

The flow of the river has been carefully measured and a concise statement appears in Part IV of the Twentieth Annual Report of the United States Geological Survey, page 47.

TABLE 41.—*Flow of the Connecticut River at Holyoke during the years 1880–1898, inclusive.*

[Drainage area, 8,660 square miles.]

Year.	Maximum.	Minimum.	Mean.	Run-off.	
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft. per sq. mi.*	*Inches.*
1880	44,100	300	8,343	0.96	12.89
1881	49,050	450	9,818	1.13	15.53
1882	45,000	250	10,018	1.14	15.40
1883	68,300	250	8,107	.94	12.70
1884	71,900	500	13,084	1.51	20.46
1885	63,950	2,950	12,635	1.46	19.65
1886	80,150	550	11,387	1.31	17.73
1887	85,500	3,300	14,329	1.65	21.32
1888	99,750	1,100	17,320	2.00	27.15
1889	37,650	1,350	13,903	1.59	21.50
1890	46,750	550	15,556	1.78	24.12

TABLE 41.—*Flow of the Connecticut River at Holyoke, etc.*—Continued.

Year.	Maximum.	Minimum.	Mean.	Run-off.	
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft. per sq. mi.*	*Inches.*
1891	67,300	900	13,190	1.51	21.48
1892	63,100	1,800	12,273	1.48	20.15
1893	94,350	750	10,295	1.19	16.19
1894	43,300	150	8,397	.97	13.17
1895	115,000	350	10,314	1.20	16.19
1896	112,050	450	12,394	1.43	19.41
1897	75,350	1,300	15,373	1.78	24.17
1898	76,150	600	13,844	1.60	21.70

Water supply.—Although a comparatively small part of the drainage area of the Connecticut has been set apart and developed as a source of water supply, the value of the resources within its basin are readily apparent. None of the cities along the main stream pump their supply from the river direct, but in the areas of the tributaries numerous reservoirs have been constructed from which are obtained water supplies of excellent quality. These will be taken up in the discussion of the different branches.

Ice.—The ice values in the Connecticut system are extensive. The same statements that were made in connection with this subject in the discussion of the Merrimac apply here. The main river has not been used largely as a source of ice supply. That it would be more acceptable than some rivers, as the Hudson, Kennebec, and Penobscot, which have been largely developed in this direction and yield enormous amounts annually, is very probable, yet it is the practice of the consumers in the Connecticut Valley to refuse to accept ice from the main stream. Therefore the small streams, ponds, and lakes within convenient distances from each municipality have been utilized. There is no estimate of the value of the ice crop in the Connecticut basin.

Character of water.—The character of water in the main river is of course largely determined by that from the tributaries feeding it, and as the water in the latter varies widely in different regions, that in the Connecticut proper is dependent upon the distance of a given sampling point from the confluence of a normal or a polluted branch. Below the entrance of a tributary loaded with sewage and manufacturing wastes the condition of the water is inferior to that at a point where it has been diluted by an influx of pure water from an unpolluted tributary.

Little or no attention has been given to the tributaries entering the main artery above the Massachusetts State line, and the highest branch concerning which we have information is Millers River.

MILLERS RIVER.

Millers River (see fig. 8) enters the Connecticut from the east at a point in Massachusetts about 10 miles south of the New Hampshire line. Its basin adjoins that of the Chicopee on the south and extends over into the State of New Hampshire on the north, covering about 395 square miles. The drainage area is hilly, especially near the river's confluence with the Connecticut, but farther back there are large areas of flat land. Lakes and ponds are plentiful, having a total area of 3,200 acres.

The flow of the river is very steady and its consequent value as a power stream is large. From Winchendon, near its headwaters, to its mouth there is a fall of 775 feet, the distance being not more than 30 miles. All of this fall is not available for development, however,

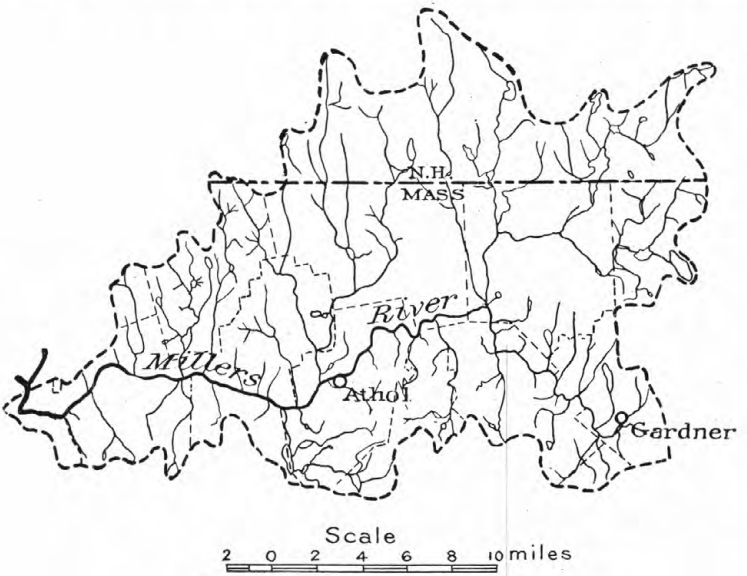

FIG. 8.—Millers River drainage basin.

as the course of the river for considerable distances partakes of the nature of a ravine; the banks are high and steep and little opportunity is afforded for the establishment of mills. The only available flow measurements are those made during October, November, and December, 1887, at the dam of the New Home Sewing Machine Company, at Orange. During this period the average monthly flow varied from 1.10 to 1.45 cubic feet per second per square mile. The population in the basin of Millers River is about 96 per square mile. This, however, does not fairly represent the conditions at the upper end of the area, for there the population is extremely dense, especially at Gardner. During the decade 1890–1900 there was a fair percentage of increase in the towns drained by this river, although it was for the most part confined to the towns of Gardner, Athol, Orange, and Win

chendon, while there was a decrease in the remaining places. Water supplies have been established at the above-named places, while sewerage systems have been laid at Orange and Gardner. These facts make it patent that Millers River receives considerable pollution, and, as the greatest population is near the headwaters, the river is unfitted for several uses throughout its whole length.

NORMAL WATER IN MILLERS RIVER.

It appears from the Massachusetts map of normal chlorine that the normal for Millers River varies from 0.8 to 1.2 parts per million, averaging about 1. Reports of the analyses of normal water are not plentiful for this drainage area, the only one appearing in the Massachusetts reports is of the well at the waterworks at Winchendon. This and several others in which the amount of chlorine does not greatly exceed the normal are reproduced in the following table:

TABLE 42.—*Analyses of normal water in Millers River drainage area.*

[Parts per million.]

Location.	Color.	Nitrogen as—				Chlorine.	Residue on evaporation.	Hardness.	Number of analyses made.
		Ammonia.		Nitrites.	Nitrates.				
		Albuminoid.	Free.						
Well in Winchendon	0.33	0.012	0.004	0.000	0.043	1.1	31.4	11	18
Orange waterworks	1.6	.112	.010	.000	.019	1.3	30.6	6	32
Athol waterworks	6.9	.342	.067	.000	.049	1.3	38.1	6	8
Gardner waterworks	.7	.161	.014	.000	.055	3.3	30.3	10	([a])

[a] Covering eight years.

The characteristics of the waters represented in the foregoing table are well shown. They are all acceptable for any of the ordinary uses and retain all the values of natural waters. The first and only normal water in the list is a well water. That it is a typical well water is shown by the color, which is very faint, practically absent. The low content of free and albuminoid ammonia is what might be demanded in a well water, and the evidences of its condition are further borne out by the absence of nitrites.

The Athol and Orange waters are from impounding reservoirs, and therefore are largely made up of surface drainage. The analyses show that oxidation had been rapid and that the character of the water is acceptable. The chlorine is above the normal, not very much to be sure, but sufficient to denote that the drainage area of the reservoirs has a certain population which contributes sewage to the natural drainage, and although its bad effects have long since been washed

away the traces still remain and neither water can be classed as normal.

The analysis of the Gardner water is instructive. It is apparently a water which has at some time been highly polluted, but which, through filtration, sedimentation, etc., has been reclaimed. The amount of chlorine, 3.3 parts per million (the normal for this country being 1.2) is unmistakable evidence of past pollution. In the previous pages mention has been made of waters which have been redeemed from contamination by means of artificial filters, but this is the clearest case noted in which the work has been done by natural conditions only.

Parts of the drainage basin of Millers River are thickly settled, which will account for the fact that none of the surface waters thus far analyzed are normal. The amount of chlorine found in a surface water bears a direct relation to the number of persons dwelling upon the land drained by that water. It follows, then, that while it may be impossible in a thickly settled country to secure normal water in large quantities, it is not necessarily impossible to so dispose of the wastes from the inhabitants that the resulting surface water may serve all purposes to which normal waters are applicable.

POLLUTION IN MILLERS RIVER.

The water of Millers River has been examined regularly by the Massachusetts State Board of Health at a point above Athol, where the pollution from Gardner and Winchendon may be detected, and again at a point below Orange, where the water contains the pollution from Gardner, Winchendon, Athol, and Orange. The analyses at these points are reported in Tables 43 and 44.

TABLE 43.—*Analyses of water from Millers River above Athol.*

[Parts per million.]

Date of collection.	Appearance.			Residue on evaporation.		Ammonia.				Chlorine.	Nitrogen as—		Oxygen consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on ignition.	Free.	Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.		
1900.														
July 17	Very slight.	Very slight.	6.1	36.0	15.0	0.072	0.264	0.240	0.024	2.0	0.010	0.000	8.1	5
Aug. 21	Decided	Considerable.	7.8	51.0	21.0	.032	.480	.344	.136	1.2	.030	.004	10.3	11
Sept. 19	do	do	7.0	64.5	17.5	.020	.775	.268	.507	1.4	.100	.002	6.7	11
Oct. 16	Very slight.	Very slight.	8.7	64.5	24.0	.048	.300	.284	.016	1.9	.110	.000	12.5	18
Nov. 20	Slight	do	7.2	53.0	17.0	.028	.360	.204	.156	1.9	.120	.000	10.9	14
Dec. 20	Very slight.	Considerable.	5.0	37.5	15.0	.018	.318 .416	.160	.158	1.2	.100	.000	7.5	16
Average			7.0	51.1	18.2	.036	.416	.250	.166	1.6	.078	.001	9.3	12

TABLE 44.—*Analyses of water from Millers River below Orange.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
July 24	Slight	5.9	0.292	0.064	0.002	0.010	2.8	35.0	5
August 22	Very slight	7.0	.292	.046	.001	.050	2.4	43.5	6
September 21	do	5.4	.240	.060	.001	.040	2.1	43.0	6
October 24	do	9.0	.376	.064	.002	.030	2.6	55.5	11
November 20	do	9.5	.284	.056	.001	.060	2.6	45.0	11
December 24	Decided	6.0	.260	.124	.000	.130	2.1	45.0	6
Average		7.1	.291	.069	.001	.053	2.4	44.5	7

DEERFIELD RIVER.

The Deerfield is the second largest tributary of the Connecticut. It rises in southern Vermont, crosses the Massachusetts State line, and, a few miles across, turns eastward and enters the Connecticut about 7 miles below the mouth of Millers River. The river has been little developed, and for the most of its length runs wild and free. There are many good and available power privileges, the slope is rapid, and the country is conveniently traversed by railroads, yet very few industries have been established in it. The elevation of the Deerfield at Readsboro, Vt., at the mouth of the West Branch, is 1,154 feet, while 42 miles below, at its mouth, its elevation is about 126 feet. There is practically no storage upon the drainage area in Massachusetts and very little in Vermont, therefore the flow is variable. In many places where power sites are otherwise excellent the valleys are too narrow for the location of mills. The river drains 656 square miles.

The total population of the basin is about 24,400, or approximately 37 per square mile. There is no important city within the watershed. Garfield, with a population of 7,927, is the largest place, but it is at the mouth of the Deerfield, and is also drained by the Connecticut itself. Shelburne and Colerain are next in size, with 1,508 and 1,749 inhabitants, respectively. Shelburne Falls is the only manufacturing town in the drainage area, although there are powers developed at Hoosac and Readsboro. There are no sewerage systems in the basin, the country is not highly fertile, and these facts, taken together with the sparse population, indicate clearly the character of the water.

The Deerfield is, in effect, another river system which has been preserved in practically its original condition, with all its normal resources unaffected.

Few analyses are available to show the character of the water of the Deerfield. These are included in Table 45.

TABLE 45.—*Analyses of water from Deerfield River at various points.*

[Parts per million.]

Number.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Place of collection.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
1	None	------	0.096	0.024	0.000	0.130	------	28.0	----	Above Readsboro.
2	Very slight	------	.120	.020	.000	.020	------	29.0	----	Monroe.
3	do	3.7	.110	.004	.000	.120	0.5	28.5	5	Florida.
4	do	.8	.085	.011	.000	.160	1.1	48.0	24	Colerain.
5	----------	.7	.054	.008	.000	.102	1.0	49.1	28	Leyden.
6	----------	3.2	.120	.008	.000	.097	1.0	36.0	17	Above Shelburne Falls.

Comment on the results set down in Table 45 seems unnecessary. The waters there represented are practically normal, the evidence of sewage pollution being very faint and the polluting substances having been practically all reduced to inorganic matter.

CHICOPEE RIVER.

The Chicopee is formed at Three Rivers by the union of the Quaboag, Ware, and Swift rivers. The Quaboag is the most southerly, and drains 210 square miles; the Ware drains 214 square miles, while the basin of the Swift covers 219 square miles. The total discharge averages 669 cubic feet per second.

Drainage area.—The drainage area of the Chicopee (see fig. 9) is larger than that of any other tributary of the Connecticut, comprising 706 square miles in central and southern Massachusetts, and occupying large portions of Worcester, Franklin, Hampshire, and Hampden counties. The country is fairly prosperous, and has constantly increased in population since the middle of the last century. During recent decades this increase has been confined to the cities and large villages, the rural population having decreased considerably. The country is very accessible, being traversed by excellent railroad systems, which have been of value to the power facilities of the river. It is hilly, with open valleys, the soil being principally bed gravel crossed by ledges of red sandstone, which form numerous falls in the rivers that flow through the district. The slope of the rivers throughout the whole system averages 15 feet per mile, but the maximum for certain sections is far greater than this.

Pondage.—There are in the basin many natural reservoirs, which serve to maintain comparatively steady flow in the streams. There

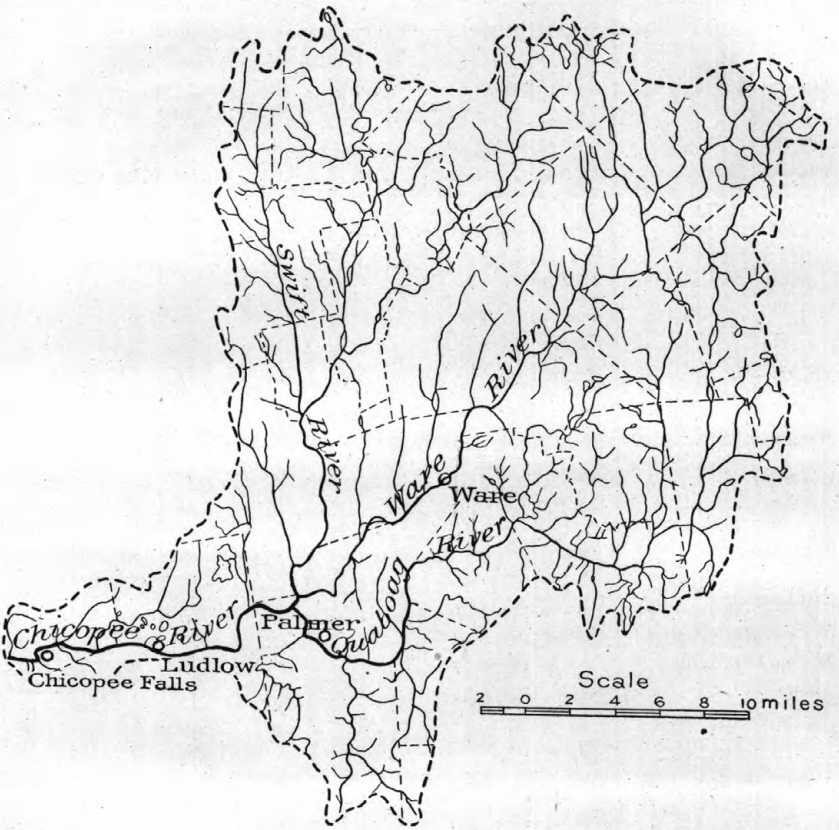

FIG. 9.—Chicopee River drainage basin.

is also considerable swamp land, especially along the Quaboag River, which materially assists in the maintenance of a uniform rate of flow.

TABLE 46.—*Principal ponds in basin of Chicopee River.*

Locality.	Name of pond.	Area.	Tributary to what stream.
		Acres.	
Prescott	On West Branch of Swift River.	154	West Branch of Swift River.
New Salem	Thompsons Pond	235	Middle Branch of Swift River.
Greenwich	Curtis Pond	155	Do.
Do	Luce Pond	124	Do.
Do	West Pond	94	Do.
Petersham	Reservoir (no name given)	175	Do.
Dana	Neeseponsett Pond	118	Do.

TABLE 46.—*Principal ponds in basin of Chicopee River*—Continued.

Locality.	Name of pond.	Area.	Tributary to what stream.
		Acres.	
Greenwich	Davis Pond	100	East Branch of Swift River.
Dana	Pottapang Pond	160	Do.
Phillipston	Phillipston Pond	202	Burn Shirt River (to Ware).
Do	Pond northeast of above	130	Do.
Hubbardston	Reservoir near Westminster.	90	Ware River.
Do	Moosehorn Pond	160	Do.
Do	Asuyconie Pond	238	Do.
Hardwick	Muddy Pond	202	Do.
Barre	Reservoir (no name given)	200	Do.
Rutland	Pond west of center	135	Do.
Do	Long Pond	160	Do.
Do	Demon Pond	138	Do.
New Braintree	Two ponds near center	94 75	Quaboag River.
Oakham	Browning Pond	140	Do.
West Brookfield	Wickaboag Pond	323	Do.
North Brookfield	Brooks Pond	178	Do.
Do	Furnace Pond	305	Do.
Brookfield	Podunk Pond	508	Do.
Do	South Pond	340	Do.
Spencer	Cranberry Meadow Pond	107	Do.
	Total area of 28 ponds.	5,040	

Power values.—The Tenth Census Report on Water Power contains an excellent description of the power utilized on the Chicopee. It states that the main river is an extremely valuable one, and has gained prominence by reason of the extensive cotton and other manufacturing industries established along its course. The available fall in the river has been practically all utilized. Of the three main branches the Quaboag is the most valuable for power because of its well-sustained flow, the value of the Ware and the Swift rivers following closely in the order named.

Character of water in the Chicopee Basin.—The following towns are situated partly or wholly within the Chicopee Basin: Chicopee, Ludlow, Belchertown, Palmer, Monson, Wales, Brimfield, Warren, Brookfield, West Brookfield, North Brookfield, Spencer, Paxton, New Braintree, Ware, Enfield, Hardwick, Oakham, Greenwich, Prescott,

Pelham, Shutesbury, Dana, Barre, New Salem, Wendell, Petersham, Phillipston, Templeton, Hubbardston, Rutland, Wilbraham, and Springfield.

The population in the drainage area is about 90,000, or 127 per square mile.

WARE RIVER.

The watershed of Ware River adjoins that of the Nashua. It has an elevation in the towns of Oakham and Barre of about 645 feet above high tide. The population is small and the pollution is therefore not objectionable, and from a sanitary point of view the stream is an excellent source of water supply. The area has been considered a favorable one by the Metropolitan Water Board of Massachusetts as a part of the natural gathering ground for the future supply of Boston and the vicinity. It forms a link in the chain of gathering grounds in central Massachusetts, which will at some day in the future, when the demands require it, be connected with the Nashua and the waters carried through the long aqueducts to the distribution stations in the vicinity of Boston.

Analyses have been made periodically by the Massachusetts State Board of Health of the water in Ware River at Coldbrook station, in the town of Barre. The average results for each year are included in Table 47.

TABLE 47.—*Analyses of water from Ware River at Coldbrook station at Barre.*

[Parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Number of analyses made.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
1894	7.4	0.178	0.005	0.000	0.023	1.4	35.5	8	12
1895	7.8	.219	.014	.000	.051	1.7	39.6	9	12
1896	7.2	.198	.003	.000	.038	1.1	33.6	8	6
1897	8.3	.193	.010	.000	.032	1.4	36.0	7	12
1898	7.6	.196	.011	.000	.027	1.4	35.1	7	12
1899	5.0	.184	.010	.000	.032	1.4	33.8	4	12
1900	6.2	.227	.025	.000	.014	1.4	36.6	5	7

The color of the water is fairly high, due, no doubt, to a considerable extent of swamp land. The amount and condition of the organic matter is not particularly suggestive, save that the free and albuminoid ammonia in 1900 is higher than in previous years, showing additional organic pollution, the source of which is not apparent. The normal chlorine for this region is from 1.1 to 1.2 parts per million, so

that the average of 1.4 parts in the table above set forth shows a slight sewage contamination.

In the basin of Upper Ware River is Musquapog Lake, the source of the water supply of Rutland. The following analyses were made of the water from this lake in the year 1900:

TABLE 48.—*Analyses of water from Musquapog Lake.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
Jan. 31	Very slight	0.2	0.118	0.098	0.001	0.010	1.6	17.5	5
Aug. 14	do	.1	.188	.010	.000	.000	1.4	17.0	2
Sept. 26	do	.2	.130	.044	.000	.020	1.4	21.0	3
Dec. 20	do	.2	.218	.070	.001	.030	2.8	29.0	5

The water supply of Barre is collected in a reservoir within the town, the water flowing from several springs in the vicinity and from the surface of the ground for a considerable area above. Analyses of this water, made in 1898, are reported as follows:

TABLE 49.—*Analyses of water from the reservoir of the Barre Water Company.*

[Parts per million.]

Date.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1898.									
Jan. 11	Decided	1.5	0.096	0.002	0.000	0.000	1.4	25.0	10
Apr. 12	do	1.1	.272	.018	.002	.002	1.5	19.0	8
July 5	Slight	1.1	.330	.042	.001	.001	1.3	25.0	5
Oct. 5	do	1.0	.536	.156	.000	.020	1.4	25.0	8
Average		1.2	.308	.054	.001	.032	1.4	23.5	8

Ware River, after flowing by the town of Barre, which has a population of over 8,000, plainly shows the effects of pollution. A large number of the houses and some of the factories of Ware empty their wastes directly into the river. Analyses of samples of water taken from the river below the town, made by the State Board of Health, in the year 1900, are given in table 50. When these are compared with those made of the water collected at Cold Brook Station the change is clearly illustrated.

TABLE 50.—*Analyses of water from the Ware River below Ware.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
July 17	Slight	4.1	0.312	0.060	0.008	0.000	2.1	46.5	10
August 22	Decided	3.7	.324	.032	.002	.040	2.2	45.0	8
September 20	do	3.4	.404	.076	.003	.020	3.3	52.0	11
October 16	Very slight	7.3	.288	.052	.002	.040	2.4	54.0	11
November 19	Decided	7.0	.275	.110	.001	.050	2.5	49.0	14
December 19	do	5.0	.288	.132	.002	.120	2.5	51.0	11
Average		5.1	.315	.077	.003	.045	2.5	49.6	11

Not far below the point where these samples were collected Ware River joins the Swift and the Quaboag. The analyses in table 49 therefore represent the character of the water contributed by the Ware River to the Chicopee system.

SWIFT RIVER.

Swift River is the westernmost of the three main branches of the Chicopee. Below the town of Enfield it has an elevation of 376 feet above tide. It drains an area of 185.7 square miles, which has a population of 128 per square mile. This area, like that of the Ware, has been considerd as a source of water supply by the Metropolitan Water Board. The water is of excellent quality and has little color. The following analyses have been made by the State Board of Health of Massachusets.

TABLE 51.—*Analyses of water from Swift River at designated points.*

[Parts per million.]

Date.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Number of samples analyzed.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
EAST BRANCH IN GREENWICH.									
1894	4.7	0.146	0.011	0.000	0.015	1.5	31.0	8	2
MIDDLE BRANCH IN GREENWICH.									
1894	3.8	0.115	0.012	0.000	0.000	1.3	31.5	9	2
BARRETTS JUNCTION.									
1900	3.2	0.167	0.012	0.000	0.040	1.6	33.3	10	3
TOWN OF ENFIELD.									
1898	0.4	0.030	0.000	0.000	0.058	1.1	25.8	7	6

QUABOAG RIVER.

The Quaboag is the southernmost of the three main branches of the Chicopee. It drains the whole area of the towns of Monson, Brimfield, New Braintree, Oakham, Spencer, and Paxton. The population per square mile is 125, which is considerably larger than in the Ware and Swift basins. The character of the unpolluted water in the drainage area of the Quaboag is well shown in the following series of analyses:

TABLE 52.—*Analyses of unpolluted water in Quaboag Basin.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
Reservoir, Monson	1.1	0.355	0.030	0.004	0.105	1.7	34.5	----
Shaw Pond, Spencer	.3	.136	.007	------	.059	1.4	26.9	----
Dug well, Monson	.1	.011	.002	.000	.095	1.2	33.3	10
Do	.0	.006	.001	.000	.078	1.3	32.2	7
Spring, North Brookfield	.0	.008	.010	.000	.245	1.4	37.0	9
Doane Pond, North Brookfield	5.3	.308	.145	.002	.050	1.2	31.5	4
Shaw Pond, Spencer	.3	.148	.018	.000	.090	1.6	22.2	5

The settlements along the Quaboag which contribute a considerable amount of matter to the river above the town of Palmer are Spencer, Brookfield, North Brookfield, Warren, and Monson. After the water has passed all these points it is in the condition indicated in the following table:

TABLE 53.—*Analyses of water from Quaboag River above Palmer.*

[Parts per million.]

Date of collection.	Turbidity.	Color	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
July 17	Very slight	4.4	0.196	0.040	0.001	0.010	1.9	41.0	11
August 21	Slight	5.1	.236	.032	.001	.010	2.5	47.0	10
September 19	Very slight	3.5	.208	.028	.001	.030	2.8	42.5	13
October 29	Slight	4.4	.248	.048	.002	.040	3.1	45.0	14
November 20	do	4.3	.216	.036	.000	.110	2.9	44.5	17
December 18	do	4.5	.198	.010	.003	.100	2.5	42.5	11
Average		4.4	.217	.032	.001	.050	2.6	37.7	13

After receiving considerable sewage from Palmer, the river below is not apparently in a worse condition from the standpoint of organic content than it was above that town. This fact is shown by the following analyses:

TABLE 54.—*Analyses of the water of the Quaboag River below Palmer.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
July 17	Very slight	4.1	0.180	0.040	0.001	0.030	1.8	41.0	13
August 21	Slight	5.0	.246	.044	.001	.050	2.4	51.5	8
September 19	Very slight	3.1	.198	.008	.001	.050	3.0	44.0	13
October 29	Slight	4.0	.248	.048	.002	.040	3.1	47.0	10
November 20	Decided	3.7	.216	.048	.000	.140	2.9	44.5	16
December 18	Slight	4.1	.190	.008	.003	.120	2.5	43.5	11
Average		4.0	.213	.033	.001	.072	2.6	45.2	12

A comparison of the two tables shown above illustrates in a fairly clear way a point made at the beginning of this discussion, which is, that analysis of water is not always effectual in showing its condition from the standpoint of general healthfulness. It is plain that the water of Quaboag River can not be as safe for public use after it has passed the town of Palmer as it was above this point. The amount of pollution from Palmer is rather extensive, but it is not apparent in the analysis of the water. The reason for this is probably that the amount of pollution is not sufficient to appreciably change the quantity of organic matter contained in so large a flow as that of the Quaboag, yet it is undoubtedly true that if the germs of any water-borne disease, such as typhoid fever, were brought into the river from Palmer, the use of the water below Palmer would be extremely dangerous, even though the analysis would seem to show that, from the standpoint of organic content, the river had not changed.

From the confluence of the Swift, Ware, and Quaboag rivers the Chicopee runs almost due west, past the municipalities of Ludlow, Wilbraham, Chicopee, and Springfield. The first village below Three Rivers is Ludlow, from which there is considerable sewage emptying into the Chicopee. The average of six analyses of the water below Ludlow made in the year 1900 is reported as follows:

TABLE 55.—*Analyses of water from the Chicopee River below Ludlow.*

[Parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900	3.8	0.240	0.042	0.012	0.098	2.8	46.0	12

After receiving sewage from Indian Orchard, Chicopee Falls, and a part of Chicopee the river enters the Connecticut. No recent analyses of the water of the river at a point below that are available.

WESTFIELD RIVER.

Drainage basin.—Westfield River is a branch of the Connecticut which enters the latter from the west at a point opposite Springfield, Mass. (See fig. 10.) It has a drainage area of about 515 square miles, all of which is situated within the State of Massachusetts. Above a point 16 miles from the mouth of the river the country is extremely hilly, and in the upper districts it is even mountainous. The maximum fall from source to mouth is, where measured via the West Branch, about 1,162 feet, or an average of 32.5 feet per mile. In the

upper part of the river, however, the fall averages usually 70 feet per mile.

The rainfall on the watershed finds its way over the steep slopes rapidly and the flow of the river fluctuates in consequence. This flood flow is not steadied by any considerable storage within the basin, for there are few natural ponds or lakes, and little or nothing has

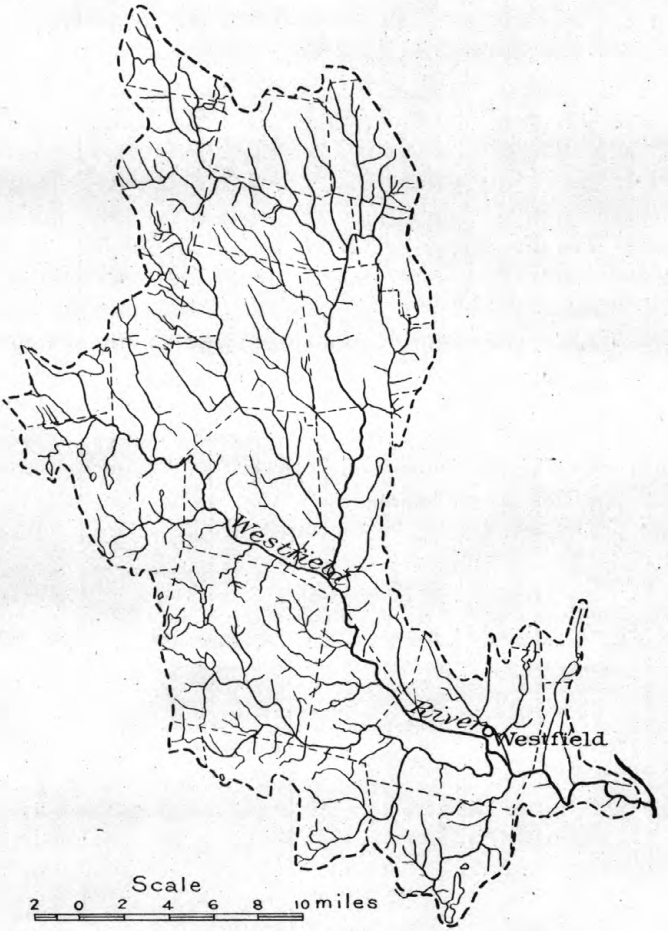

FIG. 10.—Westfield River drainage basin.

been done to impound the waters. Gen. Theodore G. Ellis, Chief of Engineers, U. S. Army, has given the average flow of the river as 500 cubic feet per second, but this is believed by Professor Porter to be too large.

Population.—The development of the drainage area of the Westfield has been slow and the growth of population slower. In a great majority of the towns there has been a decrease in the number of

inhabitants within the decade 1890–1900. A large part of the basin has no railroad facilities whatever, and there has been no need of any. In short, the country has not shared the industrial and commercial advancement which has been made by the greater part of the surrounding sections. In the lower parts of the area, notably in Westfield, there has been an increase in population amounting to 25 per cent in the last decade. Exclusive of this town and West Springfield, the most populous part of which drains into the Connecticut, the drainage area has a population of about 23 per square mile.

Character of water.—On account of the small population the character of the water is excellent, and the river above the town of Westfield may be considered practically unpolluted. The following expressive statement is found in the report of the State Board of Health of Massachusetts for 1890:

> Analyses of the water of the Westfield River have not been made regularly, because it was polluted so little during the time covered by these investigations (1887–1889) that it seemed unnecessary.

As above noted, conditions in the river have not changed, except in the lower end; therefore the passage quoted applies at the present time. The construction of a sewerage system at Westfield and the location of its outlet in the river has made it necessary to examine the waters above and below the outlet in order to show the effect upon the river. In the investigation of water supplies for different towns in the district, several analyses of water in the drainage basin were made.

TABLE 56.—*Analyses of normal water of the Westfield River system.*

[Parts per million.]

Point of taking sample.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Number of samples analyzed.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
Chester	None	0.9	0.068	0.004	0.001	0.120	1.0	32.5	11	1
Huntington (Middle Branch).	do	.9	.063	.004	.000	.043	.9	32.1	15	14
Huntington (East Branch)		1.4	.087	.005	.000	.053	1.0	33.2	14	14
Russell	Very slight.	1.2	.078	.010	.000	.070	.7	32	1	1
Granville		1.3	.071	.013	.000	.027	1.2	26.7	4	14

The above analyses represent the characteristics of water, which may fairly be called normal, obtained from different parts of the drainage area. It will be seen that there is very little difference in the color of the various samples and that the residue and the albuminoid ammonia are remarkably uniform. The Granville sample shows higher free ammonia and chlorine than the preceding ones, which for the moment looks threatening, but it will be seen that the actual departure from the normal is wholly within the limits of error, and if there is any pollution in the Granville sample it is not sufficient to produce significant changes, so that the water from nearly the whole Westfield area is of practically normal character. The basin remains in a condition in which may be realized all the resources which its streams can provide. The public demand for drinking water may be met at almost any point, and there is no blemish on the ice fields. The manufacturer may use the water with impunity, for it is not changed sufficiently to injure his products. That this district, lying between the metropolitan area of New York and the prosperous country of central Massachusetts, should remain throughout its greater part in normal condition is worthy of remark.

We will now trace the changes that take place in the water of Westfield River after it passes the town of Westfield, with its population of 12,310.

TABLE 57.—*Analyses of water from Westfield River above and below Westfield.*

[Parts per million.]

Point of taking sample.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Number of samples examined.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
Above Westfield	2.2	0.135	0.013	0.000	0.035	1.3	42.6	19	15
Below Westfield	2.0	.296	.128	.004	.069	2.3	49.9	23	11

The analyses in the table above are of peculiar interest, as they show the effect of a single sewerage system on a pure stream. From what has gone before it will be remembered that Westfield River receives practically no significant pollution until it reaches the city of Westfield, but in passing the city it is changed from a normal river to a polluted one. Let us consider the significance of the determinations in Table 57. The average of the samples taken below the city shows a great increase in the amount of polluting material. Free ammonia, nitrites, and chlorine, the special indicators of the presence of sewage pollution, are all present in increased quantities, while the

amounts of nitrates and albuminoid ammonia assume a proper relation to the whole.

HOCKANUM RIVER.

Drainage area.—On the boundary between the towns of Tolland and Ellington, Conn., there is a lake, the level of which has been so raised by a stone embankment 35 feet high that it has an expanse of 680 acres. Its drainage area is 15.4 square miles, but in addition to the surface water which accumulates from this territory, it is largely fed by hidden springs. This lake, called Shenipsit, is the source of Hockanum River, which flows thence in a southwesterly course, emptying into Connecticut River opposite Hartford. The Hockanum is principally important by reason of the power developed along its course, for although it is less than 20 miles long it furnishes 3,957 horsepower.

Flow.—According to the measurements of General Ellis, Chief of Engineers of the U. S. Army, the flow of the river averaged 132 cubic feet per second, its maximum flow being 6,167 second-feet. The flow is peculiar by reason of the fact that about 2,000,000 cubic feet a day are allowed to run from Shenipsit Lake during working hours while no water is permitted to flow at night or on holidays.

There are several factories on the banks of the river, most of them works for the manufacture of textile fabrics and paper. Just below Shenipsit is Rockville, where 1,400 horsepower are developed.

Character of water.—Shenipsit Lake drains an area which is sparsely settled, and its water is therefore practically normal and of excellent quality. It is used as a supply for the city of Rockville and has been analyzed by the State Board of Health of Connecticut.

TABLE 58.—*Analyses of water of Shenipsit Lake.*

[Parts per million.]

Date of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Samples averaged.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
1890–91	0.1	0.194	0.027	0.001	0.05	1.66	31.3	7	11
1900	.3	.107	.021	.000	.08	1.42	31.2	5	12

Taylor's reservoir, on the south branch of the Hockanum, is another body of normal water. It is used as a source of supply for South Manchester, Conn. Analyses made by the Connecticut State Board of Health in the year 1900 are reported as follows:

TABLE 59.—*Analyses of water from Taylor's reservoir, Manchester, Conn.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
Jan. 24	Very slight	0.4	0.130	0.028	0.001	0.10	1.7	34.5	3
Mar. 15	Clear	.1	.102	.044	.001	.05	1.5	32.0	5
May 10	do	.2	.110	.038	.002	.05	1.5	34.0	5
July 3	do	.1	.068	.022	.001	.02	1.7	35.0	3
Sept. 13	do	.1	.108	.018	.000	.03	1.6	36.5	4
Nov. 7	do	.1	.112	.112	.000	.08	2.1	37.5	3
Average		.2	.105	.025	.001	.05	1.68	34.9	4

Pollution.—The Board of Health of the State of Connecticut is investigating the character of the water in Hockanum River, samples being collected at three available points, viz, Windermere, North Manchester, and Burnside.

This work was done during the years 1895, 1896, and 1900, the samples being collected monthly, from May to October in each year. They indicate extensive pollution of this stream, but since its principal resource is water power, the damage done is not significant. The character of the water will doubtless be better in the future, by reason of the installation of a sewage purification plant in the village of South Manchester.

TABLE 60.—*Analyses of water from Hockanum River at Windermere, North Manchester, and Burnside.*

[Parts per million.]

WINDERMERE.

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1895	0.5	1.470	0.071	0.017	0.160	4.85	138.9	13
1896	.5	.913	.070	.008	.180	4.49	98.6	----
1900	.4	.910	.073	.010	.250	3.38	71.9	----

TABLE 60.—*Analyses of water from Hockanum River, etc.*—Continued.

NORTH MANCHESTER.

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1895	0.5	1.096	0.124	0.008	0.110	3.87	82.1	15
1896	.5	.762	.063	.009	.160	4.45	78.3	----
1900	.3	.752	.167	.022	.240	3.95	75.4	----
BURNSIDE.								
1895	0.4	0.802	0.172	0.025	0.100	6.03	98.6	37
1896	.4	1.156	.194	.023	.140	5.61	81.4	----
1900	.4	.722	.183	.025	.160	4.65	80.7	----

PARK RIVER.

Park River is a small stream entering the Connecticut from the west. In its drainage area are the cities of New Britain and a part of Hartford. The flow is small, and, as there is a large amount of sewage brought into the river, it is probably the foulest stream in the State of Connecticut. The report of the State Board of Health made in 1895 contains the following comments:

The result of the analyses at New Britain indicate that at times during the summer the water of the stream contained as much as four-fifths of its volume of sewage. Between New Britain and section No. 2, at Newington Junction, there is practically no sewage addition. From the respective areas of the watersheds the volume of the stream at Newington should be about five times what it is at New Britain, but that the dilution must be less than this is at once apparent when it is considered that the greater part of the flow at station No. 1 is sewage and comes from other watersheds, from which the water supply is drawn. A better means of measuring dilution is by the comparison of the amounts of chlorine at the two stations, for this constituent is not removed from the stream after once having been introduced, either by precipitation or by the acts of living organisms. Since the normal chlorine of the region is about 2, there would be two parts of chlorine per million in the water of dilution added between New Britain and Newington, and, since the average amount of chlorine at the two stations is 33.1 and 15.1, respectively, it is easy to calculate that the dilution at Newington Junction is 2.4.

The average amount of nitrogen of free ammonia at New Britain was 3.04. A dilution to the extent indicated above would reduce the nitrogen of free ammonia at Newington Junction to 1.25, but the amount actually found was 2.35, a very considerable increase. This, of course, was due to putrefactive change occurring during the flow of 3¾ miles. That the changes occurring during this course were putrefactive and not oxidizing in character is shown, not alone by the increase of free

ammonia, but also by the figures for nitrites and nitrates, which show no increase, but, on the contrary, a slight relative diminution.

A similar calculation for the nitrogen of organic matter in suspension shows that there was a decrease of about 30 per cent, due, doubtless, chiefly to sedimentation. The decrease of nitrogen of organic matter in solution was somewhat more than the increase of nitrogen of free ammonia. In flowing through the course of 3¾ miles, therefore, there was some purification by sedimentation, but apparently none by oxidation, and very little by precipitation and other means. The improvement in the stream at the lower point is consequently due almost wholly to dilution with clean water from the watershed between the two stations.

Below Newington Junction there is a large increase in the flow, the relative watersheds being as 1 to 5.6. There is little direct contamination until the sewers of Hartford are reached. There are several of these in the last mile above station No. 3 in Hartford. The contamination effected by their discharge is so great that, although there is a dilution of nearly sixfold, the water in the stream at this point is about in the same condition as at Newington Junction; indeed, in respect to the organic matter the contamination is greater in Hartford.

Analyses of the water of this river were made by the Connecticut State Board of Health in the years 1895, 1897, and 1899 at New Britain, Newington, and Hartford, and the average of the results for each year are set forth in Table 61.

TABLE 61.—*Analyses of water from Pipers Brook and Park River.*

[Parts per million.]

Date of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Samples analyzed.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
NEW BRITAIN.								
1895	0.5	6.71	3.04	0.396	1.15	33.0	290.9	6
1897	.4	7.08	3.41	.217	1.24	26.2	271.6	6
NEWINGTON.								
1895	0.7	1.57	2.33	0.064	0.37	15.1	160.8	6
1897	.6	2.64	2.07	.064	.28	13.2	150.0	6
1899	.8	2.52	4.42	.024	.09	16.9	155.6	6
HARTFORD.								
1895	0.6	3.71	2.27	0.035	0.19	13.1	151.9	6
1897	.5	5.21	2.17	.158	.23	17.0	172.2	6
1899	.4	2.22	1.22	.208	.20	9.2	138.3	6

The pollution of Pipers Brook by the city of New Britain led to a lawsuit against the city, the final decision in which was rendered by the supreme court of errors of the first judicial district of the State of Connecticut, during the May term, at Hartford, in 1897. The suit was brought for injunction and damages before the superior court in Hartford County by Patrick Nolan, the jury giving verdict and judgment for plaintiff in $2,000 damages. The plaintiff owned a farm near Newington on Pipers Brook below the city of New Britain, upon which were dwelling houses and other buildings. The complainant stated that from October 1, 1887, to the date of complaint, the city had dumped acid, sewage, and other deleterious matter into the river and deprived him of the use of water for stock and for domestic purposes, and he had been put to a large expense thereby, his lands being injured for pasturage, his milk business having been injuriously affected, and the ice crop upon the stream having been made valueless.

The following extracts are taken from the opinion rendered by the court, the same having been handed down by Chief Justice Andrews (69 Conn., 668):

The use of Piper's Brook which the complainant charges that the defendant has made, unless there is a lawful warrant therefor, causes a public nuisance. Anything not warranted by law, which annoys or disturbs one in the use of his property, rendering its ordinary use or occupation physically uncomfortable to him, is a nuisance. (Baltimore and Ohio Railroad *v.* Fifth Baptist Church, 108 U. S., 317.) * * * The test is not the number of persons annoyed, but the possibility of annoyance to the public by the invasion of its rights. * * * (Westcott *v.* Middleton, 43 N. J. Eq., 478.) * * * That it would be a public nuisance to render the water of a stream so impure that it could not be used for domestic purposes, or for the watering of cattle, and so that it gave off noxious and unhealthy odors, is hardly open to question (Chapman *v.* Rochester, 110 N. Y., 273), for the reason that these causes would injuriously affect every riparian owner along the whole length of the stream and every person who lived near it. If a municipal corporation, in the absence of a legal right so to do, causes sewage to pollute a watercourse, to the use of which a lower owner, through whose premises the watercourse flows, is entitled, it is guilty of a nuisance for which damages may be recovered. * * * * * * The second defense depends on the act of the legislature of 1872, mentioned in the statement of the case.

* * * The said act authorizes and points out the steps to be taken in order to complete within said city a valuable public improvement, to be paid for by that species of taxation known as the assessment of damages and benefits. It empowers the common council, "whenever in their opinion the public health or sewerage shall require such action, to take, occupy, and appropriate, in such manner as they shall, from time to time, deem expedient, any stream or part of a stream, natural or artificial, running in or through said city, and to straighten, deepen, or lower the same, or lower or remove any or all walls, dams, or other obstructions to the free and healthy flow of such stream or part of a stream, or to enlarge or cause to be enlarged or lowered, any or all culverts which at any season of the year cause the accumulation of stagnant water or interrupt in any manner the free and healthy flow of any part of such stream." This is all of the act which grants power to the defendant to interfere with Piper's Brook. * * *

If it had been the intent of the legislature, by the act of 1872, to authorize the

common council of the city of New Britain to take or to affect any lands outside of the city limits, it is certain that there would have been in the act some provision for the ascertainment of damages to be paid to the landowner. The right of the plaintiff to have the water of Piper's Brook flow through his land as it has been accustomed to flow [i. e., pure and uncontaminated] "is not an easement or appurtenance, but it is inseparably annexed to the soil." (Wadsworth *v.* Tillotson, 15 Conn., 366, 373.) To deprive the plaintiff of that part of his soil for the purposes named in that act would be the taking of private property for public use, and the plaintiff would be entitled to have just compensation.

The procedure of the trial court was sustained and the award affirmed.

FARMINGTON RIVER.

Farmington River is an important stream which rises in Berkshire County, Mass., and, after a peculiar and erratic course, enters Connecticut River from the west about 5 miles above the city of Hartford. It is a notable power stream, having a fall of about 1,200 feet, a mean discharge at the mouth of the river of about 944 cubic feet per second, and a maximum discharge of nearly 25,000.

The surface of the Farmington River Basin is hilly, the uplands are well wooded, and the valleys extensively cleared for farming purposes. There are many ponds in the basin, and these, with the surface waters, maintain a fairly steady flow during the dry seasons. Indeed, it has been claimed that the development of water storage on this river has practically reached its height.

No examinations of water of the Farmington River are available. Although there are a number of thriving manufacturing villages along its course, there are no important towns in the basin; therefore pollution can not be sufficiently extensive to greatly damage the river.

CONNECTICUT RIVER.

Analyses of the water of Connecticut River at Northfield Farms, in the northern part of Massachusetts, just below the State line, show that the pollution which enters from the States of Vermont and New Hampshire has very little effect on the apparent composition of the water. Indeed, such is the dilution of the sewage poured into the river north of the Massachusetts line that the chlorine in the water at Northfield is nearly normal. In the Connecticut Valley in New Hampshire and Vermont there are only a few important towns, and these are probably not completely sewered, if at all. Brattleboro and Bellows Falls in Vermont, with populations of 5,297 and 4,377, respectively, are the only places in that State from which there is likely to arise any appreciable pollution. In New Hampshire, the city of Keene drains into the Connecticut by way of the Ashuelot, and the town of Claremont is situated directly upon the river. These places have populations of 9,165 and 6,498, respectively.

TABLE 62.—*Analyses of water from Connecticut River at Northfield Farms.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
July 18	Slight	2.8	0.156	0.012	0.001	0.000	0.6	60.5	30
August 20	Very slight	3.0	.142	.006	.003	.040	.8	60.5	33
September 17	do	2.4	.114	.006	.000	.010	1.1	71.0	38
October 15	do	8.3	.270	.045	.000	.050	.8	62.5	22
November 19	Slight	6.8	.270	.044	.001	.050	1.0	57.5	21
December 17	Very slight	2.4	.148	.024	.006	.190	1.1	60.5	30
Average		4.3	.183	.023	.002	.057	.9	62.1	29

The available analyses of the river's water next below Northfield Farms were made at Turners Falls, in the town of Montague, from 1887 to 1889. Although, under ordinary circumstances, a series of analyses made at such an early date would not be applicable to the present conditions, the changes in the population above this point have not been sufficient to materially alter the condition of the river. The average of 21 analyses is set forth in Table 63.

TABLE 63.—*Average of twenty-one analyses of water from Connecticut River at Turners Falls.*

[Parts per million.]

Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
Slight	3.0	0.140	0.025	0.003	0.123	1.0	63.8

The report of the Massachusetts State Board of Health for 1899 gives a significant analysis of the water of the Connecticut River opposite Northampton as follows:

TABLE 64.—*Analysis of water from Connecticut River at Northampton.*

[Parts per million.]

Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
Very slight	3.0	0.232	0.018	0.001	0.030	0.9	57.5	26

Continuing downstream we find that the next available analyses are those made by the State Board of Health of water taken from Connecticut River at a point below Springfield. Here are the first prominent indications of pollution shown by analytical methods. Above this point there are Chicopee, Westfield, and Millers rivers, which are, as has been already stated, in a polluted condition. On the main river there are the cities of Northampton, Springfield, and Holyoke, as well as smaller towns, all of which contribute a large measure of pollution. It is not surprising then, that by the time the river reaches this point below Springfield it should betray by chemical analyses the abuse which it has suffered.

TABLE 65.—*Analysis of water from Connecticut River below Springfield.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
July 17	Very slight	2.5	0.184	0.112	0.002	0.010	1.7	61.0	34
August 13	Slight	2.4	.148	.112	.002	.020	1.6	61.5	34
September 18	Decided	2.9	.280	.156	.004	.040	2.9	78.5	36
October 18	Very slight	7.1	.268	.064	.002	.020	1.7	66.0	25
November 21	Decided	7.2	.368	.048	.002	.080	2.0	65.0	27
December 29	Slight	2.6	.152	.006	.001	.090	1.8	49.0	25
Average		4.1	.233	.083	.002	.043	1.9	63.5	30

Crossing over into the State of Connecticut, the river receives other and extensive pollution. The Farmington, Hockanum, Salmon, and other tributaries have already been discussed. On the main river are Hartford and Middletown, as well as numerous other smaller centers, which materially increase the amount of pollution. In the years 1890, 1893, 1894, and 1899, the State Board of Health of Connecticut made examinations of the water of the river at three points, viz: Warehouse Point, Rocky Hill, and Goodspeed Landing. Analyses made at these points are well adapted to show the effects of the contribution by various towns of new contamination to the already polluted river.

TABLE 66.—*Analyses of water from Connecticut River at Warehouse Point, Rocky Hill, and Goodspeed Landing.*

[Parts per million.]

Year.	Color.	Nitrogen as-				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
WAREHOUSE POINT.								
1890–91	3	0.126	0.034	0.002	0.12	1.23	44.2	23
1893	3	.116	.086	"much"	.20	1.85	66.5	----
1894	3	.192	.064	.005	.06	2.58	76.5	44
1899	2	.130	.048	.002	.15	2.70	77.5	30
ROCKY HILL.								
1890–91	3	0.135	0.033	0.002	0.11	1.28	44.6	25
1893	3	.112	.054	.010	.10	1.75	66.5	----
1894	3	.156	.102	.006	.30	3.50	73.5	48
1899	3	.164	.068	.008	.18	2.70	73.5	32
GOODSPEED LANDING.								
1890–91	3	0.130	0.036	0.001	0.13	1.36	45.0	25
1893	3	.110	.044	.005	.08	1.81	65.5	----
1894	2	.182	.064	.004	.08	3.04	73.0	44
1899	3	.244	.066	.008	.20	3.20	73.0	32

There is little to add concerning the Connecticut River and its relations to the various interests which have claims upon it. There is no reason why this stream could not be kept in a condition that would be acceptable to all concerned. Under the present conditions, however, much of its value is lost. The river comes down to the Massachusetts line practically uninjured, but in its course through Massachusetts it is robbed of its values as a source of water supply and of ice. Under the present policy of the State authorities the condition of the river is not likely to grow worse, but, on the contrary, will no doubt be improved, so that we can look forward with confidence to the removal of the dangerous wastes which are now poured into the Connecticut system in Massachusetts. In Connecticut the river has great values as a source of power, as a means of navigation, and as a park nucleus, but the remainder of its normal values have been destroyed.

HOUSATONIC RIVER.

NATURAL RESOURCES.

Course.—The Housatonic is an important stream flowing through the extreme southwestern part of New England. It has its origin in the central part of Berkshire County, Mass., being formed by the confluence of East and West branches, which unite at Pittsfield. From Pittsfield it flows southward in a somewhat tortuous course, passing into Connecticut through Litchfield County, and still farther south forming the boundary between New Haven and Fairfield counties, finally emptying into Long Island Sound near Bridgeport. (See fig. 11.)

Drainage basin.—The area drained by Housatonic River comprises 1,933 square miles, of which 503 are in Massachusetts. The river in its winding course traverses about 125 miles. The East Branch, which has a drainage area of 70 square miles, rises not far from Pittsfield, and flows by an extremely circuitous route through the manufacturing settlements of Hinsdale and Dalton, finally joining West Branch south of Pittsfield. The West Branch is formed by the overflow of Onota and Pontoosuc lakes, in Pittsfield, and flows in a southerly direction, draining an area of 59 square miles. One of the principal branches of West Branch is Southwest Branch, which rises in Richmond Lake and joins West Branch a short distance above its confluence with East Branch.

Fall.—The fall of the river between Pittsfield and Long Island Sound amounts to about 1,000 feet. It is distributed along gravelly shoals, with intervening stretches of quiet water. There are falls at New Milford, Bulls Bridge, and Falls Village.

TABLE 67.—*Table showing fall in Housatonic River.*

Locality.	Distance above mouth.	Elevation above mouth.	Fall between points.	Distance between points.	Average fall per mile between points.
	Miles.	*Feet.*	*Feet.*	*Miles.*	*Feet.*
Pittsfield, Mass	123	983			
Ashley Falls, Mass	81½	705	361	50.5	7.15
Falls Village, Conn	72½	622			
1.8 miles above Cornwall Bridge	64	457	165	8.5	19.41
Mouth of Shepaug River	29½	105	352	43.5	10.20
Birmingham	11	----------	105	18.5	5.68

The drainage area is hilly and even mountainous, the uplands are fairly well wooded, and the valleys are wide, with alluvial meadows. The falls in the river are over ledges of limestone and granite, and fairly good building marble is quarried. A small amount of iron ore is mined. There is also easily available a pure quartz sand which has become famous in the glass industry.

The country is prosperous, and the power facilities have attracted a skilled class of artisans. The principal industries are the manufacture of paper and woolen goods. The railroad facilities are very good.

Flow.—The flow of the river is fairly steady, because of the large storage area, which is partly natural and partly of artificial development. It is probable that the reservoir capacity has been developed to nearly its full extent. The approximate area of 35 ponds and reservoirs in the basin is 9,304 acres.

The principal ponds are Pontoosic Lake, Lanesboro, Mass., 313 acres; Onota Lake, Litchfield, Mass., 555 acres; Ashmere reservoir, Hinsdale, Mass., 310 acres; Washinee Lake, Salisbury, Conn., 400 acres; Washining Lake, Salisbury, Conn., 650 acres; Wononscopomus Lake, Salisbury, Conn., 355 acres; Quassapaug Pond, Middlebury, Conn., 535 acres; Bantam Lake, Litchfield, Conn., 1,070 acres; North Pond, Goshen, Conn., 300 acres.

There have been no gagings of the river extending over a period

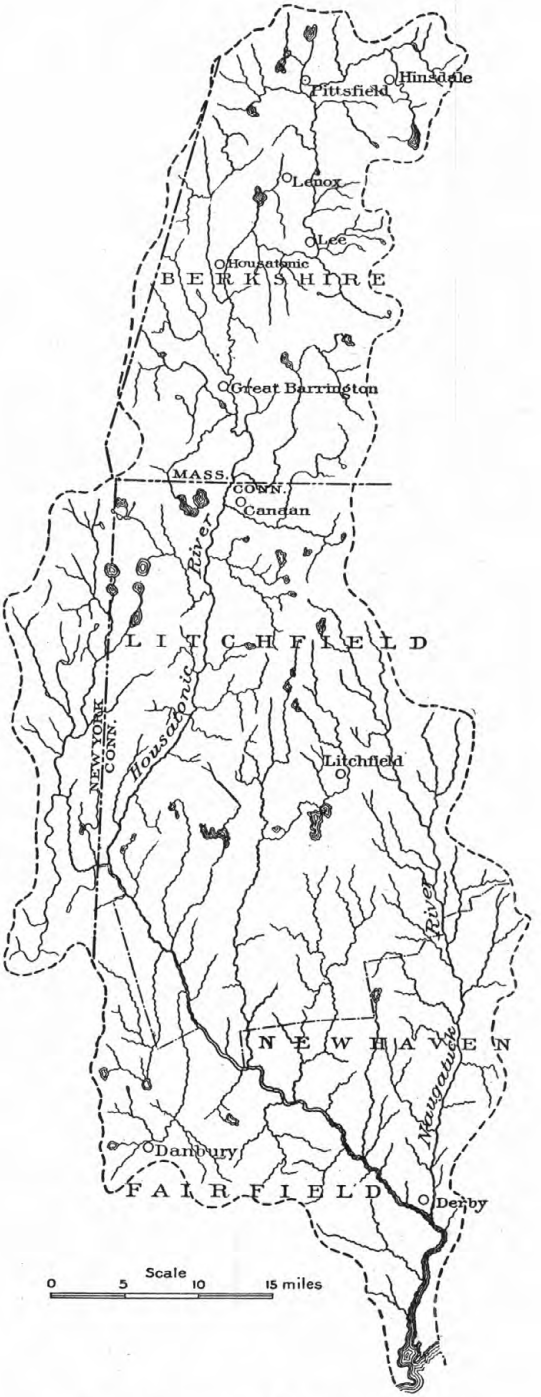

FIG. 11.—Housatonic River drainage basin.

sufficiently long to determine its flow with accuracy. In the year 1878 careful examinations were made from May to November at Kent, by the water department of New York, and the results probably show fairly well the summer flow of the river. According to these gagings the minimum flow for twenty-four hours was 260 cubic feet per second, while the average flow for the same period amounted to 460 cubic feet per second.

Water power.—After what has already been stated it is hardly necessary to say that the river may be valuable as a source of power. The total utilized horsepower on the whole system is about 18,884. In the main river the utilized horsepower is 6,434, and the remainder is distributed among the tributaries as follows: Naugatuck River, 4,909; Mad River, 1,220; Pomperaug River, 361; Shepaug River, 695; all other tributaries, 5,265.

The details of the power system are well set forth in the Tenth Census Report on Water Power, Vol. XVI.

NORMAL WATER IN THE HOUSATONIC BASIN.

The limestone formations in the Housatonic Basin make the water hard. In other respects the normal Housatonic water does not materially differ from that in the Connecticut Basin. The normal chlorine for this region varies from about 0.8 part per million at the upper end of the area to 3 parts near the mouth of the river.

The following table of analyses represents the averages of the results of various examinations of water made during the past decade.

TABLE 68.—*Analyses of various normal waters in the Housatonic drainage area.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
East Branch of Housatonic above Hinsdale.	Slight	2.0	0.138	0.036	0.001	0.180	0.8	54.0	----
Lake Oneota, Pittsfield	Very slight	0	.158	.000	.000	.030	.3	66.0	----
Pontoosuc Lake, Pittsfield.	do	0	.128	.006	.000	.000	.4	79.0	----
Egypt Brook, Dalton	do	2.9	.080	.002	.000	.196	.7	27.3	----
Green River, Great Barrington.	do	------	.028	.005	.000	.225	1.0	74.1	56
Hinsdale storage reservoir.	do	2.1	.202	.017	.000	.017	.7	20.7	1
Upper reservoir, Berkshire Water Co.	do	3.9	.303	.056	.000	.027	1.0	26.7	4
Millbrook reservoir, Pittsfield.	do	.1	.095	.011	.000	.057	.9	53.5	40
Lake Averic, Stockbridge.	do	.8	.181	.021	.000	.022	.8	62.0	40
Padaranium reservoir, Danbury.	do	.3	.162	.030	.003	.09	1.95	47.7	13
Kent reservoir	do	.1	.080	.008	.000	.12	1.56	64.5	30
North Canaan	do	.02	.030	.004	.001	.05	1.25	111.6	93
Farm Brook	do	.4	.105	.022	.001	.11	1.84	50.2	12

POLLUTION IN THE HOUSATONIC.

The population in the Housatonic Basin has increased rapidly during recent years, and the consequent pollution has become a matter of grave consideration.

The East Branch of the Housatonic receives pollution from the manufacturing villages of Hinsdale and Dalton, which have a population of 1,485 and 3,014, respectively. The report of the State Board of Health for 1890 gives analyses of water collected below these villages which show a considerable increase in the amount of organic matter present. A comparison of the analyses in Table 69 with the first analysis presented in Table 68 will clearly show indications of sewage pollution.

TABLE 69.—*Analyses of water from East Branch of the Housatonic above Pittsfield.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
1888.								
Sept. 7	Slight	2.0	0.238	0.092	0.008	0.180	1.9	112
Do	Distinct	2.0	.390	.092	.003	.200	2.0	117.5

Although these analyses were made in the year 1888, the conditions now existing in the river compare very closely to those found in the year of the analyses. The population in this part of the drainage area has not increased materially and the analyses therefore fairly represent existing conditions.

TABLE 70.—*Analyses of water from the East Branch of the Housatonic at Pittsfield.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
June 26	Slight	2.4	0.264	0.192	0.004	0.100	1.4	92.5	56
July 27	Decided	2.2	.416	.128	.006	.070	2.6	101.5	70
September 14	do	2.4	.244	.100	.009	.060	3.1	122.5	87
September 25	Very slight	2.2	.412	.168	.007	.100	3.0	126.5	91
October 23	Slight	3.0	.464	.196	.008	.120	3.9	135.5	97
November 20	Decided	4.0	.416	.060	.002	.190	2.4	98.5	63
December 18	Slight	2.1	.324	.106	.006	.310	2.3	106.5	79
Average		2.7	.369	.136	.006	.145	2.6	109.5	76

TABLE 71.—*Analyses of water from West Branch of the Housatonic at Pittsfield.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
June 26	Slight	1.5	0.268	0.084	0.001	0.010	1.5	76.5	46
July 27	do	.8	.216	.004	.000	.000	2.4	83.5	53
September 14	Decided	1.5	.432	.008	.000	.020	2.8	92.5	63
September 25	do	2.0	.452	.012	.002	.010	3.2	104.0	63
October 23	do		3.260	.970	.000	.010	15.6	458.0	89
November 20	do	2.1	.410	.080	.003	.060	2.2	102.0	60
December 18	do	.8	.328	.140	.019	.090	1.8	103.5	79
Average		1.4	.821	.209	.031	.031	4.4	155.3	65

TABLE 72.—*Analyses of water from Southwest Branch of the Housatonic at Pittsfield.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
June 26	Slight	0.9	0.376	0.372	0.016	0.040	2.3	96.5	61
July 27	do	1.4	.210	.100	.004	.060	1.2	137.5	103
September 14	Decided	1.3	.434	.064	.012	.020	1.8	154.0	96
September 25	do	1.2	.440	.092	.005	.010	2.5	144.0	94
October 23	do	1.5	.364	.304	.007	.080	2.6	180.5	123
November 20	do	2.0	.284	.180	.006	.340	2.3	180.0	126
December 18	None	.8	.072	.036	.002	.420	1.8	116.5	97
Average		1.3	.291	.166	.007	.159	2.0	144.3	101

The analyses set forth in Tables 70, 71, and 72 represent the character of the water furnished to the Housatonic River. It will be seen that every branch which contributes to form the main artery at Pittsfield is highly polluted, and therefore the Housatonic at the very outset is a badly damaged stream. The West Branch seems to be in the foulest condition, the East Branch closely following. Nearly all

the pollution in the West and Southwest branches is furnished by the city of Pittsfield. The upper reaches of these two streams remain in excellent condition.

Pittsfield, a city of 21,766 inhabitants, has a public water supply and a system of sewerage which empties into the three branches of the river. During the period in which the analyses in Tables 70, 71, and 72 were made a sewage-purification system for the city of Pittsfield was in course of construction, and when this is put into operation a large part of the sewage which now enters the river will be no longer a source of pollution.

Passing down the river we find that the next available analyses of Housatonic River water were made from samples taken at New Lenox, a point about 4 miles below Pittsfield. The drainage area of the river at this point is 145.6 square miles, the population being about 177 per square mile. The following table comprises the average result of monthly examinations of the water at this point since the year 1894:

TABLE 73.—*Analyses of water from Housatonic River at New Lenox.*

[Parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1894	2.7	0.183	0.131	0.024	0.204	2.5	131.7	85
1895	2.6	.238	.183	.038	.173	2.5	117.3	84
1896	2.6	.192	.169	.036	.208	2.2	118.8	86
1897	3.2	.240	.159	.008	.203	1.9	107.9	75
1898	2.7	.223	.106	.008	.178	1.5	94.0	64
1899	2.0	.233	.197	.017	.132	2.3	107.6	74
1900	2.2	.278	.378	.018	.118	2.8	111.7	72

Comparison of Table 73 with the three preceding tables shows that very little change has taken place in the amount and character of the organic matter in the river after it has traversed the 4 miles above mentioned. The water seems to be fairly loaded with polluting material in every state of oxidation, and there seems to be extremely rapid decomposition going on. There is nothing of an unusual nature in the above series. They present and clearly indicate an abundant pollution, which, as we have seen, is borne out by facts.

Leaving New Lenox the river flows south past the town of Lenox, which has a population of 2,942. At this place there is a sewerage system, but it is provided with a disposal plant, so that the river does not receive a large increment of pollution. A few miles farther down

the river runs through the town of Lee, which contains 3,956 inhabitants. Considerable polluting matter is poured in at this point. Shortly below Lee the river makes a sharp turn eastward and flows through Stockbridge, a town which has a population of 2,031. A sewerage system is maintained at this point and filter beds have been provided, so that extensive pollution of the river is avoided.

TABLE 74.—*Analyses of water from Housatonic River at Stockbridge.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
June 26	Very slight	1.1	0.312	0.284	0.016	0.070	2.9	120.5	96
July 31	do	.8	.198	.174	.014	.100	2.6	171.0	83
August 27	Decided	1.5	.240	.208	.026	.022	3.3	136.0	93
September 26	Very slight	1.2	.192	.072	.012	.110	3.9	135.0	103
October 23	do	1.5	.236	.228	.018	.220	4.4	166.5	117
November 21	Decided	3.5	.380	.208	.007	.210	3.7	123.5	86
Average		1.6	.260	.195	.005	.152	3.5	133.1	96

After leaving Stockbridge the river again turns south and flows through the town of Great Barrington which has a population of 5,854 and which contributes a large amount of pollution.

The next series of analyses made by the Massachusetts State Board of Health is of the water from the river at Sheffield, just north of the Connecticut State line. There seems to be considerable improvement in the water at this point over that at Stockbridge. The average of the six analyses of the water from the river made during the year 1900 is set forth in the following table:

TABLE 75.—*Average of six analyses of water from Housatonic River at Sheffield.*

[Parts per million.]

Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Number of samples.
	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
1.6	0.214	0.079	0.004	1.93	2.8	128.2	90	6

The above average of analyses clearly indicates a fairly large degree of purification over that shown in Table 74. It will be seen that while the color and residue are practically the same, the free and albuminoid ammonia and the nitrites are considerably less, while the nitrates are higher—an unmistakable indication of oxidation. The chlorine, too, seems to be in smaller proportion, the river having been largely diluted by the influx of pure water.

Passing over into the State of Connecticut the Housatonic runs by or through the towns of Salisbury and North Canaan, where the population is almost entirely rural, although these places are rather thickly settled.

At Falls Village, a few miles south of the Massachusetts border, the Board of Health of the State of Connecticut has during the year 1900 been securing samples of water for analysis the results of which are set forth in the following table:

TABLE 76.—*Analyses of water from Housatonic River at Falls Village, Conn.*

[Parts per million.]

Date of examination.	Turbidity.	Color	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
January 26	Slight	0.3	0.192	0.044	0.002	0.15	1.7	79.0	60
February 22	Distinct	.2	.102	.042	.002	.10	1.9	86.0	70
March 21	Very slight	.3	.170	.018	.004	.15	1.6	69.0	35
April 30	None	.2	.082	.046	.002	.05	1.8	67.0	75
May 17	Slight	.3	.188	.070	.008	.05	2.0	62.5	60
June 11	do	.2	.174	.090	.001	.10	2.1	111.0	90
July 5	None	.2	.112	.028	.003	.10	2.7	125.0	70
August 14	Slight	.1	.118	.024	.002	.18	2.9	131.0	63
September 12	do	.3	.207	.026	.004	.13	2.1	115.0	55
October 10	do	.2	.100	.020	.002	.13	4.0	145.5	68
November 13	do	.4	.148	.012	.002	.22	3.3	139.5	53
December 10	do	.4	.146	.034	.006	.20	1.6	106.0	59
Average		.3	.150	.038	.003	.13	2.3	103.0	63

Comparison of the above series with that made of the water at Sheffield, Mass., shows a still further purification. In some respects the water at Falls Village is considerably better than at any point since it received its first contamination at Pittsfield. One can not fail to be impressed with the fact that the Housatonic has excellent

powers of recovery, and it is very likely that if the sewage of the various towns along its banks is submitted to proper treatment the river will approach nearly its normal purity.

The State Board of Health of Connecticut has conducted another series of analyses of the water at a point 65 miles below the town of Falls Village, at the town of Derby, just below where the Naugatuck joins the river. In passing from Falls Village to Derby the Housatonic goes by the towns of Sharon, Cornwall, Kent, New Milford, Bridgewater, Brookfield, Roxbury, Southbury, Oxford, Newton, Monroe, Seymour, and Huntington. All these municipalities contain from 1,000 to 3,000 inhabitants, and contribute an amount of contaminations usual in such cases. In addition to these towns there is the city of Danbury, with a population of 16,000, which contributes raw sewage in large amount. In spite of this additional pollution, however, the analysis made at Derby shows very little change in the character of the water.

TABLE 77.—*Analyses of water from Housatonic River at Derby.*

[Parts per million.]

Date of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.								
January 29	0.3	0.122	0.052	0.002	0.10	2.3	79.0	60
February 21	.3	.108	.040	.002	.10	2.1	60.0	40
March 21	.3	.128	.050	.040	.15	1.9	51.5	27
April 26	.3	.124	.036	.002	.05	2.3	75.5	45
May 17	.3	.108	.060	.006	.15	1.9	80.5	70
June 11	.3	.100	.078	.002	.15	2.3	99.0	80
July 5	.2	.144	.050	.002	.05	2.4	108.5	70
August 24	.2	.140	.040	.000	.10	2.3	115.5	57
September 11	.2	,144	.026	.060	.05	2.8	116.5	91
October 10	.1	.144	.036	.001	.10	3.6	116.0	58
November 4	.5	.188	.016	.004	.19	3.5	113.5	36
December 10	.4	.168	.006	.006	.20	1.9	82.5	43
Average	.3	.136	.042	.008	.13	2.44	91.5	56

Below Derby the Housatonic receives the polluted water of its principal tributary, the Naugatuck, and flows thence into Long Island Sound. We have now traced the river from its source in Massachusetts to its mouth, and have found that from its headwaters it is

polluted to a sufficient extent to entirely unfit it for a source of water supply unless the water is filtered. This, however, is about as far as damage extends. Although considerable sewage enters the river at different points, such is the dilution and such the purifying capacity that it does not, except at a few points, betray its contamination, except by chemical analyses. As it crosses from Massachusetts into Connecticut it is in a condition which makes its use by the people of Connecticut as a source of water supply impossible without filtration. It is probable that the Housatonic River will in the future be constantly improved by the removal of sewage contamination through the establishment of purification works at the various points of pollution.

COURT DECISIONS IN CONNECTICUT.

The opinion of the supreme court of errors of the State of Connecticut in a suit at law against the city of New Britain, arising from the pollution of a watercourse, has already been cited. The courts of Connecticut have taken no uncertain stand on the question of river pollution. In no other State in the Union has there been such unequivocal judicial disapproval of the practice of destroying water resources, and as future work along this line will probably result in frequent reference to the Connecticut cases it seems wise to review briefly the different decisions which have been rendered.

The case of Morgan *v.* The City of Danbury is of interest, inasmuch as it involves a decision against a city which had provided a purification plant for the disposal of sewage. The plaintiff, a riparian owner and a mill proprietor on Still River, complained in the superior court that the defendant, without making him any compensation or attempting to acquire any of his rights, did discharge and was continuing to discharge into that river wastes, sewage, and other noxious substances, and prayed for an injunction against the continuance of that practice.

Danbury is a city of 20,000 inhabitants, situated on Still River, a small sluggish stream which empties into the Housatonic 16 miles below. In 1885 a system of sewerage was constructed which emptied directly into Still River. By the year 1890 the use of the sewers had increased to such an extent as to cause a local nuisance. In 1893 an outfall sewer was completed which conducted the sewage 1 mile below the city. During the summer seasons Still River has scarcely any flow, and the Woolf disinfecting system was installed in 1894, for use during the dry stages of the river. It consisted of large vats of brine, from which a solution known as hyperchloride of sodium was developed by electric currents.

An injunction was granted against further discharge of sewage. An appeal was taken.

The case was reviewed by the supreme court of errors in the January term in the third judicial district, 1896, and following are

extracts of the opinion of the court handed down by Associate Justice Baldwin (67 Conn., 484):

The complaint alleged that the city was discharging waste matter, sewage, and other noxious, corrupt, and impure substances from its sewers so as to pollute the river and to cause much of such discharges to be deposited on the plaintiff's land and mill privilege; and that thereby he had been largely deprived of the use of a valuable mill and mill privilege, he and his workmen injuriously exposed to noxious odors, the air in the neighborhood corrupted and poisoned so as to endanger the health of himself and others, his milldam partly filled up with filth, the value of his property greatly diminished, and he disabled from disposing of his land for building purposes. * * *

These allegations were denied, but have been found true; and there is nothing inconsistent with their truth in the special finding of facts. * * * It was proper that an injunction should be so framed as to protect the plaintiff against every serious and irreparable injury which he might suffer by the continuance of the nuisance, and its terms are fully conformable to the claims stated in his complaint.

* * * The supplemental answer, setting up the establishment of the Woolf disinfecting plant, avers that the discharges from the sewer have thereby been rendered "entirely harmless and free from any offensive qualities, and no solid matter is permitted to empty from said sewer into said stream, but the same is liquefied and clarified and the plaintiff is relieved thereby of all danger in the future from the said sewer." * * * These allegations were denied, and the issues upon them have been found for the plaintiff.

* * * It is not impossible that fluids discharged from the sewer, although colorless, sterilized, and apparently innoxious, may yet be such as, by combination with other substances found in the river, to become the occasion of decomposition and consequent pollution. * * *

The defendant urges that it should not be made responsible for the acts of others, and that if its sewage is thoroughly disinfected, sterilized, and purified before its discharge into the river, nothing further should be required, even though, as it flows down the stream, it may be brought into contact with other substances in such a way as to work a nuisance. But the right to deposit a thing in any place must always be dependent, not only on its own nature but on the nature of the place in question and the uses to which that has already been put.

In a similar suit brought by Platt Bros. & Co., to restrain the city of Waterbury from polluting Naugatuck River above the complainant's mill, the superior court rendered judgment for $500, and an injunction was issued. Appeal was made by the State to the supreme court of errors, and a decision was handed down January 4, 1900, by Associate Justice Hammersley. This opinion deals so clearly and admirably with that oft-repeated contention of municipal authorities that a city is not liable for damages because of sewage, if it has been authorized to turn the same into a stream by an act of the legislature, that a large part of the decision will be given here (72 Conn., 531):

The main contention of the defendant may be stated in this way: The use of the sewers, under authority of the legislature, in the manner described, is a public, governmental use; the injuries to the plaintiffs result from this governmental use and are not direct but merely consequential; the victim of consequential injuries resulting from a governmental use is entitled to no remedy unless one is given by statute; the defendant's charter provides no remedy for consequential injuries

resulting from the use of said sewers; ergo, the plaintiff has no remedy, and its damage is damnum absque injuria.

The premises essential to this conclusion are untrue. A governmental use may include any act which the State may lawfully perform or authorize. There are, however, governmental acts to which certain immunities attach; and it is with this restricted meaning that the phrase is used by the defendant. In this sense a governmental act is one done in pursuance of some duty imposed by the State on a person, individual or corporate, which duty is one pertaining to the administration of government, and is imposed as an absolute obligation on a person who receives no profit or advantage peculiar to himself from its execution. It is the State, exercising its governmental power through an agent who, in this matter, is the agent of the State and nothing more. It is to be distinguished from a large class of governmental acts which the State, by way of grant or special privilege, authorizes persons to perform in part for their personal benefit. The principal immunities belonging to a governmental act, in this restricted sense, are: (1) Freedom from personal responsibility for the consequences of the act done. So long as a lawful mandate of the State is faithfully executed, the agent acting within the scope of that authority enjoys the exemption from suit which belongs the State. (2) Freedom from personal responsibility for the negligence of his servants. The rule of respondeat superior does not apply, because the agent of the State is not the superior; the real superior is the State itself.

The defendant claims these immunities. It may be doubted whether the use of sewers under the charter of the defendant, for the collection and disposition of refuse belonging to its citizens, is a governmental act within the definition given. The charter authorized the construction of sewers for that purpose, but no absolute duty was imposed upon the city; action in pursuance of the authority was at its option and could not have been enforced by any process of law without further legislation. While sewers or drains for the disposition of surface waters collecting in highways may be considered as mere adjuncts of a highway, partaking of its nature as a governmental use (Cone *v.* Hartford, 28 Conn., 363, 372), it is different with sewers for the disposition of refuse and filth accumulated upon private property. The disposition of such stuff is in part for the benefit of the property holder. The city represents, in such respects, the interests of its inhabitants, and is granted certain special powers, in part for the promotion of their interests (Bronson *v.* Wallingford, 54 Conn., 513, 519). It is well settled that there is a clear distinction between those governmental duties imposed upon a city as a mere agent of government and those governmental powers granted as a privilege primarily for the personal benefit of its inhabitants. * * * We think it evident that the mere granting authority to a city to construct, for the convenience and benefit of its inhabitants, sewers adapted to carry off their refuse matter to some neighboring stream, does not necessarily make such use of the sewers a governmental use in the sense indicated. * * *

But if, for the purpose of this case, we concede the defendant's claim that the use is a governmental use, it is nevertheless liable to the plaintiff. The injury described by the complaint is not a mere consequential damage, like that resulting wholly from the lawful use of one's own property, or the lawful exercise of governmental power; it is a direct appropriation of well recognized property rights within the guarantee of the Constitution—"The property of no person shall be taken for public use without just compensation therefor" (Nolan *v.* New Britain, supra, p. 681), and so the defendant's claim that its charter does not authorize the condemnation of the plaintiff's property rights is immaterial. Upon a careful examination of the charter as enacted in 1871 (7 Special Acts, 206) and amended in 1881 (9 id., 233 et seq., 237), in 1883 (9 id., 839), and in 1884 (9 id., 954), and applying the rule which requires a law to be so construed, if reasonably possible, as to

give it validity, we think the city is authorized to make compensation by agreement or after appraisal, for any private property taken for the purpose of the maintenance and use of the sewers authorized. But if it were otherwise, the defendant would not be benefited. Its whole defense of acting under lawful State authority would then fail, and the mere finding of the facts alleged in the complaint would clearly support the judgment.

The defendant's brief presents its claim in a form somewhat different from that stated in the finding, and certainly novel in this State. It is substantially this: (1) A riparian city has a right to use the river for certain drainage, and such surface drainage necessarily pollutes the water to some extent, increasing with the growth of the city. (2) The use of these legitimate drains to carry off the noxious refuse accumulated by its inhabitants becomes in time an absolute necessity. (3) The right of surface drainage is thereby enlarged so as to include the right to discharge into the river, by means of these drains, such noxious refuse. Therefore the necessities of municipal growth give the city a right to convey these noxious substances to the property of downstream proprietors, and so to appropriate that property for public use without compensation.

It is unnecessary now to discuss the limitations to the right of surface drainage, for the second and third propositions are clearly wrong. The right to pour into the river surface drainage does not include the right to mix with that drainage noxious substances in such quantities that the river can not dilute them nor safely carry them off without injury to the property of others. The latter act is, in effect, an appropriation of the bed of the river as an open sewer, and the proposition that it may become lawful by reason of necessity is inconsistent with undoubted axioms of jurisprudence. The appropriation of the river to carry such substances to the property of another is an invasion of his right of property. When done for a private purpose it is an unjustifiable wrong. When done for a public purpose it may become justifiable, but only upon payment of compensation for the property thus taken. Public necessity may justify the taking, but can not justify the taking without compensation. It may be necessary for a city to thus mix with its drainage such substances, but it is not necessary to pour such mixture into the river without purification; indeed, the purification is coming to be recognized as a necessity. But however great the necessity may be, it can have no effect on the right to compensation for property taken. The mandate of the Constitution is intended to express a universally accepted principle of justice, and should receive a construction in accordance with that principle, broad enough to enable the court to protect every person in the rights of property thus secured by fundamental law.

There are certain apparent, but not real, exceptions to this protection. Emergencies may be such as to justify the taking of property without waiting to provide for compensation; property may be destroyed without compensation in certain cases when used unlawfully, or when it has become a thing of danger. But this is not a case of war or conflagration. The plaintiff has not so used its property as to subject it to the harsh police power of confiscation. The plaintiff has certain rights as a riparian landowner. These rights are property within the meaning of our constitutional guaranty, and an invasion of these rights such as the defendant has made is a taking of that property. The legislature has no power to authorize such taking except for public use, and then only upon providing for just compensation. (Kellogg *v.* New Britain, 62 Conn., 232, 239; Wadsworth *v.* Tillotson, 15 id., 366, 373; Harding *v.* Stamford Water Co., 41 id., 87, 93; Nolan *v.* New Britain, 69 id., 668, 681; Fisk *v.* Hartford, 70 Conn., 720, 731; Seifert *v.* Brooklyn, 101 N. Y., 136; Chapman *v.* Rochester, 110 id., 273, 277.)

An action for fouling a brook and mill privilege by the discharge of sewage, with a claim for damages and an injunction against the town of New Milford, was brought by Joseph E. Watson et ux. in the

superior court in Litchfield County, and on trial by the court (Shumway, J.) an injunction was refused and judgment was rendered for the plaintiff for $50 damages. An appeal was taken by the defendant for alleged errors in the rulings of the court. No error.

The finding stated these facts:

The plaintiffs' land is situated on Great Brook, in New Milford. There are no buildings on it. To use it for buildings would require some previous filling on a part of it. It has been used for pasturage, and partly for cultivation, but yields now little income. The annual rental value is $75, and has not been substantially affected by the fouling of the brook. The court, at the request of the parties, viewed the premises, in the summer, when the water was low, and saw on the margin of the brook a sediment giving off odors of putrefying sewage, unwholesome and offensive, and also undissolved constituents of house sewage lying on the ground, offensive to the sight. At times of high water such conditions would not exist.

Since 1876 the sewage from the town hall had been discharged through a drain constructed by a village improvement association into Great Brook above the plaintiffs' land. In 1893 all the school districts in the town were consolidated, and the town took charge of the public schoolhouses then erected. One of these then discharged its sewage into Great Brook, and has ever since.

The plaintiffs lived seven miles from their land in question. The waters of the brook, where it runs through it, are potable by cattle, and there are trout in it. This water privilege has no value in its present condition.

In 1893 the defendant extended certain sewers through the plaintiffs' land and into the brook thereon, and has since maintained the same. These serve to carry off the surface water from the streets, and also house sewage. Various houses have been connected with them for the discharge of their sewage into them, with the knowledge of the selectmen.

The town, by its use of the brook as a means of getting rid of the sewage from the town hall and schoolhouse, has, in connection with its use by citizens for carrying off sewage from their houses, caused the state of things viewed by the court. The damage thus caused is not irreparable, but an injunction would be a proper remedy to prevent multiplicity of suits, should the town continue such use of the plaintiffs' premises for an unreasonable length of time hereafter. It was not found that the nuisance had prevented them from effecting a sale of the property.

The case was reviewed by the supreme court of errors in the January term, in the first judicial district, 1900, and the following extract is from the decision handed down January 19, 1900, by Associate Justice Baldwin (72 Conn., 561):

A nuisance was created upon the plaintiffs' land by the deposit of sewage and sediment from sewage, offensive from its appearance or its smell. The use of the sewers which receive the surface drainage from highways, and of that built by the village improvement association, by the defendant, to carry off the sewage from its public buildings, contributed to this injury. That others also contributed to it, and perhaps more largely, did not relieve the town from liability. (Morgan *v.* Danbury, 67 Conn., 484, 496.)

That the plaintiffs suffered no personal inconvenience from the nuisance, because they did not reside in the vicinity, is immaterial. They were entitled to nominal damages, at least, for the offensive condition of things upon their land, even if they never visited it, and although its rental and selling value remained unimpaired. (Watson *v.* New Milford Water Co., 71 Conn., 442.) If those assessed

can be regarded as substantial, they are still so small in amount that no new trial should be granted for their reduction. (Buddington *v.* Knowles, 30 Conn., 26; Holbrook *v.* Bentley, 32 id., 502, 508.)

The action was well brought against the defendant as a town, and not as a consolidated school district. It is a single corporation, and the consolidation simply threw upon it additional powers and duties. It maintained as a town a nuisance previously created by a district.

That the plaintiffs in prior years had discharged sewage and dyes from a hat shop on their premises into the brook did not bar their right of recovery. If they had thus fouled the brook to the injury of landowners below them, it did not operate as a license to landowners above them to use it in a similar way.

That the water remained potable by cattle and inhabitable by fish was unimportant except in mitigation of damages.

DELAWARE RIVER.

The Delaware drainage area occupies parts of the States of New York, New Jersey, and Pennsylvania, comprising 6,855 square miles. (See fig. 12.) The main river of the Delaware system rises in New York State, in a county bordering the western part of the Catskill Mountains. The elevation at that point is said to be about 1,900 feet. It flows in a very irregular course, its general direction being southward, and empties into Delaware Bay. For about 100 miles above Port Jervis it forms the boundary between the States of New York and Pennsylvania; below that point it forms the entire western boundary of the State of New Jersey.

The principal tributaries of Delaware River enter from the west. They consist of the Schuylkill, which joins the main stream at Philadelphia, draining a country 1,912 square miles in extent; and, a little farther north, the Lehigh, at Easton, the basin of which, 1,332 square miles in extent, comprises a great mining region of Pennsylvania. The Lackawaxen River enters at Lackawaxen, draining in its course 597 square miles. At the extreme northwestern part of the Delaware basin the river forks into the East and West branches, which drain 520 and 348 square miles, respectively.

Although the drainage basin of the Delaware is a very important, prosperous, and thickly-settled region, the resources of the river system have not been utilized or appreciated to any considerable extent, and comparatively little has been done to determine the character of the water. At Philadelphia the city is now conducting extensive investigations, which, when their results become available, will furnish a clear insight into the character of the water in the Schuylkill and Delaware opposite that city. Aside from these investigations, the results of which can not be learned at present, the only data available are comprised in a short report, by Mr. Allen Hazen, on the character of the water supply of the city of Trenton, N. J., which demonstrated beyond controversy that the water of the Delaware above the city of Trenton is polluted with sewage and industrial refuse to a dangerous degree.

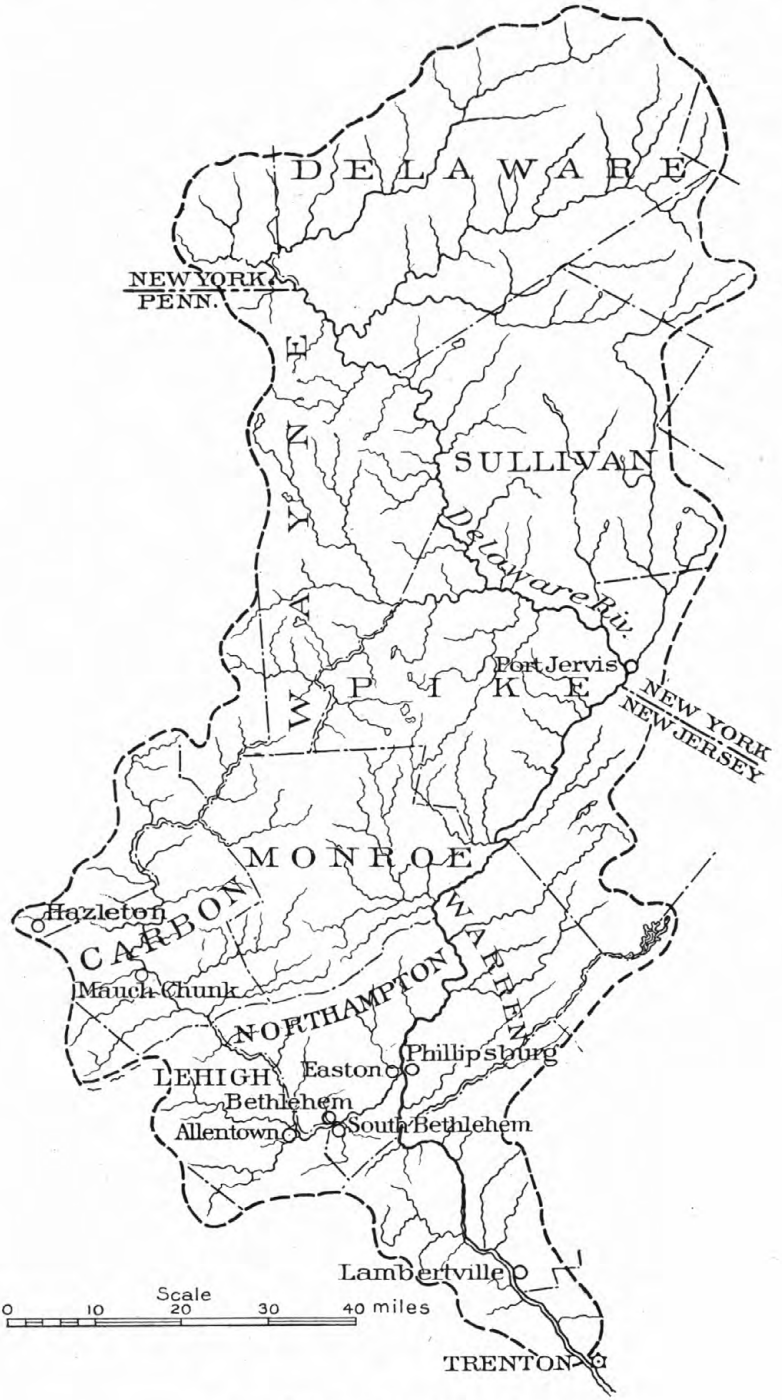

FIG. 12.—Delaware River drainage basin.

The following table, taken largely from Mr. Hazen's report, gives the names of the municipalities in the Delaware Basin above Trenton contributing polluting substances to the river:

TABLE 78.—*Cities and towns above Trenton contributing polluting substances to Delaware River.*

[Drainage area, 6,916 square miles.]

City or town.	County.	Distance above Trenton.	Population, 1900.
		Miles.	
Lambertville, N. J	Hunterdon	14	4,637
Newhope, Pa	Bucks	14	1,218
Frenchtown, N. J	Hunterdon	30	1,020
Quakertown, Pa	Bucks	42	3,014
Phillipsburg, N. J	Warren	47	10,052
South Easton, Pa	Northampton	48	25,238
Easton, Pa	do	48	
Bangor, Pa	do	56	4,106
Nazareth, Pa	do	58	2,304
Bethlehem, Pa	do	59	7,293
South Bethlehem, Pa	do	59	13,241
West Bethlehem, Pa	Lehigh	60	3,465
Washington, N. J	Warren	60	3,580
Belvidere, N. J	do	62	1,784
Allentown, Pa	Lehigh	64	35,416
Penn Argyl, Pa	Northampton	65	2,784
Catasauqua, Pa	Lehigh	67	3,963
Oxford, N. J	Warren	71	3,095
East Stroudsburg, Pa	Monroe	71	2,648
Slatington, Pa	Lehigh	79	3,773
Stroudsburg, Pa	Monroe	81	3,450
Lehighton, Pa	Carbon	90	4,629
East Mauchchunk, Pa	do	93	3,458
Mauchchunk, Pa	do	93	4,029
Summithill, Pa	do	95	2,986
Nesquehoning, Pa	do	98	2,862
Waverly, Pa	do	100	2,471
Newton, N. J	Sussex	105	4,376
Whitehaven, Pa	Luzerne	115	1,517
Hazleton, Pa	do	115	14,230
Port Jervis, N. Y	Orange	120	9,385
Hawley, Pa	Wayne	157	1,925
Honesdale, Pa	do	166	2,864

TABLE 78.—*Cities and towns above Trenton contributing polluting substances to Delaware River*—Continued.

City or town.	County.	Distance above Trenton.	Population, 1900.
		Miles.	
Hancock, N. Y	Delaware	194	1,883
Deposit, N. Y	do	205	2,051
Walton, N. Y	do	228	2,811
Delhi, N. Y	do	245	2,078

Although only a few of the municipalities mentioned in the above table have been provided with sewers, and the pollution is therefore in an early stage of its development, the effects are noticeable in the following analyses, which were made during the period of Mr. Hazen's investigation:

TABLE 79.—*Analyses of water from Delaware River at Trenton.*

[Parts per million.]

Date.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Iron.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Apr. 16	3	0.15	0.060	0.004	0.000	0.260	1.7	44.50	23.0	6.0	0.30
June 29	680	.18	.350	.040	.004	.160	1.6	480.00	27.0	8.0	11.80
July 6	7	.12	.088	.042	.003	.320	2.2	93.00	42.0	9.5	.05
July 27	480	.12	.226	.086	.004	.160	2.0	273.00	27.0	9.5	8.00
Aug. 17	3	.11	.102	.018	.006	.160	2.8	116.00	57.0	7.5	.20
Sept. 13	8	.08	.116	.024	.004	.160	3.0	103.00	57.5	14.0	.30

The investigation included a daily determination of turbidity from April to November, inclusive, in the year 1889, the results of which show that the Delaware water is usually free from suspended matter, and that, although it carries along considerable mud during freshets, subsidence is rapid.

TABLE 80.—*Turbidity of Delaware River at Trenton.*

Day of month.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1	------	6	6	9	13	6	6	6
2	------	6	6	9	13	6	6	6
3	------	6	9	6	9	6	6	6
4	------	6	9	6	13	6	6	6
5	------	6	9	6	6	6	6	6
6	------	6	9	6	6	6	6	6
7	------	6	9	6	6	6	6	6
8	------	6	6	28	6	6	6	6
9	6	6	6	13	6	6	44	13
10	6	6	6	9	6	6	6	9
11	6	6	6	6	6	6	6	6
12	6	6	6	6	6	6	6	6
13	6	6	6	6	6	6	6	6
14	6	6	6	6	16	6	400	6
15	6	6	77	6	6	6	100	6
16	6	6	77	6	6	150	56	6
17	6	6	32	6	6	32	13	6
18	6	6	32	6	6	20	6	6
19	32	2,737	28	6	6	13	6	6
20	28	28	16	6	6	9	6	6
21	16	28	9	6	6	9	6	6
22	16	28	6	6	6	6	6	6
23	16	24	6	6	6	6	6	6
24	16	24	6	6	6	6	6	6
25	13	9	6	6	6	6	6	6
26	13	9	6	28	6	6	6	------
27	13	9	6	77	6	6	6	------
28	9	9	236	56	6	6	6	------
29	9	9	16	40	6	6	6	------
30	6	6	16	32	6	6	6	------
31	------	6	------	150	6	------	6	------

OHIO RIVER BASIN.

DRAINAGE AREA.

A clear and concise description of the drainage area of the Ohio River is given in the report of Prof. Dwight Porter, published in Volume XVII of the Report of the Tenth Census, as follows:

By the union of the Allegheny and Monongahela rivers at Pittsburg the Ohio River is formed, with a drainage basin at that point of between 18,000 and 19,000 square miles, which, after a course of nearly a thousand miles to the southwest,

is increased to about 214,000 square miles at the junction with the Mississippi. The principal streams which contribute to this increase are, on the north side, the Beaver, Muskingum, Scioto, Great Miami, and Wabash rivers, and on the south side the Little Kanawha, Great Kanawha, Big Sandy, Licking, Kentucky, Green, Cumberland, and Tennessee. The headwaters of the Allegheny are in northern Pennsylvania and southwestern New York; those of the Monongahela, nearly 250 miles distant, in West Virginia. The eastern watershed line of the Ohio therefore cuts directly across the State of Pennsylvania, at a distance from the western border ranging from 80 miles in the south to about 130 miles in the north. Passing out of this State, the northern boundary of the river basin runs through New York, Ohio, and Indiana, being carried in the latter State around the upper waters of the Wabash nearly to the Michigan line and considerably more than 200 miles north of the main river itself; it then enters Illinois and strikes southerly through that State to the mouth of the Ohio at Cairo. The southern boundary runs from Pennsylvania across a corner of Maryland, embraces nearly all of West Virginia, and forms in part the dividing line between that State and Virginia; it crosses the southwestern portion of the latter State and the western part of North Carolina, and by the Tennessee Basin is extended down into Georgia and Alabama, reaching there a distance of 300 miles south of the Ohio; it continues from Alabama across the adjacent northeastern corner of Mississippi, and finally traverses the extreme western portions of Tennessee and Kentucky.

The characters of the different streams within this area are determined or modified by the various topographic features of the country. In the east and southeast the drainage area is bordered by the Allegheny Mountains, and the streams which have their origin there flow into the Ohio through a generally sparsely settled country rich in mineral deposits. From this region across to Mississippi River the surface grows flatter, rapidly in some directions, more gradually in others. Toward the Ohio there is a gradual decline in elevation, culminating in the bottom lands along that river, which have become famous for their fertility. North of Ohio River the land comprising that portion of the basin lying within the States of Ohio and Indiana rises very slowly, through many miles of undulating territory, and ends in a low range of hills which forms the divide between the Ohio Basin and the drainage area of the Great Lakes.

The various tributaries on the south side of the Ohio offer facilities for extensive development of power. The descent of the streams is swift, especially in the southern portion, but the flow is extremely variable, the drainage areas being of the "quick-spilling" variety, and consequently enormous pondage would be necessary to secure any great measure of uniformity of flow. In the case of some streams this would make the initial cost of utilization extraordinary and prohibitive. On the north side of the Ohio the country is flat and the proportion of run-off is small, so that, as a whole, the streams are not well adapted for the development of power. It is true that there has been considerable utilization of streams for local grist and lumber mills, yet it is not at all proportional to the contributing drainage area as compared with that which is possible on the streams of New

York and New England. The Ohio is therefore in only a comparatively limited sense a power stream.

The main river has great value as a channel of transportation, and some of the tributaries are navigable to a limited extent. This value has been developed largely by the Federal Government.

CHARACTER OF WATER.

In considering the characteristics of the waters of the Ohio Basin one can not fail to be impressed with the marked differences which exist between them and the waters of the Northeastern States, already considered at length. In the latter region we have studied waters which are, as a rule, fairly clear, which contain only small amounts of dissolved mineral matter, and in which the degree of hardness is usually almost insignificant. We have noted that the New England waters are highly colored, some extremely so, from the solution of chlorophyll and decaying vegetable and peaty matter. This characteristic has led to the application to these waters of the apt and expressive term "vegetable tea." In considering the water in the Ohio Basin it is necessary to remember in the beginning that we have to deal with a water which usually contains a high proportion of inorganic salts, which is hard, and which in times of freshet carries along enormous quantities of fine clay and mud. A report of a water analysis which, in the case of a New England water, would be regarded as certain evidence of artificial pollution, may in the case of Ohio water represent a truly normal river of uncontaminated and healthful character.

The following analyses illustrate this point:

TABLE 81.—*Comparison of analyses of normal waters in New England and in the Ohio Basin.*

[Parts per million.]

	Region.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1	Massachusetts	Very slight.	6.6	0.199	0.013	0.000	0.037	1.7	34.7	8.0
2	Ohio Basin	do	4.0	.514	.062	.024	1.500	2.0	730.0	43.6

Sample No. 1 in the above series was a normal water taken from an upland stream in Massachusetts. It is a fair representative of Eastern waters, having some turbidity, a high color, and considerable organic matter, as is shown by the nitrogen compounds. Sample No. 2 was a normal water taken from an upland region in the Ohio Basin

above all points of contamination. It also is a good representative of waters of its class, having a moderate color, a large residue, and an extremely high content of nitrogen, especially in the form of nitrates. Note also that the water is very hard. From the standpoint of sewage pollution both of the above samples are equally good, each being uncontaminated. From the sanitary standpoint No. 2 is the equal of No. 1, and if these analyses faithfully represented the character of the streams from which these samples come the resources of one would be equal to those of the other, other things, of course, being equal.

Another point to be borne in mind is the extreme variability of the physical characteristics of the Ohio Basin waters, especially the turbidity. In a time of drought the water will be clear, but soon after a rainstorm the turbidity will rise to a point which almost defies clarification, but in the course of a few days the water will become as clear as it was before the storm.

ALLEGHENY RIVER.

GENERAL FEATURES.

Drainage area.—The Allegheny is the largest contributor to the Ohio. (See fig. 13.) The drainage area covers 11,400 square miles and lies principally in the State of Pennsylvania, extending for a short distance into the State of New York. The length of the stream is about 325 miles, and its basin embraces a large area of the western slope of the Allegheny Mountains. The country is rough and broken, with high summits and deep valleys.

Water power.—The Allegheny is not very valuable as a source of water power. The storage capacity in the drainage area is extremely small; and although in early times the large number of springs maintained a fairly constant flow, the deforestation has reduced the whole area to a "quick-spilling" country. Although the drainage area is large, only a small portion of it contains streams that are valuable for development of power. The river is peculiar in this respect, for the descent is more rapid in the middle and lower portions than it is at the headwaters. In those portions it is deep and is used extensively for transportation, but above the head of navigation it has little value. The power which has been developed is applied mainly to the lumber industry.

Flow.—The flow of the Allegheny has not been definitely determined, and the figures available to show it are not the result of as careful and long-continued measurement as is generally considered necessary for the accurate determination of flow.[a] Measurements made in 1897 under the direction of a corps connected with the War Department seem to show that the flow of the Allegheny at Franklin

[a] See Twentieth Annual Rept. U. S. Geol. Survey, Part IV, p. 195.

was about 1,000 second-feet, and at another point 20 miles below a discharge of 1,250 second-feet was determined. In the year 1838 the discharge of the Allegheny at Pittsburg was reported as being 1,330 second-feet, while various gagings during the years 1866–1870 showed

FIG. 13.—Allegheny River drainage basin.

that at Brunots Island, 2½ miles below the junction of the Allegheny and the Monongahela rivers, the least discharge was 1,700 second-feet.

POPULATION OF BASIN.

In the drainage basin of Allegheny River the population has increased rapidly. The following table includes the most important

cities and towns, their population in 1890 and 1900, and their approximate distance from the city of Pittsburg:

TABLE 82.—*Cities and towns on Allegheny River and tributaries above Pittsburg.*

Place.	Distance in miles.	Population.		Place.	Distance in miles.	Population.	
		1890.	1900.			1890.	1900.
Verona	3	1,477	1,904	Titusville	142	8,073	8,224
Oakmont	4	1,678	2,323	Meadville	144	9,520	10,291
New Kensington	11	.....	4,665	St. Marys	148	1,745	4,295
Tarentum	14	4,627	5,472	Johnsonburg	149	1,280	3,894
Freeport	21	1,637	1,754	Wilcox	151	.....	.....
Ford City	33	1,255	2,870	Tidioute	160	1,328	1,237
Apollo	35	2,156	2,924	Edinboro	161	1,107	691
Kittanning	38	3,095	3,902	Waterford	170	838	767
Saltsburg	47	1,088	828	Sheffield	172	2,202	2,580
Red Bank	57	2,035	1,961	Union	177	2,261	3,104
East Brady	62	1,228	1,233	Clarendon	180	1,279	1,092
Latrobe	64	3,589	4,614	Warren	181	4,332	8,043
Blairsville	65	3,126	3,386	Corry	195	5,677	5,369
Derry	72	1,968	2,347	Busti, N. Y	205	.....	.....
Parker	76	1,317	1,070	Jamestown, N. Y	210	16,038	22,892
New Bethlehem	77	1,026	1,269	Randolph, N. Y	212	1,201	1,209
Indiana	78	1,963	4,142	Salamanca, N. Y	222	3,692	4,251
Emlenton	82	1,126	1,190	Mayville, N. Y	227	1,164	943
Punxsutawney	85	2,792	4,375	Bradford	240	10,514	15,029
East Conemaugh	92	1,185	2,175	Olean, N. Y	241	7,358	9,462
Brookville	98	2,478	2,472	Cuba, N. Y	256	1,386	1,502
South Fork	99	1,295	2,635	Franklinville, N. Y	258	1,021	1,360
Clarion	100	2,164	2,004	Eldred	263	1,050	963
Ebensburg	112	1,202	1,574	Port Allegany	266	1,230	1,853
Reynoldsville	112	2,789	3,435	Smethport	267	1,150	1,704
Franklin	116	6,221	7,317	Coudersport	282	1,530	3,217
Du Bois	121	6,149	9,375				
Oil City	125	10,932	13,264				
Ridgway	140	1,903	3,515				

POLLUTION.

Inspection of the above table will show that although a great majority of the municipalities are small, and probably do not contribute a large amount of sewage or manufacturing wastes to the river, there are, nevertheless, many places that are probably sewered and that naturally pour their wastes into the river. There is no

record of any examination of the water of the Allegheny River except those made by the filtration commission of the city of Pittsburg.

The question of pollution has been considered in a report made by Prof. William T. Sedgwick to the Pittsburg commission, the conclusions of which were that the water is polluted to a degree which makes it unfit for use as a source of public supply in its raw state. This opinion is borne out by recent use of the water in Pittsburg. The records show that the typhoid fever rate is abnormal. Accordingly, the city of Pittsburg has investigated, and is even now preparing to introduce a system of filters, the total cost of which will not be far from $3,500,000, while the expense of maintenance is calculated in the report of Mr. Allen Hazen, consulting engineer, to be about $200,000 annually. This gives no idea of the damage done to the city of Pittsburg alone by sewage pollution. In a well-considered article published in the Pittsburg Dispatch April 21, 1902, it was estimated that the cost of treating typhoid fever and the value of the lives lost from that disease in the city of Pittsburg during the previous three years amounted to about $3,335,000, sufficient to pay interest upon and retire a bonded indebtedness of $13,000,000. These figures were charged to the account of typhoid fever alone, no estimate being made of the sickness and deaths arising from or induced by other water-borne diseases.

CHARACTER OF WATER.

Experiments were conducted during the years 1897–98, under the authority of the filtration commission, and throughout this period weekly chemical examinations were made of the water in the Allegheny River. These results are almost the only available ones which show the character of the water; and as the samples were taken a short distance above the city of Pittsburg, they show clearly what is being contributed to the Ohio system by this branch.

TABLE 83.—*Analyses of water of Allegheny River at Brilliant, above Pittsburg.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Iron.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1897.											
June	Decided	.....	0.137	0.006	0.000	0.175	24.0	141	.....	.....	.....
July	do	.....	.347	.034	.001	.106	31.3	269	60.8	.....	1.84
August	Slight	.....	.210	.023	.000	1.050	20.3	90	40.5	13.9	.07
September	do	3.7	.133	.019	.000	.650	27.0	131	46.3	4.0	.63
October	do	2.3	.120	.017	.000	.550	38.1	177	50.9	4.0	.40
November	do	2.9	.152	.019	.000	.700	31.5	197	35.1	3.8	.95
December	do	3.0	.111	.015	.000	1.075	21.1	237	17.2	5.2	1.23

TABLE 83.—*Analyses of water of Allegheny River at Brilliant, etc.*—Continued.

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Iron.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1898.											
January	Slight	2.8	.074	.016	.000	.885	15.3	153	14.8	6.1	1.12
February	do	2.1	.099	.020	.000	1.425	14.6	119	17.3	8.6	.59
March	Muddy	2.4	.076	.015	.000	.487	12.9	140	17.5	9.7	.40
April	Slight	2.2	.077	.018	.000	.458	13.6	94	18.3	4.6	.41
May	Decided	3.0	.164	.015	.000	1.80	16.6	207	21.3	6.7	.33
June	76	2.5	.085	.019	.000	.375	24.2	191	31.0	4.0	.10
July	361	2.7	.100	.027	.000	.694	24.7	131	34.1	11.7	.20
August	105	3.1	.130	.214	.000	.435	24.2	195	31.5	8.4	.20

A mineral analysis made of the samples from the river collected September, 1898, gave the following results:

TABLE 84.—*Mineral analysis of water from Allegheny River.*

[Parts per million.]

Total solids	127.0
Loss on ignition	43.0
Calcium oxide	20.4
Magnesium oxide	4.9
Sulphuric acid	16.1
Chlorine	22.0
Silica	1.0
Iron oxide	.1

The analyses set forth in Table 83 certainly do not necessarily indicate a water of dangerous qualities. Albuminoid and free ammonia and nitrites are low, and on the whole the analyses present an extremely favorable appearance. This, then, is one of the cases in which, as stated in the introduction to this work, little can be determined concerning the dangerous qualities of a river from chemical examinations alone. Inspection of the map shows that the centers of contamination above Pittsburg on the Allegheny River are far removed from that city, and the distances intervening seem sufficient to bring about all the purification apparent in the result of the analyses above set forth; yet, as pointed out by Professor Sedgwick in the report already referred to, the velocity of the Allegheny is high, being at times from 7 to 8 miles an hour. Under such circumstances pollution poured into the river at Oil City, for instance, would reach Pittsburg with fifteen hours, and at a slower rate of flow would certainly arrive within a few days, at least. Now, it can be easily understood that although organic matter may be oxidized and diluted to such an extent that it would appear in an analysis in small proportion only, germs of disease entering the river with such pollution could arrive

at the Pittsburg water "intake" in a virulent condition. Undoubtedly such has been the case during all the years in which Pittsburg has suffered abnormal typhoid-fever morbidity.

Coincident with the examinations above described, other points along the Allegheny were made use of for the collection of samples. A series was collected at Montrose, the intake for the water supply of the city of Allegheny, 4 miles above Brilliant, at Pittsburg. Another series was taken at Hulton, where the intake for the supply of Oakmont and Verona is situated, 6 miles above Brilliant, and a third at Wildwood, 1⅓ miles above Brilliant, whence the water is taken to supply Wilkinsburg and the First Ward of the city of Pittsburg. These examinations, however, did not show that the water was materially different from that at Brilliant, and, indeed, when the rapid flow of the river is taken into account, this might have been expected. There were, however, a number of examinations of samples of water taken at Etna, 2 miles below Brilliant, on the opposite side of the Allegheny, below a point where a certain amount of pollution is received from Pittsburg, and another series of examinations of samples taken at Millvale, 4 miles below Brilliant, also on the opposite side of the river. The average of these examinations for each point is given in Table 85. It will be seen that these do not differ materially from the samples taken at Brilliant, even though the water is undoubtedly contaminated by the addition of Pittsburg and Allegheny sewage. The reasons for this will be discussed presently.

TABLE 85.—*Analyses of water from Allegheny River at Etna and Millvale.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Iron.	Number of samples.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal.		
Etna	2.9	0.119	0.030	0.000	0.682	18.6	155	32.7	5.6	0.70	35
Millvale	3.1	.149	.045	0.000	.706	25.8	147	47.0	8.5	.38	16

MONONGAHELA RIVER.

Drainage basin.—Monongahela River, which joins the Allegheny at Pittsburg to form the Ohio, has a drainage area of 7,625 miles. (See fig. 14.) It rises in the northern part of West Virginia and flows in a northerly direction, draining a part of the western slope of the Allegheny Mountains, most of which has a rugged character and lacks fertility. The region, once heavily timbered, has been very thoroughly cleared, except at the headwaters of the streams. The lower reaches of the river are fertile and yield a large crop of corn, but the country seems to be especially adapted to grazing.

Flow.—The flow of the Monongahela has not been determined in a manner more satisfactory than that of the Allegheny. In the year 1838 the flow of the Monongahela at Brownsville, 50 miles above Pittsburg, was reported to be only about 230 second-feet. This, however, was in a dry season. The lower reaches of the river constitute a "slackwater" basin, with a flow of not more than 1 foot per minute.

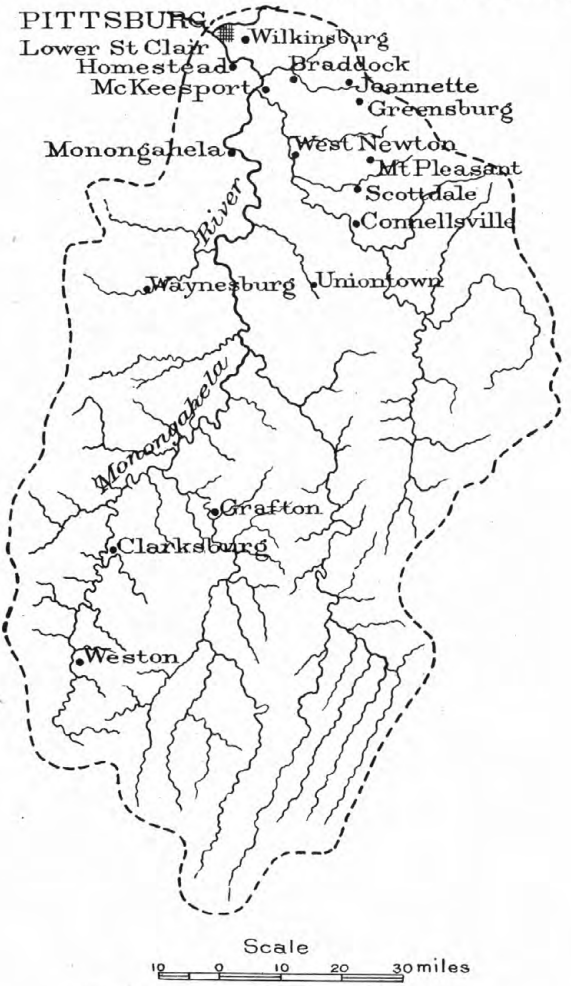

FIG. 14.—Monongahela River drainage basin.

Population of basin.—The population in the Monongahela Basin is denser than in the Allegheny, and there are larger cities, such as McKeesport, Homestead, Braddock, and Wilkinsburg, which are situated well down toward the mouth of the river. Therefore, the water which arrives at Pittsburg contains more recent pollution than that in the Allegheny. The important difference, however, lies in the fact that the flow of the Monongahela, as has been said, is slow, and there is the opportunity for sedimentation that arises in quiescent water.

TABLE 86.—*Cities and towns on Monongahela River and tributaries above Pittsburg.*

Place.	Distance in miles.	Population.	
		1890.	1900.
Lower St. Clair	3	3,680	4,638
Homestead	6	7,911	12,554
Braddock	9	8,561	15,654
Wilkinsburg	9	4,662	11,886
Port Perry	11	1,031	1,267
Turtle Creek	12	----------	3,262
Wilmerding	13	419	4,179
McKeesport	14	20,741	34,227
Elizabeth	20	1,804	1,866
Irwin	23	2,428	2,452
Jeannette	29	3,295	5,865
Monongahela	29	4,096	5,173
West Newton	32	2,285	2,467
Greensburg	33	4,202	6,508
Belle Vernon	41	1,147	1,901
Everson	50	----------	----------
Scottdale	52	2,693	4,261
Brownsville	52	1,471	1,552
Bridgeport	55	1,030	1,805
Mount Pleasant	57	3,652	4,745
New Haven	57	1,221	1,532
Connellsville	57	5,629	7,160
Dunbar	61	1,381	1,662
Uniontown	69	6,359	7,344
Waynesburg	80	2,101	2,544
Fairchance	95	1,092	1,219
Morgantown, W. Va	95	1,011	1,895
Somerset	112	1,713	1,834
Meyersdale	112	1,847	3,024
Fairmont, W. Va	120	1,023	5,655
Grafton, W. Va	140	3,159	5,650
Clarksburg, W. Va	150	3,008	4,050
Weston, W. Va	180	2,143	2,560
Buckhannon, W. Va	180	1,403	1,589

Character of water.—The increase of population, amounting to 75 per cent, as shown by the table presented above, is sure to bring about a proportional increase in pollution. It is not necessary to examine the water chemically or bacteriologically to prove that it is

unfit for use as a water supply. McKeesport, with a population of 34,227; Braddock, with 15,654; Homestead and Wilkinsburg, each following closely in the number of inhabitants, empty raw sewage into the Monongahela or its branches, and this must necessarily produce a condition which is a detriment not only to the water itself, but to the realty values along the river.

There are available a few analyses of the water of the Monongahela and some of the branches, which were made at Pittsburg at the same time as those already presented upon the Allegheny. A series of chemical examinations made of the water of Indian Creek and other creeks in its vicinity give a good idea of the character of the normal water of that section of the country, for the population on Indian Creek drainage area is small, is not at any point provided with sewerage, and is sufficiently well scattered to keep the water in its normal state, or nearly so.

TABLE 87.—*Analyses of water from Indian Creek and vicinity.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Iron.	Average of how many samples.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Indian Creek	1.5	0.101	0.028	0.000	0.480	4.9	112	20.0	0.4	0.34	12
Mill Run	2.1	.128	.027	.000	.532	4.5	258	20.3	.5	.09	14
Laurel Hill Creek	1.7	.065	.039	.000	.675	3.9	35	20.7	.5	.01	3
Castleman River	1.7	.069	.055	.000	.750	4.6	84	15.3	5.3	.01	3
Youghiogheny River	1.5	.128	.062	.000	.975	3.5	40	17.6	.4	.01	2

Coming down to Pittsburg again, we find a series of analyses made of the water just above the city.

TABLE 88.—*Analyses of water from Monongahela River at Pittsburg.*

[Parts per million.]

Date of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Iron.
		Albuminoid ammonia	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1897.										
June	------	0.136	0.081	0.000	0.740	13.5	154	------	------	------
July	------	.186	.076	.001	.768	4.3	141	28.5	21.2	1.95
August	1.0	.173	.100	.001	1.121	10.7	129	19.5	37.8	1.93
September	2.6	.130	.119	.000	.979	9.5	145	16.4	41.5	.30
October	1.2	.403	.142	.000	1.261	15.5	285	9.0	55.2	.15
November	1.9	.194	.145	.000	.825	14.7	265	14.1	48.4	1.33
December	2.5	.166	.030	.000	1.275	13.1	328	14.3	17.2	2.72

TABLE 88.—*Analyses of water from Monongahela River, etc.*—Continued.

Date of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Iron.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1898.										
January	2.1	.095	.030	.000	1.245	9.1	298	13.8	15.2	2.06
February	2.0	.177	.021	.000	1.500	11.1	219	13.2	22.4	1.29
March	2.0	.080	.025	.000	.425	9.2	203	10.4	39.9	.28
April	2.1	.097	.018	.000	.450	8.2	127	11.5	12.0	.19
May	2.8	.125	.026	.000	.275	12.1	167	14.6	25.9	.13
June	2.1	.105	.096	.000	.375	14.2	155	11.2	21.5	.04
July	2.2	.126	.041	.000	.825	14.2	170	12.8	33.6	.06
August	3.0	.190	.050	.000	.375	5.2	292	16.2	3.2	.06

Although, as has been stated, the sewage pollution of the Monongahela is more extensive near that city than in the Allegheny, it will be seen by comparison of Tables 83 and 88 that the Monongahela contains a smaller amount of organic matter than the Allegheny. The reason for this well illustrates what has already been said concerning the water of the Ohio Basin. The normal content of organic matter is so high that under ordinary circumstances the organic matter which is added to the river by the disposal of sewage therein does not increase the total amount to a significant degree. In other words, the amount of organic matter in the Ohio Basin is insignificant from the standpoint of sewage pollution, because of the fact that the unpolluted water often carries a larger amount of organic matter than the sewage brought into it. The two rivers under discussion well illustrate this point. We have in the Allegheny a "quick-spilling" basin, out of which is carried at times enormous amounts of sediment, consisting in a large measure of organic matter. The river flows swiftly, and there is little or no opportunity for sedimentation, so that when the water reaches Pittsburg its condition is not greatly improved nor changed.

In the Monongahela, on the other hand, we have a slack-water basin. Large amounts of silt are poured into it from the tributaries, as large as or larger than the amounts brought into the Allegheny. Yet because of the fact that there is ample opportunity in the slack water of the main river for subsidence, the water appears better upon chemical examination at Pittsburg in spite of the fact that comparatively large amounts of sewage are poured into the Monongahela only a short distance above. These facts illustrate excellently the point just enunciated; namely, that under ordinary circumstances the amount of organic matter emptied from sewers into the Ohio Basin

is small in comparison with that which is brought into the river from natural sources.

This consideration brings up the question of the value of determinations of organic matter in water, and seems to indicate that such determinations are of little aid in an investigation of this nature, if they are not indeed entirely useless. At all events, one should be very careful in regard to his premises before attempting to draw conclusions from determinations of organic matter.

MAHONING RIVER.

NATURAL RESOURCES.

Drainage area.—The area of the Ohio Basin next below the confluence of the Allegheny and the Monongahela rivers in which investigations have been made, the results of which have been published, is that of Mahoning River. This river drains 1,300 square miles in the eastern part of Ohio, being bounded on the north by the Lake Erie divide and on the south by the Muskingum and several other small streams, which enter the Ohio direct (see fig. 15).

The Mahoning rises in Columbiana County, Ohio, flows through the northeast corner of Stark County, and then by a circuitous course enters Portage, Trumbull, and Mahoning counties, flowing first in a northeasterly and then in a southeasterly direction, crossing the Ohio line and emptying into Beaver River in Pennsylvania, 8 miles from the Ohio boundary. Beaver River in turn enters the Ohio 40 miles below Pittsburg.

The basin of the Mahoning is rolling in some portions, while in others it is decidedly flat. It is rich in minerals and is extremely fertile. The valley is an important manufacturing place and is well supplied with transportation facilities. Under such favorable circumstances the population is rapidly increasing and the country is uncommonly prosperous.

Power.—The Mahoning is one of the best power streams in the Ohio Basin, and has been developed to an unusual extent as compared with other streams in this part of the country. Prof. Dwight Porter states that in the year 1880[a] 36 mills were situated upon the river, utilizing a total fall of 442½ feet, developing a horsepower of 1,146. It is probable that numerous changes have been made since that time in conformity with the decline of Ohio power values, and the figures are not applicable at the present date. The power developed is applied almost entirely to the grist and lumber business.

Flow.—There appear to be no satisfactory gagings of the flow of the river. In the report of the Ohio State Board of Health for 1898 there are given the results of a few measurements covering a period

[a] Tenth Census, vol. 17, pt. 2, p. 465.

of five months during a very dry season, but, as explained in that report, the gagings were attended by unfortunate circumstances which almost entirely vitiate their value, and they were not in any event continued for a sufficient period to indicate the normal flow of

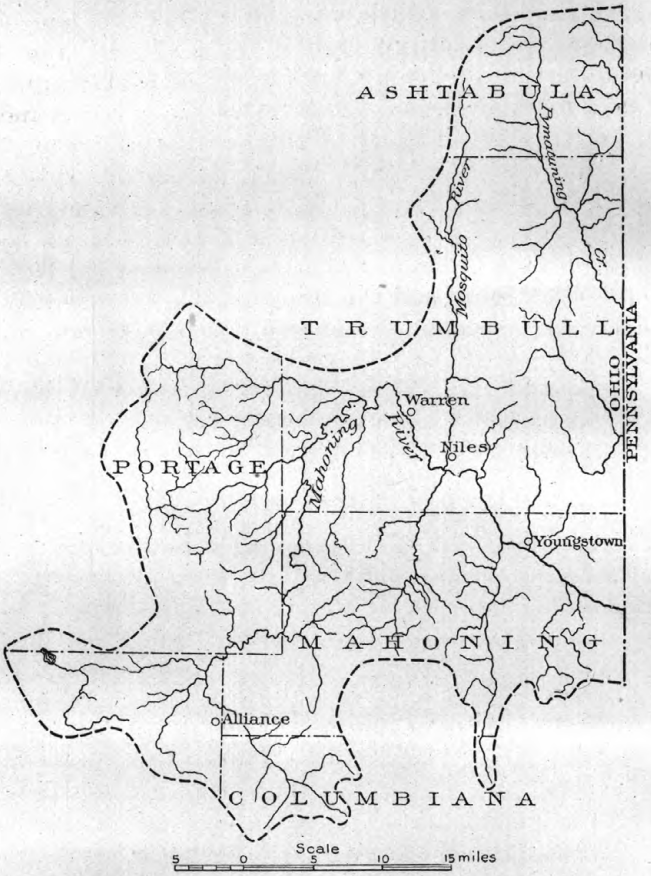

FIG. 15.—Mahoning River drainage basin.

the stream. The common observation is that the river fluctuates widely and is subject to freshets.

CHARACTER OF WATER.

No records of examinations of unpolluted water in the Mahoning Basin have been found. The excellent work of the State Board of Health was confined to districts undoubtedly polluted and therefore gives no idea of the character of the normal water in this basin. It is probable that the unpolluted surface water in the Mahoning Basin does not differ widely in character from that indicated by the analyses of the water of the river above Alliance, which will be shown below.

Alliance is a city of 8,974 inhabitants (census of 1900), and is situ-

ated in the upper part of the Mahoning Basin. Therefore it is the head of the extensive pollution for that basin. Above Alliance the drainage area comprises 73 square miles, and the population is not far from 60 per square mile. There are no mills nor factories on the river, and the country is largely devoted to manufacturing and dairying. There are six small villages on the river, the largest having probably no more than 300 inhabitants. Under some circumstances dangerous pollution might arise at two, North Georgetown and Damascus. Two miles above Alliance is situated the Fairmont Children's Home, which shelters about 200 persons, and pours raw sewage into the river. Under such circumstances when the water reaches the intake of the Alliance Waterworks it is generally in an acceptable condition, but is subject to the dangers above noted. The intake is well down toward the center of the city, so that there is undoubtedly a certain amount of contamination from Alliance itself.

TABLE 89.—*Analyses of water from Mahoning River above Alliance.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.
1897.										
June 19	None	4.5	0.528	0.136	0.012	0.23	1.5	240	110	36
July 24	Slight	7.0	.478	.126	.010	.28	.2	175	70	38
Sept. 2	Distinct	4.0	.390	.094	.005	.07	2.3	400	136	54
Sept. 29	None	1.5	.136	.059	.003	.00	3.0	415	182	58
Oct. 27	Very slight	2.0	.150	.060	.000	.00	3.2	410	204	54
Nov. 26	Decided	10.0	.592	.114	.007	6.5	2.3	470	78	64
Average			.379	.100	.006	.21	2.1	350	130	51

During the periods covered by the above table the rainfall at Akron, the nearest weather observation station, was as follows:

TABLE 90.—*Rainfall at Akron, Ohio.*

	June.	July.	August.	September.	October.	November.	Whole period.
Total fall	1.55	5.06	2.90	1.07	1.65	4.85	17.16
Variation	−2.81	+1.20	− .35	−2.12	− .77	+1.69	− 3.16

The city of Alliance is provided with a system of water supply, and the consumption approaches 5,000,000,000 gallons daily. The sewer-

age system introduced in 1896 has been well extended, and in the year 1898 poured into the chemical precipitation works 300,000 gallons of sewage daily. The purification works do not seem to be extremely efficient, if we may judge from the analyses and bacteriological examinations made by the Ohio State Board of Health. The report of the bacteriologist in the year 1898 makes the following statement with reference to the Alliance sewage disposal:

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 above the station.

TABLE 91.—*Analyses of water from Mahoning River below Alliance.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.
1897.										
June 19	None	3.0	0.422	0.200	0.022	0.07	3.0	310	128	56
July 24	Slight	8.0	.520	.196	.020	.33	.2	165	56	34
Sept. 2	do	3.0	.422	.122	.015	.12	4.8	410	138	68
Sept. 29	None	2.0	.366	.473	.035	------	9.0	415	170	68
Oct. 27	do	4.0	.356	2.100	.055	.03	15.5	480	216	98
Nov. 26	Decided	5.0	.390	.176	.022	.54	4.5	380	102	98
Average			.412	.544	.028	.18	6.2	358	135	70

The next important center of population below Alliance is Warren, in Trumbull County, which in 1900 had 8,529 inhabitants. The area of the watershed above Warren is not far from 600 miles, and the density of the rural population is about 45 per square mile. Between Alliance and Warren there are a large number of small country villages, having a population of 3,500 or 4,000, the most important being Newton Falls and Leavittsburg. At both of these places dangerous pollution may be expected, as well as from the Trumbull County Infirmary, which contributes a certain amount of sewage above the intake of the Warren waterworks. The river receives contamination from these three points, from Alliance, and from the storm sewers at Warren, which enter the river just above the waterworks.

TABLE 92.—*Analyses of water from Mahoning River above Warren.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.
1897.										
June 18	None	0.3	0.370	0.062	0.002	0.09	2.0	190	92	16
July 23	Decided	12.0	.606	.156	.010	.23	.3	130	36	22
Aug. 28	Very slight	3.0	.336	.062	.000	------	3.5	245	100	28
Sept. 30	do	1.5	.180	.036	.005	.00	4.2	275	124	32
Oct. 28	Slight	3.0	.158	.018	.000	.00	3.7	235	140	14
Nov. 27	Decided	7.0	.440	.074	.009	.85	3.3	205	54	46
Average		3.0	.348	.068	.004	.20	2.8	213	91	26

In addition to this the industrial pullution is extensive. Within the city are situated numerous works, such as a rolling mill, tube works, and linseed-oil, flour, and paint mills, as well as a galvanizing plant, from which large quantities of waste acid are turned into the river.

TABLE 93.—*Analyses of water from the Mahoning River below Warren.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.
July 24	Decided	10.0	0.552	0.204	0.010	0.28	2.1	170	40	36
Aug. 28	Very slight	3.5	.430	.096	.004	.06	4.5	235	90	26
Sept. 30	do	1.5	.194	.070	.005	.00	8.7	275	126	18
Oct. 28	Slight	3.0	.304	.102	.017	.13	42.5	335	136	30
Nov. 27	Distinct	8.0	.454	.098	.017	.86	5.0	270	56	56
Average		5.2	.387	.114	.011	.27	12.6	257	90	33

The next important place on Mahoning River below Warren is Niles, which has a population or 7,468. Between Warren and Niles there is little pollution of a dangerous character, and the water which reaches the latter place is not materially different from that shown in Table 93. At Niles, although there is no complete system of sewers, the pollution is extensive and dangerous. There are probably about

50 house connections, with short lines of pipe; but in addition to these there are works which contribute waste, notably a tin-plate and iron-galvanizing plant, which discharge chemicals, mostly of an acid nature, into the river. During the summer of 1897 the river was discolored for 9 miles below Niles and many fish were killed. In addition to this the outhouses connected with the industrial plants are situated upon the edge of the stream, as is also that of a large schoolhouse. The pollution is therefore constant and dangerous, especially in view of the fact that this place is only about 10 miles above the intake of the Youngstown waterworks.

Analyses were made of water taken from the river below Niles, and a comparison of the results with those of analyses of water taken below Warren shows increased pollution. As will be noted by comparisons of Tables 93 and 94, the increase in chlorine is enormous. This, however, is not due entirely to sewage pollution, but arises from the influx of water from several salt springs in the vicinity of Niles.

TABLE 94.—*Analyses of water from Mahoning River below Niles.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.
1898.										
June 18	----------	3.5	0.392	0.126	0.007	0.05	4.0	200	102	24
July 23	Decided	12.0	.620	.144	.010	.25	.3	135	34	18
Aug. 28	Slight	3.0	.328	.130	.005	.01	4.5	255	100	26
Sept. 30	None	2.0	.208	.078	.004	.00	4.5	245	124	12
Oct. 28	Slight	3.0	.268	.244	.001	.06	6.2	250	140	3
Nov. 27	Decided	10.0	.516	.096	.009	.88	3.3	233	54	42
Average	----------	5.5	.389	.136	.008	.21	3.8	220	92	91

The next important center of population below Niles is Youngstown, the largest city on Mahoning River, containing 44,885 inhabitants. The area of the Mahoning Basin above Youngstown is approximately 900 miles, about 50 per cent of the population of which is urban. Between Niles and the water-supply intake at Youngstown the principal points are Cortland, Mineral Ridge, Canfield, Mahoning City Infirmary, Girard, Columbiana, and a part of the city of Youngstown itself, containing approximately nearly 10,000 persons. These represent a total population of 16,352.

The pollution from these centers is not extensive, and only that from the upper end of Youngstown may be termed dangerous. The

quality of water as it arrives at the Youngstown intake is therefore superior to that which leaves Niles.

TABLE 95.—*Analyses of water from Mahoning River above Youngstown.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.
1897.										
June 18	None	5.0	0.424	0.094	0.001	0.05	5.3	245	90	28
July 23	Decided	25.0	.716	.120	.005	.18	.3	145	22	20
Aug. 28	Very slight		.436	.112	.003	.07	4.0	200	56	24
Sept. 30	None	1.5	.192	.056	.004	Tr.	13.5	370	88	86
Oct. 28	do	3.0	.194	.052	.004	.04	15.2	380	106	60
Nov. 27	Distinct	20.0	.386	.096	.009	.46	5.0	255	64	54
Average		10.8	.391	.088	.004	.13	7.2	266	71	46

For some miles the Mahoning River flows through Youngstown. The city is provided with intercepting sewers, which carry all sewage below the water intake and discharge it into the river direct. After the addition of this sewage the water has the character shown in the following table.

TABLE 96.—*Analyses of water from Mahoning River below Youngstown.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.
1897.										
June 18	None	4.0	0.436	0.166	0.015	0.10	7.0	225	96	28
July 23	Decided	25.0	.908	.120	.010	.31	.5	220	26	38
Aug. 28	Very slight	8.5	.456	.218	.015	.27	6.5	215	64	28
Sept. 30	None	2.0	.268	.230	.030	.18	18.0	390	114	70
Oct. 28	do	5.0	.454	.750	.092	.27	25.2	405	130	78
Nov. 27	Distinct	20.0	.460	.150	.017	.56	5.7	283	52	58
Average		10.5	.497	.272	.030	.28	10.5	286	80	50

There are no analyses or public records applying to points below those indicated in Table 96; therefore the character of the contribution made by the Mahoning to the Ohio can not be determined. As has been stated, the Mahoning joins the Beaver a short distance below Youngstown, just east of the boundary line between Pennsylvania and Ohio. It is extremely probable that the Beaver is not polluted to the extent that the Mahoning is, and we may therefore be fairly certain that when the waters of the Mahoning reach the Ohio River their condition is greatly improved.

MUSKINGUM RIVER.

Drainage basin.—The drainage basin of the Muskingum is the largest in Ohio, covering 7,797 square miles. (See fig. 16.) It is formed at Coshocton by the confluence of the Walhonding and Tuscarawas, and from that point flows southward, then southeastward, a distance of 110 miles, entering the Ohio at Marietta. The other important tributaries are Licking River and Wills Creek.

The basin occupies nearly all of the southeastern part of the State, extending from Marietta up to the Lake Erie drainage divide, and from the Scioto Basin on the west to that of the Ohio River on the east. Geologically the basin is made up of two portions—a glaciated and an unglaciated area. The former includes, roughly, the western and northwestern parts of the basin; the latter comprises the remainder. Agriculture flourishes in the glaciated area, where the surface is smooth, rolling, or flat, while mining interests have been developed in the unglaciated part. Many parts of the basin are entirely deforested, yet some sections still bear timber.

Population of basin.—The population of the Muskingum Basin is large, and has been increasing at a rapid rate during the decade ending 1900. According to the Twelfth Census the total population is not far from 750,000, or about 97 per square mile. Of this, the urban population is approximately 200,000, leaving for the rural districts 550,000. These figures, while not exact, represent a careful estimate taken from the Twelfth Census reports.

WALHONDING CREEK.

The Walhonding has its origin in the west-central portion of Richland County. The highest section of the river is known as Black Fork; flowing southeastward it is joined by Rocky Fork and Jerome Fork, and below the confluence of the latter is known as Mohican River. Flowing still farther southeastward it is intercepted by Kokosing River, and from this point to Coshocton the term Walhonding Creek is applied to it.

BLACK FORK.

At the head of Black Fork the basin is a sparsely settled agricultural region, containing only four small hamlets, the largest having not more than 150 inhabitants. Shelby, a growing manufacturing town, having a population of 4,685, is the highest point of appreciable

FIG. 16.—Muskingum River drainage basin.

pollution. The run-off water from the area above this place is probably nearly normal.

The Ohio State Board of Health has made a faithful survey of the basin, and a series of chemical examinations was made during the spring, summer, and fall of the year 1899. In the published report of this work there appears a series of analyses of samples

of water taken from Black Fork above Shelby, which is reproduced below.

TABLE 97.—*Analyses of water from Black Fork above Shelby.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Precipitation, departure from normal for month.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1899.											*Inches.*
May 3	18	w [a]	0.166	0.071	0.008	0.06	4.1	406	197.6	33	—2.15
May 29	28	e	.660	.110	.002	.11	Tr.	956	120.8	13.9	------
June 27	25	v	.174	.070	.002	.10	1.5	354	176.8	33.8	+ .44
July 18	30	e	.268	.061	.016	.06	.9	407	153.6	84.8	+ .29
Aug. 17	20	v	.246	.088	Tr.	.02	4.3	428	191.6	81.6	2.21
Sept. 18	16	v	.166	.053	Tr.	.03	2.1	411	191.4	59.2	+1.31
Oct. 12	25	None.	.146	.033	Tr.	.00	1.3	414	227.4	48.2	+ .06
Nov. 17	45	e	.132	.018	.004	.02	1.7	468	181.8	98.6	—1.62
Average	26	------	.245	.063	.004	.05	2.0	480	180.1	56.6	------

[a] w, woody; e, earthy; v, vegetable.

The results above reported indicate that the water analyzed contained considerable organic matter, which, if we may judge from the conditions existing in the contributing drainage area, is of vegetable origin. The water is not highly colored and there is no indication that pollution exists other than that inevitably arising from decayed vegetation. The free ammonia, nitrites, and chlorine are low; the water contains a comparatively large proportion of alkaline salts, which cause a high degree of hardness. It is evident, however, that nearly 75 per cent of these salts are carbonates. In general, the series of analyses is important because it is one of a very few available reports upon a normal or practically normal surface water in the northern drainage basin of the Ohio River.

For purposes of comparison, analyses of water from Black Fork below Shelby were made by the State Board of Health, the samples being collected at the same time as were those reported in Table 97.

TABLE 98.—*Analyses of water from Black Fork below Shelby.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—			Chlorine.	Total residue.	Hardness.		Precipitation, departure from normal for month.
			Albuminoid ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1897.										*Inches.*
May 3	12	d [a]	0.238	0.015	0.06	11.7	538	115.8	100.9	−2.15
May 29	32	e	.530	.032	.15	7.8	435	103.0	54.1	------
June 27	17	d	.198	.034	.12	12.5	473	137.8	87.0	+ .44
July 18	60	v	.352	.022	1.25	6.3	383	110.2	88.8	+ .29
Aug. 17	20	v	.236	Tr.	.05	28.3	810	57.2	327.6	−2.21
Sept. 18	20	Cattle	.442	.002	.06	32.1	959	90.4	350.6	+1.31
Oct. 12 [b]	----	--------	-------	------	------	------	------	-------	-------	+0.06
Nov. 17	20	m	.100	.014	.06	8.7	598	77.4	225.6	−1.62
Average	26	--------	.299	.017	.25	15.3	599	98.8	176.4	------

[a] d, disagreeable; e, earthy; v, vegetable; m, moldy. [b] No water flowing.

The effect of pollution from Shelby is evident in the analyses above reported. There is a significant rise in the proportions of free ammonia, nitrites, and chlorine, which can be due to nothing else than sewage pollution. It is worthy of note that there is a great change in the character of the alkaline salts contained in the water. The marked decrease in alkalinity, accompanied by the increase in normal hardness, shows that through some influence, probably by the discharge of some chemical at Shelby, the carbonates have been changed to sulphates or chlorides.

Black Fork is joined by Rocky Fork about 30 miles below Shelby, but the intervening country is sparcely settled and there is little further material pollution except that from Richmond County Infirmary.

ROCKY FORK.

The drainage area of Rocky Fork lies in the central part of Richland County, immediately south of that of Black Fork. During past years it has been one of the most grossly polluted streams in Ohio, because of the discharge into it of raw sewage from Mansfield, a city of 17,640 inhabitants. The condition of the stream below this city has been so offensive that it became necessary to establish a system of sewage disposal. The Ohio State Board of Health examined, previous to the installation of this disposal plant, two series of samples of water from Rocky Fork, one of the sampling points being located

above the city and the other below. That part of the drainage area above Mansfield comprises a country richly fertilized for agricultural purposes, and the run-off is therefore not normal for the basin.

TABLE 99.—*Averages of analyses of water from Rocky Fork, above and below Mansfield.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Number of analyses made.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Mansfield	20	....	0.282	0.051	0.005	0.08	2.9	512	169.7	59.0	8
Below Mansfield	23	f[a]	.413	.088	.088	.14	16.7	583	146.1	55.5	8

[a] f, fishy.

It is hardly necessary to comment on the contrast offered by the two averages set forth in the above table. The second statement shows an enormous increase in organic matter, in chlorine, and in all other constituents which serve to indicate extensive sewage pollution. It is believed that the river has been improved since the establishment of the Mansfield sewage purification works, but an analytical proof is not at hand.

Between the junction of Rocky Fork and Black Fork and the entrance of Clear Fork is the village of Loudensville, containing 1,500 inhabitants. There is no public water supply or sewerage system, but there is nevertheless considerable drainage into the stream by private sewers, ditches, and gutters.

Clear Fork appears to be a comparatively clean stream, the principal center of population within its drainage area being Belmont, which has a population of 1,039.

JEROME FORK.

At the confluence of Black and Jerome forks is the head of Mohican River. Jerome Fork drains the greater part of Ashland County and the western portion of Wayne County. The only place of importance upon the stream is the city of Ashland, with 4,087 inhabitants, provided with a water supply and sewerage system.

MOHICAN RIVER.

From the above statements, it is clear that the water contributed to Mohican River by the tributaries described is badly polluted and of little value in its raw state as a water supply. The remainder of

the resources vested in the water of this stream are probably not greatly affected by pollution.

OWL CREEK.

Mohican River flows nearly due south to its confluence with Owl Creek, and there are upon its banks no important centers of population. The water flowing in the channel must, therefore, constantly improve in quality. Owl Creek, however, is a different stream; it drains the greater part of Knox County, and extends to the Scioto River divide. The country is level and is a very fertile agricultural region. In the middle of the drainage area is the city of Mount Vernon, having a population of 6,633. It is a rather important manufacturing town, although it has not grown much during the last decade. A water supply and a system of sewerage has been provided, the latter emptying directly into Owl Creek. There is also considerable surface pollution from vaults and cesspools. Above the city of Mount Vernon there are, in Owl Creek Basin, several small villages, which, together with the richly fertilized fields, contribute a sufficient amount of pollution to the river to materially change the quality of the water, which would otherwise be normal.

TABLE 100.—*Averages of analyses of water from Owl Creek above and below Mount Vernon.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Number of analyses made.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Mount Vernon	13	o[a]	0.095	0.036	0.003	0.05	1.2	292	192.0	13.9	8
Below Mount Vernon	14	M	.121	.060	.009	.08	3.1	303	190.7	33.3	8

[a] o, oily; M, musty.

KILLBUCK CREEK.

Killbuck Creek enters Mohican River a short distance below the mouth of Owl Creek. It drains a large part of Wayne and Holmes counties and a small part of Coshocton County. At the headwaters of this stream is a comparatively large rural population, the principal centers of which are Warsaw and Creston, while the highest town of importance is Wooster, a city of 6,063 inhabitants.

Above Wooster two points were selected by the Ohio State Board of Health for the collection of samples of water for analysis; one in Killbuck Creek, above the mouth of Apple Creek, which flows in at Wooster; one in Apple Creek above Wooster, and the third below Wooster,

the latter representing a mixture of waters from both Killbuck and Apple creeks. Above Wooster on Apple Creek are the Wayne County Childrens' Home and the Wayne County Infirmary, which pollute the water of the stream to some extent. At Wooster are Wayne College and several industrial establishments.

TABLE 101.—*Averages of analyses of water from Apple and Killbuck creeks above Wooster and from Killbuck Creek below Wooster.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Number of analyses made.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Killbuck Creek above Wooster	28	M[a]	0.336	0.112	0.006	0.05	5.4	336	130.1	23.4	8
Apple Creek above Wooster	19	None.	.153	.038	.003	.05	2.6	254	140.2	16.6	8
Killbuck Creek below Wooster	28	M	.322	.165	.022	.09	6.5	359	130.5	28.3	8

[a] M, musty.

Between Wooster and the junction of Killbuck Creek with Walhonding Creek there are numerous small villages, a few being provided with small sewerage systems. It is more than likely that the condition of the water shown in the last analysis in Table 101 is maintained by these small pollution points in practically the same condition as that indicated in the table.

From the mouth of Killbuck Creek it is only a short distance down Walhonding Creek to Coshocton, the head of Muskingum River. The Ohio State Board of Health has made an analysis of the water of Walhonding Creek above Coshocton which shows clearly the character of the water contributed to the Muskingum by the Walhonding Basin.

TUSCARAWAS RIVER.

The basin of the Tuscarawas covers about 2,547 square miles in the northwestern portion of Muskingum watershed. It is the largest tributary of the Muskingum, flowing through a fertile, prosperous country, which has a large population, and is dotted over with rapidly growing municipalities. In the central-southeastern part of the basin coal mining is largely developed, while agriculture is confined in general to the northern and western portions. The river rises in Summit County, and, by a somewhat circuitous route, finally takes a course southwest, flowing through Stark, Tuscarawas, and Coshocton counties, and meets Walhonding Creek at Coshocton to form the Muskingum.

The tributaries of the Tuscarawas are important, and cover diversified portions of the drainage area. Chief among these is Big Stillwater Creek, which flows from the south, through Harrison and Tuscarawas counties, draining an area of 472 square miles. Sugar Creek flows in from the northwest, its basin comprising 356 square miles. Sandy Creek is an important stream which flows in from the east, along the northern part of Carroll and the southern boundary of Stark counties.

HIGHLAND TRIBUTARIES.

Wolfe and Chippewa creeks drain the northernmost portions of the Tuscarawas Basin, comprising parts of Summit, Medina, and Wayne counties. There are numerous small villages in the basin, which have no important influence on the character of the run-off water, although they undoubtedly pollute it to some extent. The first important center of population is Barberton, a comparatively new town, the growth of which has been rapid, by reason of the recent establishment of manufacturing. A system of sewers has been provided, which serves about 3,000 people, and has an outlet in Wolfe Creek. The manufacturing refuse, too, damages the stream to some extent. Wadsworth, Orrville, Dalton, and Doyleston are situated in the drainage area. These municipalities are not important, although from Wadsworth there is considerable contamination of the stream from the salt works established there. Rillman is also an important center of the salt industry, the wastes from which impregnate the whole drainage from this section.

The largest city in the Tuscarawas Basin is Massillon, an important manufacturing place in Stark County, situated a few miles below the confluence of Wolfe and Chippewa creeks, and having a population of 11,944. Refuse from strawboard factories and other manufacturing plants, as well as the sewage from a combined system of sewers, pollutes the stream. The Ohio State Board of Health has made a series of analyses of the water taken from the river above and below Massillon, the average results of which are set forth in Table 102.

TABLE 102.—*Averages of analyses of water of Tuscarawas River above and below Masillon.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Number of analyses made.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Massillon	23	v [a]	0.175	0.060	0.003	0.06	102.8	513	136.8	58.8	8
Below Massillon	29	M	.343	.093	.007	.10	64.5	578	152.0	33.6	8

[a] v, vegetable; M, musty.

In the above analyses the effects of waste from salt works are readily apparent in the high chlorine content. Aside from this, the river shows a high content of organic matter, which, although no records of normal water are available for comparison, seems to indicate pollution from the country above. The average representative analyses of water from the river below Massillon show a characteristic increase in the amount of organic matter, yet the chlorine does not appear to be present in so large proportion as above the city. This is not explained in the last report of the Ohio State Board of Health; it may be due to dilution, as there are two streams entering the river between the sampling point above the city and that below.

SANDY CREEK.

Sandy Creek enters the Tuscarawas a short distance below Massillon, and contributes a considerable amount of pollution from Canton, Wellsville, Minerva, and other small places. Minerva has a population of 1,200 and is situated upon Clear Fork, at the extreme eastern end of the Muskingum Basin.

NIMISHILLEN CREEK.

The principal stream of interest in the Sandy Creek drainage area is a tributary called Nimishillen Creek, which drains the country to the north, including the city of Canton and the village of Louisville. The latter is situated upon the east branch of the creek, has a population of 1,374, and is provided with a public water supply, but no sewers. The east branch runs through Canton and joins the west branch at the lower end of the city. The Ohio State Board of Health has conducted two series of analyses of water from west branch, one above and one below Canton.

TABLE 103.—*Averages of analyses of water from Nimishillen Creek above and below Canton.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses made.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Above Canton	28	23	v [a]	0.176	0.051	0.006	0.35	2.0	294	150.6	35.1	2,400	8
Below Canton	70	28	M	.446	.741	.039	.30	10.4	343	151.7	50.2	95,000	8

[a] v, vegetable; M, musty.

The contrast presented by the above averages indicates unmistakably the great change in the character of the water after it receives pollution from Canton.

TUSCARAWAS AT CANAL DOVER AND NEW PHILADELPHIA.

Canal Dover and New Philadelphia are cities situated on the opposite sides of Tuscarawas River at the junction of Sugar Creek, a stream which drains a considerable area of country to the northwest. The former city has a population of 5,422; the latter contains 6,213 inhabitants. Both are important manufacturing places, and their industrial plants contribute a large amount of foul matter to the river. Canal Dover has no sewerage system at present, but the drainage into the river is nevertheless extensive. New Philadelphia has an excellent sewerage system, which discharges into the river. We have, then, at this point a combined population of 11,635, the wastes from which have an important effect on the quality of the Tuscarawas River.

TABLE 104.—*Averages of analyses of water from Tuscarawas River above Canal Dover and below New Philadelphia.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Number of analyses.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Canal Dover	23	e [a]	0.227	0.062	0.005	0.07	23.9	369	112.8	39.3	8
Below New Philadelphia	24	e [a]	.237	.060	.005	.10	23.4	343	107.4	36.2	8

[a] e, earthy.

Comparison of the results of analyses from the two points above stated shows that the water in Tuscarawas River is not materially changed after receiving the pollution from Canal Dover and New Philadelphia. It is probable that the amounts of nitrogen and of chlorine are practically the same, and that the color, turbidity, and odor do not differ widely. The reason for this is not far to seek. Examination of the map will show that between the sampling point above Canal Dover and that below New Philadelphia three tributaries enter—Sugar Creek, Stone Creek, and Oldtown Creek. The first of these tributaries drains an area of 356 square miles; the other two have basins considerably smaller. The water flowing from these tributaries is not polluted to any significant extent, and it is reasonable to believe that the large measure of dilution, which must, of necessity, arise, is sufficient to account for the lack of material difference in the character of the water as shown by analyses at the two sampling

points. The quantitative determinations of bacteria made by the State Board of Health, however, tell another story. It has also been remarked that the differences between gelatin culture media manufactured in different laboratories are often the cause of varying results in determining the number of bacteria, so that when the same water is tested the number of bacteria found in different cases varies widely. Therefore little value can be given to quantitative determinations, unless numbers vary to such an extent that the difference between one and the other is greater than any possible error introduced by the discrepancy in the work. In the report of the Ohio State Board of Health, above referred to, the average number of bacteria per cubic centimeter above Canal Dover is 2,350, and below New Philadelphia 6,200, a difference so wide that it can not be reasonably accounted for by variations which might be introduced into the work by the use of nonuniform culture media. The media used in these determinations were all made in the same laboratory and, presumably, after the same methods, so that it is probable that the above-described variation would not occur. The fact that there are so many more bacteria in the water below New Philadelphia than above Canal Dover arises unquestionably from the difference in the character of the organic matter. In other words, the fact that there is sufficient organic matter of a certain kind in the water at the lower sampling station to provide food for 6,200 bacteria, while at the upper station it is suffi ient in amount to provide food for only 2,350, shows that the character of the organic matter has been seriously changed, even though the large degree of dilution arising from the cause above stated preserves the proportionate amounts practically the same.

STILLWATER CREEK.

After proceeding down Tuscarawas River for 5 or 6 miles one comes upon the confluence of Stillwater Creek. This stream has a drainage area of 472 square miles, lying principally in Harrison, Belmont and Tuscarawas counties. The river forks a few miles from this confluence with the Tuscarawas, and thereafter the northernmost branch is called Little Stillwater Creek, while that immediately to the south is known as Big Stillwater Creek. The pollution in the basin of Little Stillwater Creek is not extensive, while in the upper part of the Big Stillwater Basin there are only a few small centers of population, such as Barnesville, Piedmont, and Freeport. At the junction of the two forks are situated the municipalities of Uhrichsville and Dennison.

The following statement of averages of analyses of water above Uhrichsville and below Dennison are taken from the report of the Ohio State Board of Health, above referred to.

TABLE 105.—*Averages of analyses of water from Stillwater Creek above Uhrichsville and below Uhrichsville and Dennison.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Number of analyses made.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Uhrichsville	25	M[a]	0.287	0.089	0.007	0.07	4.5	344	114.1	17.8	8
Below Uhrichsville and Dennison	25	M	.288	.188	.007	.17	7.1	376	98.8	40.2	8

[a] M, musty.

The evidences of increase in pollution appearing in the two averages above referred to are easily appreciable, notably by the rise in free ammonia and chlorine.

Below the mouth of Stillwater Creek, in the course of the 40 miles which intervene between that point and the head of Muskingum River, small villages are situated upon the banks of the stream, containing the usual number of industries, but the only important center of pollution is Newcomerstown, which has, according to the Twelfth Census report, 2,659 inhabitants.

MUSKINGUM RIVER BELOW COSHOCTON.

Walhonding Creek and Tuscarawas River are further polluted at their confluence by drainage from the city of Coshocton, which has a population of 6,473. Along the water front of this city are located important manufacturing plants, which pour their wastes into the stream. The city is provided with a water supply and sewerage system, and the sewage, together with that carried by surface drains, as well as the town garbage, is poured into the river. There arises, therefore, at this point an important contamination, which is said to be offensive during periods of low water. Three series of analyses have been carried on at Coshocton by the Ohio State Board of Health. The sampling points chosen were Walhonding Creek and Tuscarawas River, both above the confluence of Coshocton pollution, and a point on Muskingum River at a proper distance below the confluence of the two main tributaries where it was reasonably certain that the waters of the two streams and the pollution from Coshocton were thoroughly mixed.

TABLE 106.—*Averages of analyses of water from Walhonding Creek and Tuscarawas River above Coshocton and from Muskingum River below Coshocton.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Number of analyses made.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Walhonding Creek above Coshocton	------	21	e[a]	0.187	0.045	0.004	0.10	5.4	303	139.0	14.4	8
Tuscarawas River above Coshocton	------	16	----	.128	.028	.003	.05	20.6	303	119.0	29.1	8
Muskingum River below Coshocton	113	20	----	.180	.043	.005	.05	19.4	329	120.4	49.2	8

[a] e, earthy.

Comparison of the analyses of water from Walhonding Creek above Coshocton with those of water from Tuscarawas River shows that the latter is not so highly colored. The amount of residue is the same as in the Tuscarawas, the alkalinity higher, but the normal hardness less. It is notable that the content of chlorine in the Tuscarawas is higher, the difference being due principally to contamination from the salt works in the upper part of the basin of that tributary. The Walhonding has more organic matter than the Tuscarawas. In both streams the water is greatly damaged by pollution, but the nuisance occasioned thereby is not general, being confined to certain localities near points of discharge of certain city sewers.

WILLS CREEK.

Wills Creek enters the Muskingum from the east a short distance below Coshocton. It is the drainage outlet of Guernsey County, and the basin comprises also small areas in Noble and Belmont counties. The creek is formed by the confluence of Buffalo Fork and Seneca Falls Creek a short distance north of Noble County line, and pursues an extremely winding course to its outlet, running through Guernsey, Coshocton, and Muskingum counties and into the Muskingum River. The only considerable center of population in the drainage area is Cambridge, a city of 8,241 inhabitants. This is an important coal-distributing point, and it contains tin and iron mills, which contribute considerable amounts of wastes to the river. Sewers have been introduced at Cambridge and, although they have not been widely extended, they do their full measure of damage to the stream. Leatherwood Creek, which enters Wills Creek at Cambridge, drains an important mining district and, as a result, is very turbid by reason of a large amount of coal-mine waste.

The Ohio State Board of Health has conducted a series of analyses of water above and below Cambridge on Wills Creek. That above Cambridge is not representative of the character of Leatherwood Creek water.

TABLE 107.—*Averages of analyses of water from Wills Creek above and below Cambridge.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Number of analyses made.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Cambridge	784	23	v[a]	0.227	0.109	0.017	0.12	26.6	474	136.8	40.7	8
Below Cambridge	464	24	M	.235	.204	.025	.14	10.0	352	92.5	65.6	8

[a] v, vegetable; M, musty.

The results above set forth indicate a considerable rise in free ammonia, nitrites, and chlorine after the water passes Cambridge. Mr. Benjamin H. Flynn, engineer of the Ohio State Board of Health, is of the opinion that there is not sufficient discharge of sewage from Cambridge to account for so great a rise in the constituents indicating sewage pollution, and that the change is probably due to industrial wastes. The reduction in the amount of turbidity is interesting, as it indicates a possible discharge of coagulating material from the mines, probably sulphate of iron. To this extent, therefore, the industrial pollution may be regarded as a benefit.

LICKING CREEK.

About 20 miles below the confluence of Wills Creek is the city of Zanesville, at which point Licking Creek joins the Muskingum. This stream drains the north of Licking County and part of Knox, Perry, and Muskingum counties. The western part of this basin is level and is devoted to agriculture, while the eastern part is hilly. At the headwaters of the stream are many small towns, the principal ones being Centerburg, Utica, Pataskola, Johnstown, and Granville, having a combined population of 4,270.

Newark, with a population of 18,157, is the commercial center of the basin. It contains many manufacturing industries and several slaughter houses, and these, together with the city sewage, make the river very foul at times.

Analyses of water from Licking Creek above Newark indicate that it is rich in organic matter, yet there is no special evidence of dangerous contamination, while the samples taken from the stream below Newark present the usual contrast.

TABLE 108.—*Averages of analyses of water from Licking Creek above and below Newark.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses made.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Above Newark	87	13	None.	0.106	0.029	0.002	0.04	1.6	309	184.0	21.3	700	8
Below Newark	99	14	M[a]	.162	.088	.006	.07	3.0	329	181.4	13.4	5,200	8

[a] M, musty.

The city of Zanesville, with population of 23,538, is the largest center of pollution yet considered in the drainage basin of the Muskingum. The water supply is taken from Muskingum River just above the city, but the water is so impure that steps are now being taken to improve its quality or to procure another source of supply. A sewerage system has been provided, and the manufacturing industries are important. In addition to the contamination from sewers and from these manufacturing plants, the river receives sewerage drainage, which is dangerously polluted by slovenly methods of disposing of garbage and night soil.

The Ohio State Board of Health has conducted three series of examinations, eight samples being taken from each of the following points: Muskingum River above Zanesville, Licking Creek above Zanesville, and Muskingum River below Zanesville. The averages of the results of these examinations are reproduced below.

TABLE 109.—*Average results of analyses of water from Licking Creek above Zanesvile and from Muskingum River above and below Zanesville.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Licking Creek above Zanesville	15	0.288	0.059	0.006	0.05	3.2	510	165.3	21.4	2,700	8
Muskingum River above Zanesville	25	.285	.063	.006	.08	10.0	498	114.2	35.9	2,700	8
Muskingum River below Zanesville	24	.324	.098	.009	.08	9.6	530	118.7	23.4	12,000	8

There is a striking similarity in the analyses of the waters from Muskingum River and from Licking Creek above Zanesville. In fact,

the determinations practically conform, the only significant departure being in the case of chlorine. In the preceding pages it has been noted that salt works contributed large quantities of waste to the Tuscarawas River, which results in raising the amount of chlorine to a height unwarranted by existing sewage pollution. To this is probably due a part of the excess of chlorine in water in Muskingum River above Zanesville over that in Licking Creek.

In the introduction to this paper it was stated that the chlorine contributed to surface water does not undergo mechanical change similar to that which takes place in the nitrogen compounds, but firmly maintains its identity, fluctuating in amount according to the dilution which it receives from tributaries, or the contributions from sewers and other polluting factors, and when organic matter is completely changed to inorganic compounds, and all other trace of contamination is lost, the chlorine remains an unshaken witness of past pollution. We have also seen in the pages immediately preceding that large amounts of sewage are poured into the streams in the Muskingum Basin. By the time the water reaches Zanesville the organic matter poured in from the cities in the upper part of the basin has been nearly or completely consumed, and that which appears on analysis is undoubtedly of recent origin. But the chlorine in the Muskingum, which is in so great excess over that in Licking Creek, is largely the evidence of pollution both from sewage and from the salt works in the upper part of the basin.

The condition of the water of Licking Creek is so similar to that of Muskingum that it can not be said that either stream is a detriment or a benefit to the other. In the one case we have a water recently polluted, while in the other it appears that the water was at one time more seriously contaminated, but through the effects of oxidation, sedimentation, and dilution the evidences of this contamination have been nearly lost, and the most apparent pollution is that derived from sources not far above Zanesville.

Analyses of the water of the Muskingum below Zanesville show, in a fairly satisfactory manner, the effect of the commingling of the waters of Licking Creek and Muskingum River in conjunction with the wastes of Zanesville.

Below Zanesville, on the Muskingum and on the minor tributaries, there are a number of small towns which, while collectively they contribute some foreign matter, do not influence the character of the water extensively. There is no place of importance until McConnelsville is reached, the county seat of Morgan County, containing 1,825 inhabitants, and provided with water supply and sewers. Just above this place the Ohio State Board of Health has taken a series of samples for examination, the results of which are embraced in the following table.

TABLE 110.—*Analyses of water from Muskingum River above McConnelsville.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1899.												
April 28	35	10	None.	0.178	0.038	0.004	0.08	5.8	269	101.1	56.8	350
May 24	271	28	e[a]	.234	.060	.007	.08	3.8	304	73.0	50.0	1,400
June 22	(b)	20	e	1.064	.152	.003	.13	2.1	1,784	44.5	7.6	7,000
July 25	206	.....	v	.230	.058	.009	.26	11.8	296	90.8	21.8	1,400
August 30	114	22	v	.228	.156	.018	.04	14.8	329	147.2	40.0	1,400
September 27	65	20	e	.164	.046	.012	.10	14.3	306	152.2	None.	420
October 17	52	10	v, e	.140	.028	.015	.06	15.7	308	152.2	31.8	370
November 22	52	20	None.	.162	.034	.004	.11	19.0	315	142.2	49.0	420
Average	.....	19	.....	.300	.075	.009	.11	10.9	489	112.9	32.1	1,600

[a] e, earthy; v, vegetable. [b] Enormous.

From McConnelsville to Marietta, at the mouth of the river, there are the usual number of small villages, the effects of which upon the character of the water are not important. Marietta, with population of 13,384, has considerable manufacturing and a public water supply and sewerage system, which empties into Ohio River, so that it has no effect on the Muskingum. There is, however, considerable manufacturing sewage poured into the latter.

TABLE 111.—*Analyses of water from Muskingum River above Marietta.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1899.												
April 28	52	10	p[a]	0.102	0.056	0.002	0.10	5.7	275	112.4	57.9	350
May 24	600	25	e	.216	.046	.009	.09	2.9	396	71.8	22.4	550
June 22	(b)	22	e	.464	.136	.004	.12	9.3	1,017	93.9	52.0	3,900
July 25	210	28	v	.296	.066	.008	.05	8.2	234	93.6	17.0	600
August 30	80	20	e	.202	.052	.012	.04	8.9	245	122.2	55.0	170
September 27	80	25	e	.158	.022	.010	.05	13.5	304	143.6	6.4	300
October 17	110	10	m	.120	.016	.008	.03	11.2	300	146.8	62.0	275
November 22	49	10	None.	.112	.016	.004	.16	17.9	322	144.2	39.4	1,700
Average	.....	19	.....	.209	.050	.007	.08	9.7	390	116.1	39.0	1,000

[a] p, peaty; e, earthy; v, vegetable; m, moldy. [b] Enormous.

The above analyses show fairly well the character of the water contributed to the Ohio system from the Muskingum Basin. The water

improves in quality between Zanesville and the mouth of the river, and therefore the effect of the Muskingum system on the Ohio is less damaging than might be supposed after considering the points of pollution in the Muskingum.

The analyses given certainly show that the Muskingum is in many places a very foul stream. Indeed, there are few points at which water can be collected in its normal and undamaged state. This stream is certainly not a proper one to use as a sewage course, for its greatest value is in its water resources. It is not good for much as a source of power, its navigation is insignificant, and the humid climate of the country makes its use for irrigation unnecessary. There are, perhaps, certain points along the course of the stream which are fit places for the harvesting of an ice crop, but the Muskingum can never be an extensive ice field. Therefore the water-supply value of the river is practically the only important one, and, as has been shown, this is greatly damaged. It is unwise to utilize for domestic purposes the waters of the Muskingum and its tributaries at almost any point unless efficient means of purification are adopted. On the other hand, the character of the river basin is such that self-purification readily takes place. There is no doubt that if means were used to purify the sewage which is now poured into the stream, the waters could, in certain places, be used as a water supply without any treatment.

SCIOTO RIVER.

DRAINAGE BASIN.

The drainage basin of Scioto River occupies a long, narrow strip of country in the central and southern part of Ohio, extending from the Lake Erie drainage divide on the north to the Ohio River at Portsmouth on the south, and comprising about 6,400 square miles. The source of the river is in Auglaize County, in a portion of the drainage area which juts westward and lies north of the Great Miami Basin. Thence it runs in a generally southerly direction 40 miles, to a point a little southwest of the city of Marion. The fall along this section is nearly 500 feet. Thence its course is almost due south. It passes through the city of Columbus, capital of the State of Ohio, the fall from Marion to this point being 430 feet. Continuing south, the river joins the Ohio at Portsmouth, 110 miles above Cincinnati. The fall of the river between Columbus and Portsmouth averages 26 feet per mile along the entire length of 130 miles. The entire course of the river, measured in a straight line, is 175 miles, although when actually traversed it amounts to nearly 210 miles.

The tributaries are not so large nor so important in this drainage area as they are in the Muskingum, by reason of the fact that the watershed is somewhat narrow. The most important tributaries and the area drained by them are named below.

TABLE 112.—*Drainage area of Scioto River and tributaries.*

	Sq. miles.
Olentangy River at mouth at Columbus	547
Big Walnut Creek at mouth	513
Darby Creek at mouth	592
North Fork of Paint Creek	236
Main Fork of Paint Creek above junction with North Fork	828
Paint Creek at mouth	1,083
Scioto River at southern boundary of Marion County	628
Scioto River at Columbus, above junction with Olentangy River	1,139
Scioto River at Columbus, below junction with Olentangy River	1,686
Scioto River at Circleville and Darby creeks	3,275
Scioto River at Chillicothe	3,923
Scioto River at mouth	6,400

The principal economic value of Scioto River lies in its availability as a source of water supply. It is not an important power stream, although in past years the aggregate of power developed by the numerous plants along it was fairly large, but on account of the flatness of the area there is not sufficient opportunity to develop many or extensive power sites, those which have been utilized being of the capacity which are found necessary to the development of saw and grist mills only. The development of cheaper power in other parts of the country and the improvement of transportation facilities have led to the abandonment of a large number of the power privileges afforded by the Scioto, and very few of those that remain are of much value. Even as a source of water supply the opportunities for conservation are not all that could be desired, for it is necessary in some places to pump the water directly from the flowing stream into distributing reservoirs, the storage capacity of which is not in every case sufficient to allow the water to be properly stored and purified. This condition aggravates the dangers due to polluted river water, for under these circumstances pollution becomes more certain in its unfavorable effects upon the water consumer than it could be if a longer term of storage were afforded.

NORMAL WATER IN THE SCIOTO BASIN.

There are no public records of analyses of a distinctively normal water in the Scioto Basin. The work of the Ohio State Board of Health has so far been confined almost entirely to the examination of polluted streams, and it is only from the series of analyses made near the headwaters of the rivers and above the highest points of appreciable sewage pollution that we are able to obtain any ideas concerning the character of these waters in their normal state. In the basin of the Scioto it is probable that the analysis affording the best idea of the character of its normal water is that which has been made of samples collected above the city of Kenton, in Harding County. The population above the city is almost entirely rural, there being a few small villages, containing from 25 to 100 inhabitants, and while the

contamination which they impart to the headwaters of the Scioto is hardly appreciable, yet it can not be said that the water which reaches Kenton is normal. It is probably nearly so, and for all practical purposes can be so considered. The analyses of this water appear in the following table:

TABLE 113.—*Analyses of water from the Scioto River above Kenton.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1898.											
June 12	4	None.	0.514	0.062	0.024	1.50	2.0	730	210	226	1,300
July 16	4	e[a]	.462	.098	.003	.42	1.0	805	232	.....	480
August 25	2	None.	.292	.084	.000	.00	2.5	625	234	130	430
September 25	4	e	.238	.028	.000	.00	3.8	670	226	122	270
October 23	3	M	.240	.030	.000	.00	3.3	605	252	112	390
December 1	5	M	.638	.571	.030	9.38	1.5	1,075	104	510	1,900
Average	4	.....	.379	.145	.010	1.900	2.3	752	210	183	790

[a] e, earthy; M, musty.

POLLUTION IN BASIN OF THE SCIOTO.

Kenton is a city of 6,852 inhabitants, provided with sanitary sewers and storm-water drains. Both systems discharge into the river. The effect upon the water is easily appreciable upon examination of the following table:

TABLE 114.—*Analyses of water from the Scioto River below Kenton.*

[Parts per million.]

Date of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1898.										
June 12	4.5	0.430	0.142	0.026	1.60	4.0	710	214	228	.....
July 16	3.0	1.720	.476	.000	.00	4.5	720	32	.....	5,800
August 25	2.0	1.328	.384	.010	.00	6.5	605	232	118	2,400
September 25	3.5	.360	.764	.003	.00	12.5	645	238	114	4,200
October 23	3.0	.588	2.160	.005	.00	18.0	650	258	114	17,000
December 1	5.0	.624	.584	.030	.44	2.0	975	118	466	14,000
Average	3.5	.841	.751	.012	.....	7.9	718	182	173	8,700

Continuing down the Scioto no further important source of pollution is met with until the mouth of Little Scioto River is reached. In the drainage area of this river is the city of Marion, containing, according to the Twelfth Census, 11,862 inhabitants. Sewer outlets enter the river a short distance above its confluence with the Scioto, and there are published records of analyses of the water from Little Scioto, above and below the sewer outfall, which are reproduced in Table 115.

TABLE 115.—*Analyses of water from Little Scioto River above and below the Marion sewers' outfall.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses constituting average.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Above Marion	3	0.489	0.378	0.013	1.25	5.3	469	204	75	8,200	6
Below Marion	3	.464	1.897	.037	1.31	16.5	553	231	85	9,500	6

The report of the analyses of water from Little Scioto River, taken below the Marion sewer outlets, shows clearly the foulness of the contribution which the system receives from this tributary.

The next point of examination of the Scioto below the confluence of Little Scioto is the Ohio Girls' Industrial Home, which contains a population of over 400. A complete system of sewers is here provided, the wastes from which are poured directly into the river. Table 116 shows clearly the effects of this contamination upon the stream.

TABLE 116.—*Analyses of water from Scioto River above and below the Ohio Girls' Industrial Home.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses constituting average.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Above industrial home	3.0	0.334	0.086	0.008	0.176	6.6	509	175	123	1,600	3
Below industrial home	3.0	.320	.103	.009	.206	7.5	507	173	126	1,600	5

The next important center of pollution is the city of Columbus, where enters Olentangy River, the largest stream tributary to the Scioto. Above the confluence of these two rivers the State Board of Health has made three series of examinations, one at Wyandot Grove, above Columbus pollution, another about 3 miles below at Jones's dam, where the city's sewage begins to have effect; and a third at Sandusky street bridge, near the mouth of the Olentangy. The results of this interesting series of examinations appear below.

TABLE 117.—*Analyses of water from the Scioto River at Wyandot Grove.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1898.											
June 13	2.0	s [a]	0.260	0.040	0.002	0.200	4.0	445	194	52	730
July 17	3.0	------	.378	.028	.002	.170	5.5	500	182	94	910
August 23	2.0	None.	.344	.096	.003	.030	3.8	440	172	88	290
September 23	1.5	e	.316	.098	.002	.030	7.8	550	176	126	300
October 21	2.0	e	.268	.048	.002	.050	7.7	585	200	140	200
December 3	5.0	e	.366	.100	.020	6.300	1.5	467	146	132	2,000
Average	2.5	------	.322	.068	.005	1.150	5.0	498	178	105	740

[a] s, sweetish; e, earthy.

TABLE 118.—*Analyses of water from Scioto River at Jones's dam.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1898.											
June 23	2	None.	0.276	0.037	0.002	0.340	4.5	455	194	48	810
July 17	3	None.	.398	.028	.003	.200	3.8	510	184	104	400
Aug. 23	2	m [a]	.380	.092	.003	.080	4.1	450	178	80	590
Sept. 23	2	e	.306	.088	.003	.000	7.3	510	176	116	350
Oct. 21	2	e	.296	.082	.006	.050	7.4	454	192	124	700
Dec. 3	5	e	.354	.102	.025	6.500	1.7	464	140	136	2,200
Average	3	------	.335	.071	.007	1.20	4.8	489	177	101	840

[a] m, moldy; e, earthy.

TABLE 119.—*Analyses of water from Scioto River at Sandusky street bridge.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1898.											
June 13	2.0	None.	0.342	0.110	0.007	0.320	7.0	480	190	62	1,470
July 17	3.0	M[a]	.376	.048	.002	.260	4.0	480	184	92	1,030
Aug. 23	2.0	M	.394	.200	.015	.070	10.1	445	180	78	4,540
Sept. 23	2.0	M	.420	.280	.005	.000	11.5	460	152	106	10,800
Oct. 21	1.5	d	.392	.086	.004	.040	8.7	525	158	98	1,150
Dec. 3	6.0	d	.418	.110	.025	5.820	2.3	474	144	136	10,200
Average	2.5	.....	.390	.139	.010	1.090	7.2	477	168	95	4,900

[a] M, musty; d, disagreeable.

OLENTANGY RIVER.

The Olentangy drains an extremely narrow basin lying east of and running parallel throughout the greater part of its length to the middle section of the main river. It rises in the northern part of Morrow County and flows for a short distance northwestward into Crawford County, passing the city of Galion, whence it takes a southerly course, running within 5 miles of the city of Marion, and after flowing through Delaware County and past the city of Delaware enters the Scioto at Columbus.

The highest point of pollution on Olentangy River is Galion, a city of 7,282 inhabitants. The population above this city is sparse, and the water in the river is therefore nearly normal. The State Board of Health conducted in the year 1898 a series of analyses of the water in the river above and below the outlet of Galion sewers, the average results of which appear below in Table 120. As the analyses indicate, the effect of Galion sewage on the river is marked.

TABLE 120.—*Analyses of water from Olentangy River above and below Galion.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses constituting average.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Above Galion	3.5	M[a]	0.476	0.132	0.007	0.640	8.3	463	206	69	450	5
Below Galion	3.5	M	.994	4.696	.111	.640	50.7	873	262	190	49,000	5

[a] M, musty.

The point of pollution worthy of consideration next below Galion is Delaware, the largest city in and the county seat of Delaware County. Many tributaries enter the river between these two cities, so that the stream is many times larger at Delaware than it is 40 miles above, at Galion. The water in the river above Delaware is markedly improved, as might be expected, but after receiving the contents of the city sewers the conditions are again undesirable, as shown in the following table:

TABLE 121.—*Analyses of water from Olentangy River above and below Delaware.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses constituting average.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Above Delaware	3.5	M[a]	0.322	0.073	0.004	0.860	2.5	408	186	61	1,030	6
Below Delaware	3.5	M	.357	.118	.017	.810	14.5	484	188	96	1,130	6

[a] M, musty.

There are of public record two series of analyses in the lower part of Olentangy River. The sampling point at Olentangy Park is above the serious pollution of Columbus, while the other is at Dublin Bridge, in the city of Columbus, just above the confluence of the Olentangy and Scioto rivers.

TABLE 122.—*Analyses of water from Olentangy River at Olentangy Park.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1898.											
July 16	3.0	e[a]	0.426	0.062	0.003	0.240	3.0	390	178	50	680
Aug. 24	2.5	None.	.334	.094	.003	.050	5.8	450	206	74	700
Sept. 23	3.0	e	.354	.076	.002	.000	10.2	555	204	134	400
Oct. 21	2.0	e	.286	.072	.005	.120	7.7	620	226	122	280
Dec. 3	5.0	e	.362	.066	.020	4.950	3.0	404	126	98	1,800
Average	3.0	.....	.353	.074	.007	1.070	5.9	484	188	96	770

[a] e, earthy.

TABLE 123.—*Analyses of water of Olentangy River at Dublin bridge, Columbus.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1898.											
June 13	2.0	e[a]	0.294	0.066	0.011	0.210	5.5	415	202	48	1,150
July 17	3.0	....	.388	.058	.004	.320	3.2	360	166	44	1,600
Aug. 23	2.0	M	.302	.096	.002	.020	5.4	440	194	72	2,100
Sept. 23	2.0	M	.352	.126	.001	.000	8.5	525	192	110	770
Oct. 21	1.5	M	.294	.036	.002	.000	8.7	585	218	112	520
Dec. 3	10.0	M	.372	.074	.020	4.800	3.0	387	132	96	4,000
Average	3.4	....	.334	.076	.007	.890	5.7	452	184	80	1,700

[a] e, earthy; M, musty.

The analyses in Table 123 show the character of the water contributed to the Scioto system by its main tributary. Comparison of the various tables of analyses of the water of the Olentangy will show that at the mouth of the river the condition of the water is far better than it is below Galion, near its headwaters. Along the lower length of the river, however, the water is highly polluted and is unfit for use as a public supply without purification. The other values of the river are not seriously impaired, but as its resources are confined almost entirely to those of water supply, there is little that remains as available assets.

Below the confluence of the Scioto and the Olentangy the bed of the main river is very flat, so that it becomes in places almost a slack-water stream. The storage advantages are thus increased, and the river has remarkable self-purifying powers. Below Columbus the first sampling point is Frank road bridge, which is situated well down toward the lower part of the city. Analyses of the water taken at this point show the effect of the mixture of the upper Scioto and Olentangy waters and the sewage from Columbus.

TABLE 124.—*Analyses of water from the Scioto River at Frank road bridge, Columbus.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1897.											
June 11	2.0	d[a]	1.130	2.322	------	0.030	16.0	495	238	86	8,900
July 17	4.0	d	.896	1.644	0.188	.000	13.0	440	182	84	64,000
August 23	4.0	d	1.136	3.824	.000	.000	21.0	520	256	94	195,000
September 23	3.0	d	.876	7.600	------	.000	39.0	680	330	112	250,000
October 21	5.0	d	2.340	10.170	.000	.000	41.5	765	346	92	183,000
December 4	4.0	o	.780	.880	.070	4.420	6.0	472	160	134	135,000
Average	4.0	----	1.193	4.406	.043	.74	22.7	562	252	100	140,000

[a] d, disagreeable; o, oily.

Seven miles below Frank road bridge is Shadeville bridge, at which a series of analyses was made, the average results of which are reproduced in the table below:

TABLE 125.—*Analyses of water from the Scioto River at Shadeville bridge.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses contributing to average.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Shadeville bridge	3.5	0.806	3.352	0.121	0.121	19.3	510	285	74	7,200	5

Circleville is a village of 6,991 inhabitants, situated near the central part of Pickaway County, about 30 miles below Columbus. A series of examinations made of the river water taken at Main street bridge has been made by the State Board of Health, the reports of which are set forth in Table 126.

TABLE 126.—*Analyses of water from the Scioto River at Circleville.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1897.											
July 22	10.0	e[a]	0.660	0.118	0.030	1.13	1.7	285	114	54	14,000
Aug. 26	2.0	-----	.378	.352	.023	.16	5.5	395	228	20	600
Sept. 27	1.5	e	.320	.210	.007	------	11.7	400	242	28	500
Oct. 25	2.5	M	.314	.534	.045	.13	11.2	435	282	28	800
Dec. 4	5.0	M	.424	.344	.050	2.68	2.5	393	144	76	3,500
Average	4.0	-----	.419	.312	.031	.82	6.5	382	202	41	3,900

[a] e, earthy; M, musty.

It will be seen that the water at Circleville has been purified to a considerable extent in its course from Columbus down. Free ammonia, nitrites, and chlorine, the standard indicators of sewage pollution in water, are very much reduced, and the analyses at the lower point indicate better conditions.

The only important point of pollution below Circleville is the city of Chillicothe, containing 12,975 inhabitants. No analyses of water taken below this place are recorded. Sixty miles below Chillicothe the river enters the Ohio at Portsmouth.

Little remains to be said concerning the Scioto. The conditions of the river are wholly favorable to the purification of foreign matters that are poured into it, but the raw sewage it receives from the various cities constitutes a source of contamination that can not be overcome. The river is little more than a dumping ground for refuse, and its misuse affords a good example of the wanton destruction of a valuable resource; but the work of the State Board of Health of Ohio bids fair to be fruitful, so that we may confidently expect great improvements in sanitation in the Scioto Valley.

OHIO RIVER AT CINCINNATI.

On Ohio River, below the mouth of the Scioto, a series of notable investigations has been made by Mr. George W. Fuller, following his work on the water supplies of Louisville and Cincinnati, and the reports of these inquiries are probably the ablest that have been presented on the subject in this country. The Cincinnati report, in a concise, definite, and methodical manner, gives just the facts necessary to the discussion, and shows the character of the water of the Ohio as it comes down to Cincinnati, bearing traces of all the pollution heretofore considered, as well as a large amount derived from tributaries that have not yet been investigated, or the investigations of which are not of public record. Therefore one can arrive at an

understanding of the character of the Ohio River at this point no better than by consulting the above-mentioned report, parts of which are, for convenience, here reproduced.[a]

At the outset it is imperative, for a clear understanding of this report, that there should be fixed in mind the two most characteristic features of the local river water, as follows:

1. The wide range in the amount of suspended matter present in the water.
2. The great variations in the nature of the suspended matter, and especially in the size of the particles.

A comprehensive idea of the amounts of suspended matter found at different times in this water during the year 1898 is shown in the following summary:

TABLE 127.—*Turbidity of Ohio River water.*

[Parts per million.]

Number of days, 1898.	Corresponding range of suspended matter.	Number of days, 1898.	Corresponding range of suspended matter.
0	([a])	29	501–1,000
41	11– 50	5	1,001–2,000
63	51–100	1	([b])
127	101–250	Average	230
99	251–500		

[a] Less than 10. [b] Over 2,000.

The great variation in the character and size of the suspended matters is best illustrated by the following table, in which there is indicated the different hydraulic subsiding values (or sizes) of two extreme types of the river water. Type I is characteristic of the water during the early portion of a heavy freshet, when it is heavily laden with silt and fairly coarse clay, and Type II is representative of the water during later portions of rises, while it is charged to a greater relative degree with very fine, minute particles of clay.

TABLE 128.—*Periods of subsidence necessary with water from Ohio River at Louisville, Ky.*

Period of subsidence (hours).	Suspended matter in parts per million.		Per cent removed.	
	Type I.	Type II.	Type I.	Type II.
0	2,333	205	0	0
1	932	81	60	55
3	653	80	72	56
6	396	79	83	56
12	350	73	85	58
24	300	61	87	63
48	259	44	89	67
72	210	36	91	70
96	186	31	92	72

Between Types I and II there are found in the course of a year an almost endless number of intermediate combinations.

* * * * * * *

The direct causes of these variations in the Ohio River water are the rises or freshets which are so characteristic of this stream. Indirectly there are a number

[a] Report on investigations into the purification of the Ohio River water, 1899, p. 9 et seq.

of factors which exert much influence. Among them are the amount, rate, distribution, and frequency of the rainfall in the valley, and also the surface geology, topography, area, and length of the watershed, and the condition of the soil at the time of heavy rains. To solve the problem of establishing the relation between the composition of this river water and the factors affecting it is a complex matter; and so far as our knowledge goes there are available no adequate data for the purpose, nor are such data being obtained.

* * * * * * *

The watershed of the Ohio River above the intake of the new Cincinnati waterworks at California has an area of about 70,600 square miles. This area includes portions of the States of Ohio, New York, Pennsylvania, Virginia, North Carolina, West Virginia, and Kentucky.

Above the intake of the Front street pumping station (used during these tests) the area of the watershed is estimated at 72,400 square miles. In addition to the area at the new intake the last area includes that of the watershed of the Little Miami River, and that of the Ohio River itself between the Little Miami and the Front street intake, a distance of about 6 miles.

About half a mile downstream from the Front street intake the Licking River empties into the Ohio River on the Kentucky side. At this point the normal width of the river is about 1,000 feet. The Front street intake is situated about 200 feet from the Ohio shore, and in a straight line is distant about 4,000 feet from the mouth of the Licking. Under some conditions of river stages and of windstorms the waters of the Licking reach the Front street intake.

The Licking River has a watershed of about 3,300 square miles. Adding this to the above, there is obtained 75,700 square miles as a total area of the watershed of the Ohio River above the present intake opposite the city.

TABLE 129.—*Table showing the monthly rainfall in inches at various stations in the Ohio River Valley for the year 1898.*

Station.	Jan	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Cincinnati, Ohio	7.76	2.21	6.70	1.15	3.03	1.58	3.26	2.61	2.62	2.90	2.69	2.46	38.97
Portsmouth, Ohio	10.03	1.69	5.14	2.05	3.53	3.13	5.27	6.92	1.97	3.59	2.54	2.76	48.62
Catlettsburg, Ky	8.05	2.48	6.93	2.19	4.83	4.52	4.84	6.93	2.10	4.14	2.65	2.83	52.49
Point Pleasant, W. Va	8.04	1.93	5.81	1.48	3.51	2.87	2.79	6.40	2.07	3.15	2.67	2.57	43.29
Parkersburg, W. Va	5.73	2.24	5.43	2.17	2.76	4.98	4.38	4.66	2.09	3.90	2.50	2.16	43.00
Marietta, Ohio	5.74	2.39	6.03	2.30	2.77	5.04	5.20	5.31	3.69	4.24	3.15	2.21	48.09
Wheeling, W. Va	4.79	2.50	5.15	3.72	3.63	2.98	5.81	7.82	3.24	3.37	2.66	3.03	48.93
Pittsburg, Pa	3.40	1.60	5.45	1.60	3.99	3.98	2.56	4.01	1.06	3.85	2.34	1.90	35.74
Oil City, Pa	5.32	2.53	5.74	2.13	4.64	4.56	4.45	6.73	2.11	5.18	4.33	2.90	50.62

TABLE 130.—*Table showing the normal monthly rainfall in inches at various stations in the Ohio River Valley.*

Station.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Cincinnati, Ohio	3.5	3.7	3.3	3.2	3.4	4.4	3.4	3.7	2.4	2.4	3.3	3.2	39.9
Portsmouth, Ohio	3.5	3.2	3.5	3.2	3.5	4.0	3.9	3.4	2.8	2.8	2.9	3.5	40.2
Catlettsburg, Ky	4.3	4.0	4.2	3.2	4.0	3.8	4.4	3.6	2.9	2.7	3.5	2.9	43.5
Point Pleasant, W. Va	3.5	4.1	3.9	3.7	3.5	4.2	4.4	4.0	2.4	2.4	3.1	2.7	41.9
Marietta, Ohio	3.1	3.1	3.2	3.3	3.9	4.1	4.4	3.9	3.1	3.1	3.1	3.4	41.7
Parkersburg, W. Va	3.9	3.8	3.0	3.2	3.5	4.0	4.4	3.8	3.1	2.3	2.8	2.3	40.1
Wheeling, W. Va	3.4	3.1	2.6	2.8	4.1	3.7	3.7	4.1	2.8	2.6	2.7	3.0	38.6
Pittsburg, Pa	2.6	2.5	2.8	3.0	3.5	3.6	4.0	3.4	2.9	2.8	2.6	2.9	36.6
Oil City, Pa	3.3	3.6	2.8	2.7	3.9	4.6	3.6	2.7	3.4	2.6	3.2	2.8	39.2

COMPARISON OF THE FREQUENCY, INTENSITY, AND DURATION OF RISES OR FLOODS IN THE OHIO RIVER AT CINCINNATI DURING 1898 WITH THE NORMAL.

This subject is one of great importance from a practical standpoint, because it deals with factors which directly produce the large quantities of and variations in the matters suspended in the river water. In view of the fact that these suspended matters are a point of vital significance in connection with the construction of an applicable system of clarification and purification, and also in the efficiency and economy of its operation, it is necessary to know, at least in general terms, how nearly normal was the suspended matter during these tests, and further, it would be very desirable to be able to foretell the conditions with regard to the suspended matters due to rises, as an aid in the operation of a plant.

To accomplish these purposes involves a study of the frequency, intensity, and duration of the rises in the river. It is an easy matter to deal with the first of these factors, except when the rises overlap each other; but to establish a relation between suspended matter, both in amount and character and the intensity and duration of rises, is a very difficult and perplexing problem. At the beginning of a freshet the rapidity with which the water rises seems to be a great factor, and the more rapid is the rise the greater is the amount of suspended matter and also the percentage of silt. When the rise is of a long duration it is found that, with the waters coming from the head of the valley, the weight of suspended matters gradually decreases, but the percentage of clay steadily increases, owing to the deposition of silt in the stream itself.

Just how it is best to arrange the available data to throw light upon these points is not wholly clear to us, since all efforts in this direction are wholly arbitrary and of necessity incomplete. However, it is believed that a comparison of the intensity and number of rises in the river with the rises for the past ten years will give as good a comparison for this purpose as can be obtained. In the following table, therefore, are given the number of days on which the river was rising moderately, rapidly, very rapidly, and when there was developing an extreme freshet:

TABLE 131.—*Number of days in the year on which the Ohio River was rising at various rates during the last ten years.*

Year.	Rate of rise in feet per day.			
	1.0-2.9.	3.0-5.9.	6.0-11.9.	Over 12.
1889	66	12	3	0
1890	63	31	4	0
1891	44	24	4	0
1892	33	10	5	1
1893	34	23	2	0
1894	24	8	4	0
1895	26	11	5	1
1896	47	24	2	0
1897	45	21	2	1
1898	54	25	7	0
Average	44.6	18.9	3.6	0.3

TABLE 132.—*Summary of amounts of the several constituents found in water of Ohio River during the year 1898.*

Constituent.	Parts per million.		
	Maximum.	Minimum.	Normal.
Total suspended matter	2,333.0	24.0	230.0
Suspended organic matter (nitrogen as albuminoid ammonia)	0.758	0.022	0.200
Total dissolved residue	223.0	67.0	120.0
Total nitrogenous organic matter	0.868	0.106	0.290
Nitrogen as free ammonia	0.074	0.008	0.025
Nitrogen as nitrites	0.030	0.000	0.003
Nitrogen as nitrates	1.34	0.37	0.60
Chlorine	44.0	3.0	10.0
Sulphuric acid	46.0	13.0	24.0
Normal hardness	57.0	11.0	33.0
Alkalinity	70.0	20.0	45.0
Microscopic organisms per cubic centimeter	40.0	----------	----------
Carbonic acid	47.0	6.0	26.0
Bacteria per cubic centimeter	150,000	1,000	20,000

Odor.—The river water ordinarily has a slight odor characteristic of surface waters, the nature and intensity of which are somewhat variable. At different times the odor is musty, aromatic, resinous, and vegetable. The latter is most noticeable after heavy rains during the warm portions of the year. These odors become more pronounced upon heating the water, but, so far as noted during these tests, there is a practically complete absence of disagreeable or objectionable odors.

Color.—Independent of the suspended matter in it the normal river water is practically colorless, although in absolute terms it contains a small but measurable amount of color. It seems quite probable that, at times following certain kinds of rises in the river, there is an appreciably larger amount of dissolved color in the water than is normally the case; but experience shows that ordinarily it is easier to remove the unusual amounts of dissolved color than is the case with the finest particles of suspended clay. After passage through a Pasteur filter or a fine paper filter the water contains no color which is ordinarily visible.

Taste.—Ordinarily the river water has an earthy taste, which, however, does not become disagreeable except at times of great turbidity. Freed of its suspended matter, this water has a very satisfactory and agreeable taste.

Appearance.—The turbidity of the river water is such that its appearance is almost always unsatisfactory and uninviting, and for about half of the time it is so turbid that it is repulsive when considered for domestic use.

Weight of suspended matters.—When expressed in parts by weight per million parts of water by volume, the suspended matters in this water normally range from 20 to 2,500 and average about 230 parts.

Character of suspended matters.—In character as well as in amount of suspended matter the river water possesses a wide and rapidly changing degree of variability. The water in the course of the year contains an almost endless combination of varying proportions of fine sand made up of particles of quartz and hard silicates, with high specific gravity and a diameter larger than 0.002 inch; of silt with its intermediate size, specific gravity, and composition; and of very fine clay particles of aluminum silicate, with varying degrees of hydration, of low specific gravity, and of a size ranging from 0.0002 inch to less than 0.00001 inch.

Amount of organic matter.—The organic matter in the river water ranges from an amount which is fairly normal for Eastern waters to quantities (during rises) which are excessive, as judged by the data for many years collected from rivers not located in this general section of the country. The local data summarized above are a striking proof of the fact that it is not the amount but the character of the organic matter which is of importance from a sanitary standpoint.

Character and stability of organic matter.—From the immediately adjoining portion of the watershed there is quite an amount of sewage pollution. Owing to the large dilution, the deleterious effect of this is greatly attenuated. By no means is it eliminated at times of comparatively clear water, but during rises this crude organic matter to a considerable degree seems to be united and attached to particles of suspended matter, and thus carried to the bottom.

The consequence of this dilution and sedimentation is that the water contains very little organic matter, except that of a fairly stable character coming from the washings of the surface of the earth. With water taken from the new intake, above the local sources of pollution, this will be true to a still greater degree.

Alkalinity.—The alkalinity is caused by the carbonates and bicarbonates of lime and magnesia, and in a measure corresponds to temporary hardness (bicarbonates). It is the alkalinity which measures the capacity of the water to decompose sulphate of alumina and other coagulating salts. This water contains an average and minimum alkalinity of 45 and 20 parts per million, respectively. By these amounts of alkalinity there can be decomposed, respectively, about 6.5 and 3 grains per gallon of sulphate of alumina of ordinary composition, assisted by the average absorption of chemical by the suspended matters in the water.

Incrusting constituents.—Those constituents of water which produce incrustations in steam boilers comprise the sulphates, chlorides, and perhaps nitrates of lime and magnesia. In this water they are present (on an average of 33 parts per million) to a degree greater than in most of the Eastern waters, but smaller than in the waters farther west. On the whole, this water is a good one for boiler purposes, so far as incrusting constituents are concerned.

Gaseous constituents.—Atmospheric oxygen is apparently present in this water during cold weather to about the limit of saturation, and during the warm season there is contained in the water rather more oxygen than is the case with some surface waters, although the quantity at times becomes only about 40 per cent of that found during the winter. Carbonic acid (carbon dioxide) is present in this water to a degree which is apparently high, according to the limited data available from Eastern sources, but much lower than is the case with waters farther west coming from limestone regions.

Taking together atmospheric oxygen and the carbonic acid, they make the natural conditions quite favorable for the corrosion of unprotected iron receptacles, but the corrosion of lead pipes is promptly arrested by the action of dissolved constituents of the water itself.

Numbers and kinds of bacteria.—On an average the numbers of bacteria in the

river water (about 20,000 per cubic centimeter) are rather higher than in the ordinary river water. The range is also very great, 1,000 to 150,000, and is associated very intimately with the rises of the river.

At the present point of intake, opposite the city, a considerable number of the bacteria are of sewage origin. These sewage bacteria will be largely absent apparently in the water taken from the new intake at California.

Microscopic organisms.—The turbidity of the Ohio River water was so great during the larger part of the year 1898 that the sunlight was excluded to a degree practically inhibiting the growth of algæ and similar micro-organisms. When the river water was low and fairly clear these organisms were present in considerable numbers, but did not become of practical significance. The dissolved constituents (such as nitrates) in the river water, and especially at times of low water, are well adapted, however, as a food for the organisms which also require sunlight for their development.

TABLE 133.—*Suspended matter in water of Ohio River at Cincinnati from January 10 to March 23, 1898, with corresponding stages of height of river in feet.*

[In parts per million.]

Date.	Stage of river.	Suspended matter.	Date.	Stage of river.	Suspended matter.	Date.	Stage of river.	Suspended matter.
Jan. 10	33.0	2,333	Feb. 3	25.0	372	Feb. 24	33.0	221
11	32.2	1,151	4	21.5	184	25	33.2	332
12	35.4	1,024	5	18.7	134	26	32.4	170
13	38.0	719	6	16.5	113	27	30.7	123
14	37.7	578	7	14.7	108	28	28.0	141
15	39.7	470	8	14.0	96	Mar. 1	25.0	150
16	42.5	433	9	13.4	88	2	27.6	43
17	44.3	416	10	13.0	172	4	18.7	125
19	44.5	308	11	13.7	237	5	17.5	114
21	45.5	358	12	16.2	401	8	15.4	57
22	44.4	285	13	17.3	377	12	16.3	393
23	49.7	401	14	19.5	182	15	17.6	102
24	50.4	535	15	23.5	425	16	19.0	174
25	51.3	522	16	27.6	262	17	22.6	406
26	52.2	601	17	30.0	246	18	25.2	684
27	51.2	533	18	31.4	236	19	28.6	300
28	49.3	292	19	30.7	192	21	41.0	782
29	47.1	269	20	31.1	413	22	42.3	479
30	43.5	207	21	30.5	293	23	46.7	476
31	39.1	57	22	30.6	149			
Feb. 2	29.5	248	Feb. 23	30.6	310			

Of great importance as evidence of sewage pollution were the tests for Bacillus coli communis, which, as stated in previous pages, is an intestinal parasite. Mr. Fuller found that there was little room for

doubt that this germ was constantly present in the river water. He states:

From the evidence at hand it is probable that, by taking 2 cubic centimeters for each test, this germ would be found practically without exception. Upon taking 1 cubic centimeter for each test the identity of this bacillus was established in 60 per cent of the samples as shown by the results of tests, as follows:

TABLE 134.—*Result of tests (positive and negative) for Bacillus coli communis in Ohio River water at Cincinnati.*

Date.	Result.	Date.	Result.	Date.	Result.	Date.	Result.
1898.		1898.		1898.		1898.	
Mar. 24	—	May 2	+	June 7	+	Aug. 1	+
25	—	3	+	9	—	2	—
26	—	5	+	10	—	3	+
29	+	6	+	13	—	5	+
31	+	7	—	15	+	6	+
Apr. 1	—	8	—	16	+	7	+
2	—	9	+	18	—	9	—
3	—	10	+	19	+	10	+
4	—	11	+	20	+	12	+
5	+	12	+	24	+	13	+
6	+	13	—	25	+	15	+
7	—	14	+	28	+	16	+
8	+	16	+	29	—	18	+
9	+	17	+	30	+	19	+
10	—	18	—	July 1	+	20	+
11	—	19	+	2	+	22	—
12	—	20	—	4	+	23	—
13	+	21	—	7	+	24	+
14	—	22	—	8	+	27	+
15	+	23	+	9	+	30	—
16	+	24	+	10	+	31	+
17	—	25	—	13	+	Sept. 2	+
18	+	26	+	14	+	3	+
20	+	27	+	16	+	5	—
21	—	28	+	18	+	9	+
22	+	29	—	19	+	10	—
23	+	30	—	20	+	13	+
25	+	31	+	22	—	14	—
26	—	June 1	—	23	+	15	+
27	—	2	—	25	—	16	+
28	—	3	+	27	—	17	+
29	+	4	—	28	+	18	—
30	+	6	+	29	+	21	—

TABLE 134.—*Result of tests (positive and negative) for Bacillus coli communis in Ohio River water at Cincinnati*—Continued.

Date.	Result.	Date.	Result.	Date.	Result.	Date.	Result.
1898.		1898.		1898.		1898.	
Sept. 22	+	Oct. 15	+	Nov. 7	+	Dec. 2	—
23	+	17	—	8	+	3	—
26	+	19	—	10	—	6	—
27	+	20	—	11	—	8	+
29	+	22	—	12	—	10	—
Oct. 1	+	23	—	16	—	13	+
3	—	24	+	17	+	15	+
5	+	27	+	19	—	17	+
7	—	28	+	20	—	20	+
9	+	28	+	21	—	21	+
10	+	30	+	24	—	24	+
11	+	Nov. 1	+	26	+	27	—
13	+	2	+	28	—	29	—
14	—	4	+	30	—		

MIAMI AND LITTLE MIAMI RIVERS.

The important tributaries entering the Ohio next below Scioto River are Miami and Little Miami rivers. They occupy the most elevated portions of Ohio, and the drainage basin of the larger river extends into Indiana. Taken altogether, the area drained by the two rivers covers 6,950 square miles, of which 5,601 lie in Ohio. (See fig. 17.) The population in the basin is 641,657, or about 92 per square mile. Thirty cities and villages, representing a population of 242,762, have water supplies. This is 91 per cent of the urban population in the river basin and 44 per cent of the entire population. Fifteen of the cities have been supplied with sewerage systems, all of which discharge into the neighboring streams without previous purification.

LITTLE MIAMI RIVER.

The drainage basin of the Little Miami River occupies a small, wedge-shaped portion of the State of Ohio lying between the basins of the Scioto and Miami rivers and fronting at the broad southern end on Ohio river. From its headwaters to its confluence with the Ohio the Little Miami traverses 94 miles and has a total fall of 696 feet, or 7.4 feet per mile. The tributaries of the Little Miami are Cæsars Creek, Todds Fork, and the East Branch of the Little Miami, the latter, draining an area of 475 square miles, being the most important.

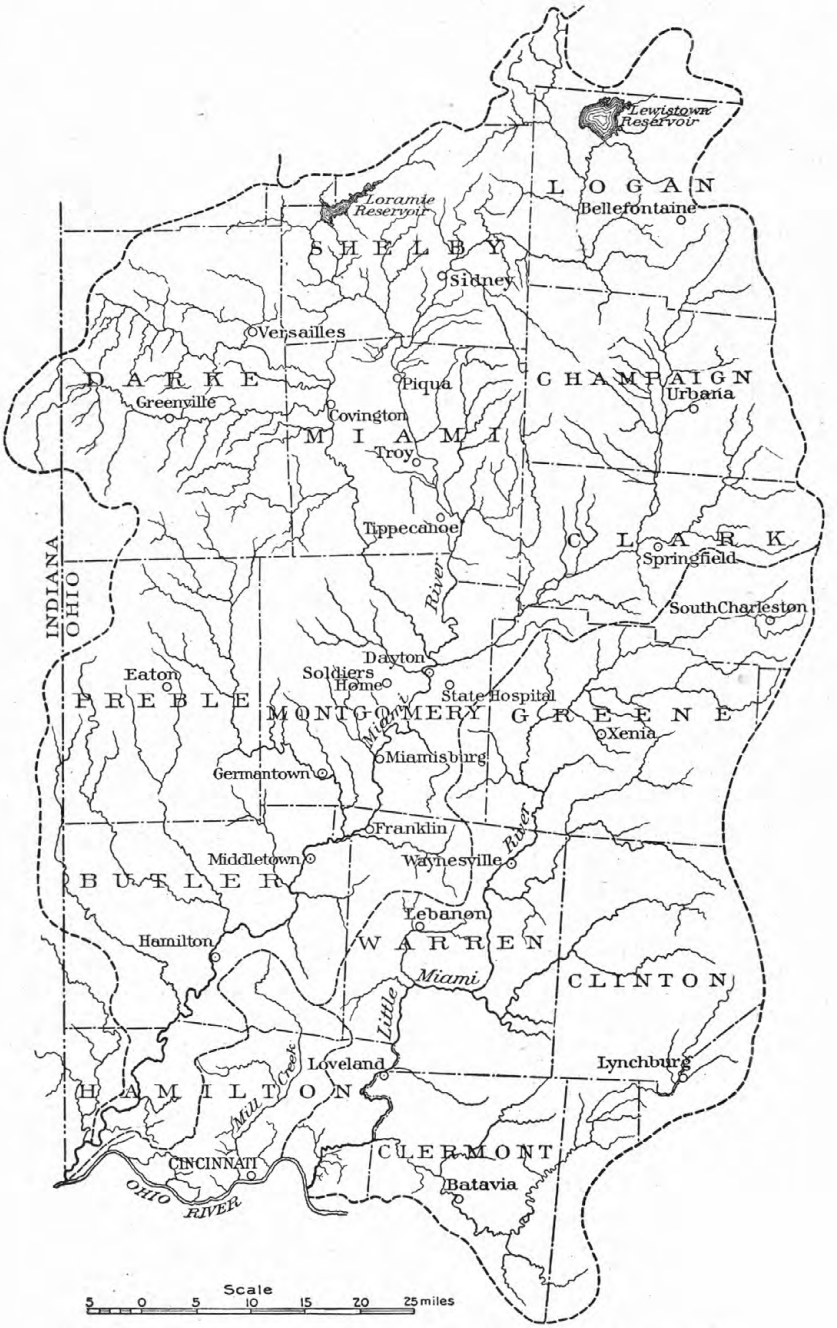

FIG. 17.—Drainage basins of Miami and Little Miami rivers.

The drainage area of the Little Miami is almost entirely devoted to farming. It is a prosperous country, with a rural population of 81,314 and an urban population of only 39,645. Sewage pollution from cities is, therefore, not so important here as in other areas which have been studied; but the run-off water from highly fertilized fields shows on analysis a large proportion of organic constituents which, if interpreted from the analysis alone, without special acquaintance with the origin of the water, would perhaps indicate a high degree of sewage pollution.

At the headwaters of the river, in Clarke County, the first important settlement is South Charleston, which has a population of 1,096. There are three short sewers in the village, and the water supply is from private wells 15 to 20 feet deep. South Charleston can therefore be considered the head of pollution upon Little Miami River. Above this place the waters are probably free from specific sewage contamination. Analyses show, however, that the organic matter is extremely high, due undoubtedly to the run-off from manured fields and rank decay of vegetable growths.

TABLE 135.—*Analyses of water from Little Miami River above South Charleston.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Rainfall during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1901.													*Inches.*
May 28	47	26	e[a]	0.200	0.138	0.042	1.24	------	354	225.8	66.0	3,800	0.72
June 26	144	40	v	.442	.262	.090	.66	------	390	239.4	39.8	2,200	.80
July 17	120	30	v	.522	.230	.022	.06	1.5	438	290.2	7.4	3,800	.74
Aug. 20	130	30	e	.540	.156	.018	-------	0.0	349	221.8	36.2	2,800	1.59
Oct. 18	95	23	v	.242	.080	.013	.000	0.0	362	223.2	00.0	3,400	.03
Nov. 7	100	29	v	.356	.112	.018	.000	4.0	423	266.2	00.0	3,000	.23

[a] e, earthy; v, vegetable.

The analyses set forth in the above table indicate a water of comparatively high organic content. The testimony of the free ammonia and nitrite determinations would seem to indicate a fairly high degree of sewage pollution, but this is not borne out by the remainder of the analytical statement. The water can not be regarded in any sense as normal, but it is probably free from dangerous impurities.

Below South Charleston, on Little Miami River, are Clifton and Yellow Springs, with populations of 262 and 1,371, respectively, producing no appreciable contamination of the surface drainage.

On Massicks Creek, which enters the Little Miami just above Xenia,

are situated Cedarville and Wilberforce College. At the former place a strawboard works contributes the usual amount of deleterious matter, while at the college a part of the plumbing system is connected with the creek.

The water which comes down to Xenia in the channel of Little Miami River has received the pollution from several unimportant settlements, but most damaging refuse comes from the strawboard works at Cedarville. Analyses of the water (see Table 136) indicate that, from a chemical standpoint, it is of as good quality as that found at the headwaters, above artificial pollution. The bacteriologic examination, however, is indicative of an organic content more highly putrefactive than that which was present in the water above South Charleston.

TABLE 136.—*Analyses of water from Little Miami above Xenia.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Rainfall during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1901.													*Inches.*
Apr. 26	45	20	v[a]	0.220	0.032	0.028	1.17	1.1	335	223.8	18.4	44,000	0.96
May 28	80	28	v	.270	.230	.034	.70	.5	396	234.8	27.8	120,000	1.35
June 28	175	33	v	.314	.174	.038	.67	.8	423	250.8	00.0	4,800	.93
July 17	142	30	v	.794	.280	.056	.03	.7	374	260.8	00.0	1,700	.38
Aug. 22	110	43	v	.296	.090	.030	.02	.0	369	230.2	22.2	17,000	2.92
Sept. 17	50	16	v	.226	.066	.022	.06	1.4	315	235.8	00.0	3,200	.18
Oct. 18	48	35	M	.302	.136	.009	.0	.8	386	269.8	00.0	180,000	.05
Nov. 9	28	65	v	.306	.006	.010	.12	1.9	368	287.2	00.0	80,000	.23

[a] v, vegetable; M, musty.

Below Xenia the water of the Little Miami does not seem to be inferior to that above. Although the city has a population of 8,696, no sewers have been established, and the contamination of the river is not so great as might be expected from a municipality of this size. Xenia is not situated directly upon Little Miami River, but some distance up a small stream called Shawnee Run. The greatest source of pollution about Xenia is the Ohio Soldiers and Sailors' Orphans' Home, situated on Shawnee Run, southeast of Xenia. This home has an average population of 1,010, and has its own water supply and sewerage system connected with the stream.

TABLE 137.—*Analyses of water from Little Miami River below Xenia.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Rainfall during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1901.													*Inches.*
Apr. 26	45	26	v[a]	0.286	0.020	0.032	1.28	1.6	362	240.2	13.8	62,000	0.96
May 28	87	32	v	.292	.310	.058	.89	4.3	418	254.4	7.0	12,000	1.35
June 28	175	33	v	.328	.180	.036	1.04	2.2	383	221.6	32.0	5,100	.93
July 17	105	28	v	.314	.142	.032	.36	3.2	375	256.6	.0	1,200	.38
Aug. 22	90	38	v	.462	.070	.030	.00	.0	344	236.6	.0	177,000	2.92
Sept. 17	55	17	v	.282	.078	.022	.00	1.9	388	242.4	.0	2,600	.18
Oct. 18	54	33	M	.212	.134	.009	.00	1.7	380	252.4	.0	34,400	.05
Nov. 9	35	58	v	.324	.050	.010	.10	1.6	378	281.0	.0	148,000	.23

[a] v, vegetable; M, musty.

Proceeding down the river from Xenia, the most important points of pollution discovered are Waynesville, having a population of 723; Wilmington, on Todds Fork, inhabited by 3,613 people; Blanchester, on the same tributary, with 1,788 inhabitants; Lebanon, on Turtle Creek, with 2,867, below which is Loveland. At this point a series of examinations has been made by the State Board of Health of Ohio, the results of which are reproduced in Table 138.

TABLE 138.—*Analyses of water from Little Miami River above Loveland.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Precipitation during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1901.													*Inches.*
Apr. 24	40	18	v[a]	0.216	0.036	0.011	1.26	1.0	316	194.2	20.2	1,800	0.45
May 29	430	30	e	.332	.076	.018	.52	.8	483	157.6	15.2	21,000	1.67
June 26	250	15	m	.324	.096	.009	.40	2.2	389	238.8	12.4	1,500	.00
July 17	235	13	v	.254	.066	.026	.30	2.6	350	219.6	11.2	1,200	.39
Aug. 20	800	33	e	.312	.124	.024	.31	.0	338	128.2	20.6	8,000	.86
Sept. 17	103	20	e	.321	.036	.006	.00	2.8	316	210.0	.0	1,900	.00
Oct. 19	90	18	v	.220	.032	.006	.00	2.9	378	224.0	.0	2,100	.00
Nov. 9	60	26	e	.176	.022	.010	.00	2.7	343	221.2	.0	1,400	.27

[a] v, vegetable; e, earthy; m, moldy.

The analyses above set forth, when compared with those in tables 135, 136, and 137, indicate a considerable improvement in the general character of the water. Free ammonia and nitrites, which are indicative of sewage pollution, are present in the Loveland water in smaller proportion than in water taken higher up in the drainage area. The chlorine content, however, maintains the same high proportion, and is

an evidence of the contaminating influences of the municipalities above mentioned.

EAST FORK OF LITTLE MIAMI.

Below Loveland enters the East Branch of Little Miami River, the principal centers of population on which are Lynchburg and Batavia. At the former place a surprisingly large amount of refuse is discharged into the stream from a distillery and from numerous drains which lead out of the town. At Batavia a public water supply has been established and a number of storm sewers conduct surface drainage into the stream. Tables 139 and 140 are reports of analyses made by the Ohio State Board of Health, which fairly indicate the character of the water above and below Batavia.

TABLE 139.—*Analyses of water from the East Fork of Little Miami River above Batavia.*

[Parts per million.]

Date of collection.	Turbidity	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Precipitation during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1901.													*Inches.*
Apr. 25	65	25	e[a]	0.300	0.044	0.001	0.03	2.1	270	154.8	39.0	3,200	0.65
June 1	95	33	v	.372	.018	.006	.14	.5	258	160.8	42.0	--------	1.49
June 27	70	25	v	.296	.148	.002	.12	.5	257	149.4	23.4	750	.77
July 20	86	25	m	.310	.118	.010	.04	.0	251	167.6	.0	2,100	1.71
Aug. 21	900	28	e	.332	.086	.012	.00	.0	307	80.0	.0	40,000	1.69
Sept. 19	116	23	v	.398	.060	.003	.00	1.1	238	135.4	50.2	2,300	.00
Oct. 19	165	28	v	.268	.035	.003	.00	2.2	251	111.4	10.2	5,400	.00
Nov. 8	70	28	v	.330	.034	.002	.08	4.6	233	121.8	6.8	1,500	.33

[a] e, earthy; v, vegetable; m, moldy.

TABLE 140.—*Analyses of water from East Fork of Little Miami River below Batavia.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Precipitation during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1901.													*Inches.*
Apr. 25	60	25	e[a]	0.350	0.052	0.002	0.02	2.4	299	157.6	63.8	3,500	0.65
June 1	95	33	v	.348	.032	.007	.16	1.1	277	161.2	19.4	--------	1.49
June 27	70	28	v	.266	.146	.010	.13	.9	261	143.2	73.8	1,300	.77
July 20	80	25	v	.302	.136	.010	.03	.9	262	195.2	.0	2,200	1.71
Aug. 21	800	28	e	.314	.104	.013	.00	.0	353	80.2	8.2	38,000	1.69
Sept. 19	110	23	v	.326	.102	.005	.00	1.8	246	139.0	.0	1,500	.00
Oct. 19	165	32	v	.234	.020	.005	.00	3.0	243	115.0	.0	6,000	.00
Nov. 8	65	25	M	.276	.034	.002	.04	4.4	230	124.4	23.2	2,300	.33

[a] e, earthy; v, vegetable; M, musty.

From the confluence of the East Branch the Little Miami flows southward and empties into the Ohio just above the city of Cincinnati. From the mouth of the East Branch to the confluence of the river with the Ohio the pollution is insignificant. Analyses of the water below Linwood, a suburb of Cincinnati, make it appear preferable to any reported from the drainage area above.

TABLE 141.—*Analyses of water from Little Miami River, below Linwood.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Precipitation during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1901.													*Inches.*
Apr. 24	35	13	v[a]	0.192	0.042	0.010	0.57	2.6	308	190.6	19.4	6,100	0.45
May 29	+3,000	25	e	.638	.097	.010	.18	0.5	1,529	106.6	26.4	30,000	1.67
June 26	187	23	v	.260	.118	.006	.08	3.2	345	212.8	3.0	3,000	.00
July 19	+3,000	25	e	.658	.134	.014	.10	1.3	1,913	127.6	25.2	43,000	1.53
Aug. 20	1,000	28	e	.246	.068	.022	.10	0.0	352	108.2	.0	7,300	.86
Sept. 18	120	23	e	.370	.076	.006	.00	3.4	326	205.8	.0	1,300	.00
Oct. 13	200	32	e	.302	.064	.006	.00	3.1	356	161.6	.0	3,900	[b]1.12
Nov. 8	40	25	e	.202	.026	.000	.04	4.1	302	229.2	8.6	1,200	.27

[a] v, vegetable; e, earthy. [b] Storms one week previous.

The drainage basin of Little Miami River is without special interest from the standpoint of water pollution. As has already been observed the urban population is comparatively small and the sewage it contributes to the river does not seem to have very marked effects on the water. The analyses show a high content of organic matter from the headwaters down, and while the water may not have been much damaged it is certainly not so desirable for public use as some of the purer waters found in other parts of the State. It can hardly be said, however, that Little Miami River has suffered greatly from city or manufacturing refuse, and it is more than likely that if all sewage were removed from the stream and its tributaries the natural drainage of an area so highly fertilized would so change the character of the run-off water that it would be hardly acceptable for city water-supply purposes without filtration. The other resources vested in the natural waters of this area do not appear to be damaged appreciably.

MIAMI RIVER.

Entering Ohio below Cincinnati, the Miami River drains a basin to the north thickly dotted over with towns and cities. The main stream is formed at Dayton by the confluence of the Upper Miami, Stillwater, and Mad rivers, which have drainage areas of 1,158, 645, and 653 square miles, respectively. From Dayton to the mouth the river flows in a somewhat winding course to the southwest. From its

headwaters in Lewistown reservoir, in the extreme northern part of the drainage area, to its mouth the Miami has a length of 163 miles.

NORMAL WATER IN THE MIAMI BASIN.

In a drainage area like that of the Miami it is difficult to secure samples of normal water. The run-off from land given over to agriculture is seldom, if ever, of a quality which approaches the normal very closely. There appear, however, in the report of the Ohio State Board of Health for 1901 three series of analyses of water taken from streams which, so far as is known, bear no direct sewage pollution. These streams are Mad River above Urbana, Buck Creek, a tributary of Mad River, above Springfield, and Greenville Creek above Greenville City. The population upon the drainage area of these streams above the points named is of the usual agricultural nature, and the pollution of the run-off water is probably confined to the drainage of manured fields.

The analyses made by the Ohio State Board of Health are set forth below in Table 142.

TABLE 142.—*Analyses of nearly normal waters in the Miami River Basin.*

BUCK CREEK ABOVE SPRINGFIELD.

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Precipitation during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1900.													*Inches.*
Apr. 16	.....	10	None	0.104	0.016	0.005	0.84	0.4	407	242.0	2.98	325	0.54
May 24	25	10	v[a]	.328	.032	.010	1.14	.3	431	244.0	27.20	1,200	1.49
June 20	32	23	e	.096	.036	.008	.83	.2	438	268.0	12.00	375	.00
July 10	90	15	e	.176	.028	.010	1.06	.4	463	260.2	30.00	800	.33
Aug. 9	57	17	v	.134	.042	.010	1.64	.0	384	227.6	29.00	400	.00
Sept. 5	60	13	v	.206	.044	.011	1.46	.0	386	239.4	1.80	600	.40
Oct. 3	35	15	v	.112	.022	.002	1.63	.4	425	219.4	3.00	1,200	1.63
Nov. 3	16	17	None	.078	.019	.014	2.12	.5	399	249.4	13.20	1,000	.23
MAD RIVER ABOVE URBANA.													
1900.													*Inches.*
Apr. 19	100	32	e	0.258	0.014	0.010	1.87	0.0	497	229.0	60.6	12,000	1.42
May 24	17	12	e	.104	.040	.010	.82	.5	347	265.4	3.0	700	.86
June 20	70	21	v	.170	.050	.009	.83	.0	434	271.8	26.8	1,700	.00
July 9	100	18	v	.220	.060	.017	.64	.2	410	266.2	11.4	2,200	1.05
Aug. 9	95	22	v	.182	.054	.016	1.04	.2	396	250.4	.0	3,300	.11
Sept. 5	165	28	e	.380	.032	.007	.83	.0	438	230.4	21.0	5,900	.25
Oct. 3	90	18	v	.130	.032	.006	1.26	1.0	462	260.2	1.6	4,000	1.31
Nov. 3	28	20	None	.086	.019	.005	.00	.0	390	251.4	1.4	2,200	.20

[a] v, vegetable; e, earthy.

TABLE 142.—*Analyses of nearly normal waters in the Miami River Basin*—Cont'd.

GREENVILLE CREEK ABOVE GREENVILLE.

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Precipitation during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1900.													*Inches.*
Apr. 17	28	20	v[a]	0.188	0.030	0.016	3.44	0.2	449	217.8	83.0	3,300	0.60
May 22	24	28	v[a]	.211	.094	.038	2.09	.0	380	226.2	40.0	1,100	1.22
June 18	28	25	v	.184	.084	.014	.55	.6	467	278.4	31.0	1,300	.00
July 10	70	27	v	.214	.060	.020	.44	.4	369	280.0	.0	1,100	.52
Aug. 7	65	22	v	.268	.134	.011	.00	2.7	421	255.4	3.2	2,000	1.68
Sept. 3	55	23	v	.186	.096	.010	.00	1.0	413	269.0	.0	4,700	.00
Oct. 1	120	42	v	.272	.063	.024	2.12	.0	432	189.6	35.0	19,000	3.22
Nov. 1	28	20	e	.164	.019	.002	.00	1.5	472	274.0	26.6	6,400	.35

[a] v, vegetable; e, earthy.

Inspection of the above table readily shows that the water in Buck Creek above Springfield is decidedly the best. Throughout the whole table the content of organic matter indicated is comparatively low and maintains a fair degree of uniformity. In the Buck Creek analyses the free ammonia, nitrites, and chlorine are much lower than in any analyses heretofore presented for this area. There is the same steadiness in the total residue column that was evidenced in the Little Miami examinations. Turbidity and bacteria per cubic centimeter are comparatively uniform in spite of the fact that there were wide fluctuations in the precipitation during the ten days previous to each examination.

Turning now to the three affluents of the Miami, let us consider the conditions existing within the drainage areas of each.

MAD RIVER.

Mad River has its origin in Logan County and flows with a general southwesterly trend to Dayton. The city of Urbana, with 6,808 inhabitants, lies at the head of sewage pollution. A water supply has been established in Urbana, but the sewerage system is confined to a few private lines of pipe. The principal source of pollution, however, is the highly contaminated run-off occasioned by the storage of polluting material in vaults and cesspools, rarely cleaned, but allowed to filter into the ground. The most important point of pollution is the city of Springfield, which has a population of 38,253.

Water and sewerage systems have been established, but the latter is said to be very poor, and only about 20 per cent of the population has access to it. The most flagrant source of pollution from Springfield is the method of disposing of garbage, night soil, and dead animals. These are dumped promiscuously into the river or buried on or near the banks. There is also considerable pollution from various industries.

There are available the results of analyses of series of samples

taken from Mad River above and below Urbana, above and below Springfield, and above Dayton; also from Buck Creek, above Springfield. The reports of the first and last named have already been given in Table 142.

In the following table the average results of monthly determinations at the above-named places are set forth:

TABLE 143.—*Analyses of water from Mad River.*

[Averages for eight monthly examinations, in parts per million.]

Place of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Urbana	80	21	0.191	0.038	0.010	0.91	0.2	422	253.1	14.5	4,000
Below Urbana	115	47	.608	.039	.060	.47	1.2	456	278.7	16.5	160,000
Above Springfield	80	27	.260	.076	.028	.48	.5	431	272.1	12.1	9,500
Above Springfield (Buck Creek)	40	15	.154	.030	.009	1.34	.3	417	243.8	18.2	738
Below Springfield	75	24	.270	.201	.042	.60	3.3	435	270.6	9.2	31,000
Above Dayton	80	20	.194	.033	.011	1.32	2.8	417	254.8	14.0	6,750

Inspection of the above analyses shows the usual unmistakable evidences of contamination of the river from the two principal polluting points and the improvement of the water as it flows from one of these points to the other. The character of the water above Urbana on Mad River and above Springfield on Buck Creek has already been discussed. As the water passes by Urbana there is a notable increase in the content of organic matter as well as in turbidity and in the number of bacteria per cubic centimeter. From Urbana to Springfield the water shows undoubted improvement, but is again changed in passing the city of Springfield, while the analyses made of samples taken above Dayton show that the water has so far improved as to be, from a chemical standpoint at least, almost as good as it appears above Urbana. The Dayton samples show the character of the water contributed to the Miami system by Mad River.

UPPER MIAMI RIVER.

Upper Miami River has its origin in Lewistown reservoir and flows south by a somewhat circuitous route to join the Stillwater and Mad rivers at Dayton. The head of pollution upon the Upper Miami is Bellefontaine, a village of 6,649 inhabitants, supplied with water and a short system of storm sewers. The principal pollution from this point consists of the drainage of a few plumbing systems into the storm sewer, the refuse from slaughterhouses, and the pollution of run-off water through putrescible material stored in the ground. A few institutions, such as the Logan County Infirmary, Logan County Childrens' Home, and the Shelby County Childrens' Home and Infirmary, contribute more direct sewage pollution to the river than any of the small villages situated along the stream. The village of Sidney, having a

population of 5,688, has a water supply and has just introduced a system of sewers. These, together with a brewery and a tannery and various other incidental contaminating points, produce considerable damage to the river.

Next below Sidney is Piqua, having a population of 12,172. The public water supply at this point is not used for domestic purposes. A separate system of sewers, to which about 30 per cent of the people have access, has been established. These sewers empty directly into the Miami River. In the town are located strawboard works, oil mills, breweries, and several large slaughterhouses, and the effluent from these and the sewers is the occasion of serious nuisances at times.

Below Piqua is Troy, containing 5,581 inhabitants, and still farther down is Tippecanoe City, with 1,703. Both places have public water supplies and a few short, combined sewers, to which a small proportion of the people have access. Garbage and night soil are dumped along the river and into the Miami and Erie Canal, which flows along the river bank. In addition to the pollution from sewers, the river receives the refuse from three distilleries, two breweries, and several large slaughterhouses.

Chemical examinations of the water of the Upper Miami have been made above and below the cities of Sidney, Piqua, and Troy, and above Dayton, and the averages of the eight monthly analyses of samples taken at each point appear in the following table:

TABLE 144.—*Analyses of water from Upper Miami.*

[Averages of eight monthly examinations, in parts per million.]

Place of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Sidney	60	23	0.295	0.066	0.009	0.52	0.7	404	219.8	33.3	1,900
Below Sidney	45	24	.289	.074	.014	.57	2.3	379	223.9	25.9	4,700
Above Piqua	290	28	.400	.077	.010	.65	1.2	484	200.6	31.9	11,000
Below Piqua	240	27	.374	.048	.027	.90	3.4	468	208.9	25.0	22,500
Above Troy	55	26	.344	.105	.018	.54	2.4	388	214.7	27.2	5,600
Below Troy	35	24	.378	.112	.019	.61	3.2	364	221.9	20.4	52,000
Above Dayton	100	25	.307	.049	.013	.68	1.5	407	220.9	24.9	5,600

The effect of sewage on the Miami River above Dayton, as indicated by the above analyses, is so obvious as hardly to merit discussion. The same general features, repeatedly observed in the discussion of drainage areas in previous pages, occur here. As the Miami enters the city of Dayton, the water, from a chemical standpoint, is only a little inferior to that in the same stream above Sidney.

STILLWATER RIVER.

Stillwater River, entering the Miami at Dayton, drains the country to the northwest, comprising large areas in Darke and Miami coun-

ties. The principal source of pollution along the entire length of Stillwater River is the city of Greenville, which has a population of 5,501. At this place water and sewerage systems have been installed, the latter being one of the best in the drainage area. In addition to the contaminating matter carried into the former from the sewers, there is the polluted surface drainage from that part of the town which has not yet been connected with the sewerage system.

In the drainage area of the Stillwater there are several institutions which furnish the usual amount of contamination. The villages of Versailles and Covington, containing 1,478 and 1,791 inhabitants, respectively, are the only remaining points within the watershed that are important from the standpoint of stream pollution.

Three sampling points were selected by the Ohio State Board of Health as a basis for their investigation into the character of the water in Stillwater River. These are located above and below Greenville, on Greenville Creek, and above Dayton.

TABLE 145.—*Analyses of water from Stillwater River.*

[Averages of eight monthly examinations, in parts per million.]

Place of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Greenville	55	26	0.211	0.072	0.017	1.08	0.8	425	248.8	27.3	4,900
Below Greenville	70	27	.274	.091	.022	1.17	2.6	475	251.7	85.4	13,500
Above Dayton	80	23	.251	.041	.009	2.02	.9	380	218.9	8.3	45,500

Examination of the results above set forth shows nothing of an uncommon nature. Above Greenville, as has been already shown in the consideration of normal waters in the Miami drainage area, there is little evidence of specific sewage contamination. Below Greenville there is, as might be expected, an increase of those ingredients whose presence is generally accepted as an indication of pollution, but the amount of this increase is not so great as might be expected when all the circumstances are considered. The analyses of samples taken above Dayton indicate the usual improvement in a water after it has flowed beyond the point of contamination for a considerable distance.

The city of Dayton has a population of 85,333, the largest on the drainage area of the Miami. It is provided with a water supply and a sewerage system, to which 30 per cent of the people have access. Garbage is burned in a crematory and night soil is disposed of upon the farms outside the city, so that the pollution of the river is confined to the affluents from the sewerage system and the refuse turned into the stream by industrial plants, which consist of breweries, slaughter and packing houses, oil mills, soap works, and paper and strawboard manufactories.

MIAMI RIVER BELOW DAYTON.

Below the city of Dayton, on the Miami, are located the National Soldiers' Home and the Dayton State hospital. The combined population of these two institutions is 5,810. Both are provided with sanitary sewers and improved systems of plumbing, which discharge directly into the river. This is the largest center of pollution in the whole drainage area, greater, in fact, than the city of Dayton itself. Continuing down the river from the two institutions above mentioned, the next important point is Miamisburg, which has a population of 3,941. Industrial pollution seems to be the most important at this village, which has no water or sewerage system.

The village of Franklin, a few miles below Miamisburg, is inhabited by 2,724 persons and is supplied with water and a small system of sewerage. In addition to the contamination afforded by the latter, a large proportion of the garbage of the town is dumped into the river and some of the industrial plants, such as paper mills and slaughterhouses, pour their refuse into the stream.

Middletown is situated a few miles below Franklin, on the east bank of Miami River. It has an excellent water supply and sewerage system, through which the sewage of about 2,000 persons is carried directly into the river. The waste from a large number of manufacturing establishments also finds its way there. Among these are gas works, breweries, malt houses, etc.

A few miles below Middletown is the city of Hamilton, through the center of which Miami River passes. Hamilton has a population of 23,914, a good water supply, and an extensive system of sanitary and storm sewers. In addition to the polluting material poured into the river by these sewers, it receives the refuse from a large and varied assortment of industries.

Below Hamilton there is little of interest until the mouth of the river is reached.

Sampling points selected by the Ohio State Board of Health are below Dayton, above and below Middletown, above and below Hamilton, and below Cleves.

TABLE 146.—*Analyses of water from Miami River.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Below Dayton	81	25	0.309	0.067	0.021	1.99	4.2	407	220.9	24.9	65,000
Above Middletown	215	27	.261	.045	.015	.46	3.3	432	212.2	18.5	19,000
Below Middletown	257	29	.340	.047	.022	.51	5.3	461	220.5	15.4	43,000
Above Hamilton	1,820	28	.345	.058	.012	.75	3.1	626	188.7	13.9	25,500
Below Hamilton	1,300	26	.361	.072	.018	.57	4.7	551	199.4	14.5	33,000
Below Cleves	2,250	26	.406	.056	.012	.63	3.9	813	191.7	12.4	7,000

The character of the water contributed to the Ohio system by the Miami is not all that could be desired, nor indeed as good as might easily be furnished. In the course of the river from Dayton to its mouth the changes in the organic constituents of the water are not exceedingly sharp. The undesirable condition of the run-off at Dayton is maintained steadily throughout the remainder of the course. The sewage of Dayton and the two institutions just below it is apparent in the report of the analyses of samples taken above Middletown. The additional polluting material poured in from Middletown is perfectly evident, and by the time the water reaches Hamilton only a very small improvement can be noted. The water contributed to the system by the three main affluents above Dayton seems to be far superior to that which flows by Cleves into Ohio River.

OHIO RIVER AT LOUISVILLE.

During the years 1895, 1896, and 1897 extensive investigations were carried on by the Louisville Water Company to determine the character of the water in Ohio River opposite that city. Mr. George W. Fuller was placed in charge of this work, and in the year 1898 submitted an exhaustive report on the purification of the water of Ohio River. Daily examinations of the water of Ohio River were made from October 16, 1895, to July 24, 1897, the reports of which will not be given here in full, but attention will be directed to several important determinations.

Relative to the drainage area and general hydrographic conditions Mr. Fuller writes as follows:

The water of the Ohio River at Louisville varies widely from time to time in its composition. This variation is caused by a number of factors, among which are the following:

1. The size and varying geological formation of the watershed.
2. The number of comparatively large tributaries which drain areas of distinctly unlike geological character.
3. The amount of precipitation (rain and snow).
4. The distribution of the precipitation over the watershed.
5. The condition of the soil at the beginning of heavy rain storms.
6. The amount and rate of precipitation during single storms.
7. The stage of the river.
8. The velocity of flow of the river.
9. Agitation of the water in the river due to wind storms, etc.

The total population resident on this watershed above Louisville is estimated at 4,500,000, of which 1,575,000 is contained in 220 towns and cities, according to the census of 1890, increased 15 per cent for the six years of the present decade. The nearest city discharging sewage into the water which passes this pumping station is Madison, Ind., situated about 50 miles above Louisville, with a population of about 12,000. The next city is Frankfort, Ky., situated on the Kentucky River, 67 miles from its mouth. This city has a population of about 10,000. The Kentucky River joins the Ohio about 57 miles above Louisville. The nearest large center of population discharging sewage into this water supply is at Cin-

cinnati, Ohio. Opposite this city are the cities of Newport and Covington, Ky. Their aggregate population (three cities) is about 420,000, and they are distant above Louisville about 150 miles by river.

The rises and floods in the Ohio River, with their associated factors, produce wide and rapidly changing variations in the composition of the river water. Owing to the fact that the composition of the river water is a prominent factor in the cost of purification, analyses were made practically every day during these tests of the water before its application to the systems of purification. Before giving attention to the results of analyses, however, the question of frequency and depth of freshets or floods is to be considered.[a]

TABLE 147.—*Amount of carbonic acid gas (carbon dioxide) dissolved in the Ohio River water at Louisville.*

[Parts per million.]

Date.	Carbonic acid gas.	Date.	Carbonic acid gas.	Date.	Carbonic acid gas.	Date.	Carbonic acid gas.
1896.		1897.		1897.		1897.	
June 18	[b]30.8	Mar. 24	44.9	May 7	57.4	June 18	82.7
22	[b]26.4	25	41.9	8	110.6	19	106.3
24	[b]27.7	26	36.5	9	66.7	20	100.3
27	[b]29.7	27	47.0	10	72.1	21	100.3
July 3	[b]30.6	29	56.6	13	65.2	22	100.3
8	[b]21.1	30	80.0	14	76.6	23	107.4
Nov. 28	83.0	Apr. 1	53.6	15	50.8	24	100.3
Dec. 10	98.0	2	59.0	18	67.3	25	105.6
1897.		3	53.5	19	71.8	26	113.7
Feb. 16	80.4	7	79.6	21	88.7	27	120.0
Mar. 2	63.4	8	46.0	22	95.9	28	92.1
3	59.0	9	91.0	23	94.3	30	105.9
4	67.8	10	80.0	26	80.2	July 1	93.9
5	49.3	12	65.0	27	80.0	2	75.3
6	47.6	13	44.0	28	107.3	3	73.1
7	51.4	14	75.7	29	101.6	6	100.4
11	99.5	15	88.3	June 1	66.6	7	106.1
12	88.0	16	50.2	2	90.5	8	99.9
13	122.4	21	41.2	4	82.7	12	71.8
15	45.8	22	42.7	7	89.0	15	47.0
16	33.4	23	43.0	10	133.0	16	28.8
19	38.8	25	55.0	11	107.6	17	49.4
20	42.6	27	94.9	15	98.8		
22	46.4	29	85.9	16	103.3		
23	40.4	May 4	86.8	17	107.6		

[a] Report on the investigations into the purification of the Ohio River water at Louisville, Ky., made to the president and directors of the Louisville Water Company by George W. Fuller, 1898.

[b] The results of June and July, 1896, were obtained by the Pettenkoffer method, without the Trillich modification, and are probably much too low

The normal hardness or amount of incrusting constituents in the Ohio River water is set forth in the following table:

TABLE 148.—*Normal hardness of water of Ohio River at Louisville.*

[Parts per million.]

Date.	Normal hardness.	Date.	Normal hardness.	Date.	Normal hardness.	Date.	Normal hardness.
1895.		1897.		1897.		1897.	
Dec. 9–11	43.9	Mar. 15	14.0	Apr. 20–21	15.5	May 28–29	16.8
1896.		16	20.5	21–22	17.5	31	--------
May 6	43.0	17	24.6	22	12.0	June 1	17.0
14	33.8	18	36.7	22–23	14.6	2–3	17.6
22	40.1	19	16.7	23–24	14.3	4–5	23.5
29	41.1	20	22.0	27	12.7	7–8	22.5
June 11	44.0	22	12.0	28	17.0	9–10	23.8
18	30.0	23	9.6	29	32.0	11–12	28.8
July 30	35.0	24	10.8	29–30	21.7	21	28.8
1897.		25	10.0	30	--------	22	31.0
Feb. 17	18.7	26	13.9	May 1	20.0	23	27.8
22	24.7	29	12.8	4	23.0	24	21.9
23	17.2	30	33.3	5	17.0	25	19.0
24	21.2	Apr. 1	29.1	6–7	15.5	27	17.5
25	16.1	2–3	18.2	8–9	15.8	28	25.5
26	8.0	3–4	11.0	13	16.1	29–30	20.0
Mar. 1	15.8	5	29.9	14	23.2	July 2	20.0
2	10.0	6	23.4	15	11.3	6	20.9
3	8.0	6–7	30.0	17–19	9.0	7	27.0
4	12.0	8	19.8	19–20	10.8	9–10	11.0
5	25.3	9	14.2	21	11.9	12–13	12.0
6	34.6	9–10	13.3	21–23	15.9	14–15	14.8
7	16.0	11	9.0	23–24	10.2	16	14.0
9	23.4	12	12.7	25	20.2	17–18	12.3
10	17.9	13–14	16.0	25–26	14.5	19–20	24.2
11	30.0	14–15	20.0	27	16.7	21–22	24.2
12	33.0	15–16	18.1	27–28	19.3	23–24	43.8

An interesting investigation into the amount and corrosive effect of dissolved carbon dioxide in the river water brought out the fact that such determinations are of more importance than had been previously supposed. The observation is made in Mr. Fuller's report that at times the weight of the dissolved carbon dioxide in the river water equals and even exceeds the weight of all dissolved solids. The amount of carbon dioxide found in the water at each examination is set down in Table 147.

SUMMARY.

In the foregoing pages we have reviewed the important and readily available records of water examinations which have been carried on in this country, except those now being prosecuted in connection with the Chicago Drainage Canal and Illinois River. It is apparent from this review that the pollution of natural waters follows social municipal progress. Those rivers which remain in their normal condition are situated in areas that have not been penetrated to any extent by the growth of American institutions. Nearly all important streams have been damaged and their normal resources diminished. The question may be asked: Is not the damage done to these streams by the sewage of cities and by industrial plants merely a part of the compensation which we should willingly pay for the advantages that we have gained through the establishment of those polluting influences? Undoubtely, to a certain degree; but the fact still remains that in most cases when such damage is carried beyond a certain point it must be regarded as needless and unwarranted.

Water pollution is inevitable wherever the human race is clustered together in large numbers, but by the application of the methods of sewage disposal which modern science has made available, and by the exercise of an ordinary amount of municipal decency, such pollution can be so restricted that it will result in the destruction of only one or two of the resources which are vested in natural waters.

There is no doubt that the run-off water from a thickly settled country is likely to be dangerous for domestic uses unless it is filtered, and the current methods of sewage disposal, while theoretically perfect, are practically not sufficiently so to warrant us in using the so-called purified effluents as we would use the run-off from an uninhabited region. Yet, if proper precautions are taken and the same attention is paid to sewage disposal that is ordinarily given to other departments of municipal affairs, every community will be the richer and the tremendous waste of natural resources which is now taking place will ultimately be restricted to that which is necessary.

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