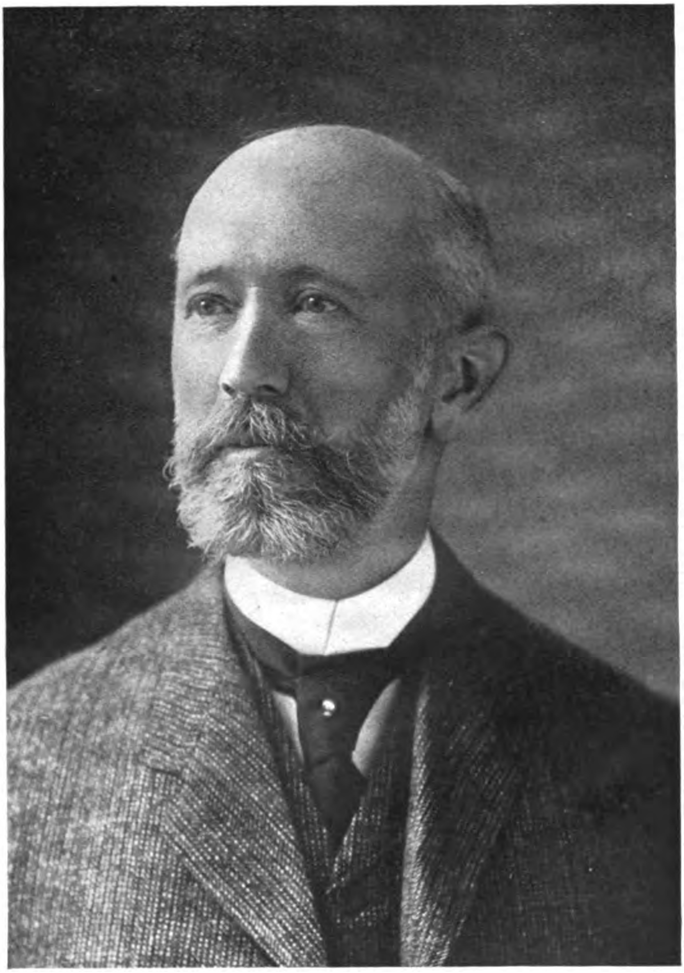

FREDERIC P. STEARNS

STATE SANITATION

A REVIEW OF THE WORK OF THE MASSACHUSETTS STATE BOARD OF HEALTH

BY

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FOREWORD

A most interesting way of studying history is that of reading original documents, addresses and writings by contemporaries of the events described; and this is just as true in the field of public health as in that of general history. There are no more important series of scientific writings on subjects pertaining to preventive medicine, hygiene and sanitation than those which have appeared in the annual reports and special reports of the Massachusetts State Board of Health during the period, covering nearly half a century, from 1869 to 1914. Several hundred in number and scattered through sixty or seventy volumes, some of which can be found only with the greatest difficulty, these writings are in danger of being lost to the world, or, at least, of escaping the attention of present day students of public health.

The best way to rescue these reports from oblivion seemed to be to index them and in addition to prepare a series of abstracts of leading articles, while the best way to give new life to the most important writings, which might appropriately be called the Massachusetts Classics in Sanitation, seemed to be to reprint them, with such abridgment as might be necessary to bring them within the compass of a single book. Such reprints and abstracts are given in the present volume. It is hoped that these writings which inspired the fathers will also inspire the sons.

In making the selections especial prominence has been given to the subjects of water supply and sewage disposal, for it was in the investigation of these subjects that the State Board of Health of Massachusetts acquired early fame. In these writings the names of Nichols, Mills, Stearns, Drown, Sedgwick, Hazen, Goodnough and Clark stand out prominently. But the reprinted writings include also inspiring addresses by Dr. Henry I. Bowditch on the subjects of public health, preventive medicine, the physician of the future, and intemperance; the statesmanlike reports of Dr. Henry P. Walcott on such great metropolitan improvements as the water supply and sewerage of Boston and its suburbs, and the Charles River Basin; the wonderfully exact scientific investigations of Dr. Theobald Smith in the field of bacteriology; the careful statistical researches of Dr. Samuel W. Abbott; the dairy studies of the impetuous Secretary, Dr. Charles Harrington, as well as some of the more modern writings on infantile paralysis by Dr. Mark Richardson and food inspection by Mr. Hermann H. Lythgoe.

The abstracts are arranged chronologically in order that the reader may obtain a better perspective of the studies with which the sanitarians of the State Board of Health were concerned at different periods of its history.

The joint indices to the annual reports and special reports will be published as a third volume.

The proof of this volume was corrected at long range during the author's journey to Russia as a Member of the Red Cross Mission to that country. The chances for errors to escape notice are therefore greater than usual and the reader is asked to be charitable if such are found. The index to this volume was very kindly prepared by Mr. Melville C. Whipple, Instructor in Sanitary Chemistry, Harvard University, to whom I wish to express my sincere thanks.

George Chandler Whipple.

Tokio, Japan
July, 1917

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PART III

SELECTIONS FROM THE REPORTS OF THE MASSACHUSETTS STATE BOARD OF HEALTH

I

STATE MEDICINE

By Dr. Henry I. Bowditch

[Address of Dr. Henry I. Bowditch to the Gentlemen of the State Board of Health at the first meeting of the Board, held at the State House, September 15, 1869. *First Annual Report*, 1870, p. 9. — G. C. W.]

By the orders of the Governor of the Commonwealth, it devolves upon me to call you together. As the subject-matters for our discussion may be somewhat indefinite in all of our minds, I take the liberty of addressing a few words to you, in order that you may know not only what I consider the general nature of our duties, but may also understand how high I place these duties when I consider them in their relations to the present and future health of the citizens of the state. I may be mistaken in my estimate of the importance of the movement, the commencement of which today devolves upon us. I confess to you that I know of no higher office in the state than that which we now hold, viz., that of inaugurating the idea of "State Medicine" in Massachusetts. Upon our high or low appreciation of the position and of the duties resulting from that position, and upon our wise or foolish performance of these duties, depends the success of the object aimed at in the establishment of a State Board of Health. The last Legislature, unconsciously, perhaps, on the part of many members thereof, has proposed a system that may be made by us capable of good to the citizens in all future time, or it may prove a perfect abortion. Our work is for the far future as well as for the present, and at this very opening of our labors we should try to place ourselves above the region of merely local or temporary excitement or of partisan warfare, in order that we may act wisely and for the ultimate good of the whole people.

In these introductory general remarks, as you will see, my object has been to impress upon you my views of the essential dignity of the offices we now hold, and that we should assume them with minds loyal to the truth and under a sense of individual responsibility in the premises.

I have used one expression about which I wish to enter into some detail, viz., " State Medicine in Massachusetts." What is the precise meaning of the expression ? It is of very recent growth in our language. It has, in fact, arisen, I believe, within the last few years in England, where already it has become a great power for good. Its objects rank among the most important matters now discussed by the highest intellects and humanest hearts in Great Britain. It is, as I understand it, a special function of a state authority, which, until these later days of scientific investigation, has been left almost wholly unperformed, or exercised only under the greatest incitements to its operation, such as the coming of the plague, cholera, smallpox, or some other equally malignant disease. By this function the authorities of a state are bound to take care of the public health, to investigate the causes of epidemic and other diseases, in order that each citizen may not only have as long a life as nature would give him, but likewise as healthy a life as possible. As the chief object of the physician is the cure, if possible, of any ailment which is submitted to his care, so the far higher aim of State Medicine is, by its thorough and scientific investigations of the hidden causes of diseases that are constantly at work in an ignorant or debased community, to prevent the very origination of such diseases. Much has already been suggested in England towards the crushing out of fevers, etc. Still more recently one of the grandest results of the State Medicine is its virtual recognition under international law, by the appointment of joint governmental commissioners for the investigation and prevention of the spread of Asiatic cholera.

The history of State Medicine in Great Britain may be briefly summed up as follows: —

Only twenty-one years ago, namely, in 1848, England, stimulated by the medical profession and the philanthropists, passed an Act establishing a " General Board of Health." It gave very extensive powers, and statements of its doings from year to year were published by Parliament. The Registrar-General's reports also tended to open the eyes of all to the importance of more thoroughness of work.

In the early part of 1858, the Privy Council of England was directed to consider the matter of public health. Accordingly its chief medical officer, Mr. Simon, one of the most eminent of the medical profession of London, was ordered to report to the council on any matters pertaining to that subject. Every year since then he has sent out, under official sanction, very valuable documents. He has been allowed to call to his aid all the special talent in the kingdom; and investigations of importance, not only to the state, but to the science of medicine, have been annually made and published by the council. And I beg you to bear in mind that all these investigations have been made by the state with one sole object in view, viz., the improvement in human health, and for the lengthening out of human life of each individual man or woman. Certainly no object can be nobler, none more deserving the attention of learned men or of philanthropists or statesmen.

Dr. Farr (*Medical Times and Gazette*, July 31, 1869), in his very recent and able address as president of the section on State Medicine in the British Medical Association, pursues the following lines of thought upon this subject: " Public hygiene is a want as much as air, and public roads and waters are public necessities, and as such must be cared for and paid for by the community." Diseases as disastrous as those among the Greek hosts before Troy befell the English camp in the Crimea. Before Troy, appeals by prayer were made to appease the anger of the gods; but God's divine laws of hygiene were unknown or uncared for. During the Crimean war the people of England not only prayed, but with indignant haste they hurled from power an inefficient ministry because it neglected these same laws. Out of this upheaval of the nation's heart arose Florence Nightingale and Lord Herbert, with their Christian sanitary law, bringing health and comparative comfort to the war-worn soldier.

" A sanitary code," says Dr. Farr, " is needed, with proper sanitary officers; for otherwise a code would be a dead letter." Hence, continues he, " a Ministry of Public Health will eventually be needed for the British Empire." I would remark, in passing, that Jeremy Bentham suggested in his " Constitutional Code " the same idea more than thirty years ago. " Such a ministry," says

Dr. Farr, " would divide itself into four departments — administration, medicine, engineering, statistics — each of which should be organized so as to work in harmony with a council of health and executive heads. Each town should have its board of health and its health physician in communication with and in aid of the Central Board of Health."

But public health has so wide a field that help is needed from all; from the chemist, the engineer, the naturalist, and from the humblest citizen as well as the highest statesman.

" The primary object of public medicine," says Dr. Farr, " is to prevent disease, but it also surrounds the sick with conditions most favorable to recovery, and diminishes the death-roll of the people."

Dr. Farr concludes his admirable address with the following thought: " Supposing every condition favorable for the perfect operation of the powers of State Medicine, we should still see grave defects in many persons; shortcomings in others; in many, organic degeneracies; in many, criminal depravities.

" How out of the existing seed to raise races of men to divine perfection is the final problem of public medicine."

You see, gentlemen, from these memoranda taken from Dr. Farr's address, that I am not alone in considering the object we have to care for as among the highest that can be presented to any reasonable man, or to any lover of his race.

The establishment of our Board by the last general court inaugurates this system of State Medicine in Massachusetts. I think that this is the first State Board of Health established by any American state; at least, with objects as extensive as those now given to our charge.

The law under which we act, while not specifying so much as the English law of 1848, gives us the amplest powers for investigation and funds at our disposal for any legitimate purpose.

Let us look for a moment at some of the general objects and duties involved in the Act establishing our Board.

1. It directs the Board to take cognizance of everything tending to public health, and of course requires us to endeavor to eradicate everything tending to public disease and death.

2. It directs us to diffuse among the people a knowledge of the means of obtaining individual and public health and of preventing disease.

3. We are ordered to investigate the effects of the use of intoxicating liquors upon the industry, prosperity, happiness, health and lives of the people, and it is intimated that we may suggest legislation on any or all of the subjects committed to us for investigation.

Now in order that the workings of the Board may become harmonious and of real service, it is a self-evident proposition that exact methods of procedure must be followed in all cases, and that certain by-laws for the legal governance of the Board will be necessary, and which shall not be varied from except under special directions at a full meeting of the Board.

[Dr. Bowditch then proceeded to suggest certain plans for the organization of the Board, and continued as follows]: —

The law requires us to diffuse among our people any already established laws of public health, and also whatever we may hereafter discover on that subject. I look upon this feature of the law with deep interest, for I believe by it we may do much service to the people.

How shall we diffuse this knowledge ? Permit me to allude to a few evident methods.

(*a*) By lectures from our Secretary or from members of the Board on various special subjects connected with public hygiene — such as ventilating, and building, and location of houses; on various well-known diseases capable of partial or entire prevention on knowledge of causes being given. It may be a question, moreover, whether we should not authorize the Secretary to communicate with lecture committees of various towns and the American Literary Bureaus, and to make arrangements with physicians and others to deliver lectures relating to public health in various towns.

(*b*) By the Secretary holding meetings in the various parts of the state for discussions on the subject, meetings analogous to those now held on education, agriculture, etc. He might invite the co-operation of local medical societies or special physicians. I have no doubt that such meetings, properly conducted, would attract the attention and interest of the public.

(*c*) By the publication in a compact form and the wide circulation of the pith, so to speak, of our general knowledge on public hygiene. How this should be done would remain an open question. If it could be done, there is no doubt of the good that would eventually result.

(*d*) By our annual reports to the Legislature, which, I trust, will always be models of brevity and of compact learning — not a word too much or a word for effect merely — and so thoroughly indexed that even the busiest man on 'change can in three minutes get at the essentials, and be prepared to study the details of any part or parts he may wish further to examine.

In conclusion, gentlemen, let me say that, while I feel alike our grave responsibilities and the dignity conferred on each one of us by His Excellency the Governor in his selection of us for these offices, I have at the same time no misgivings; but on the contrary, the liveliest hope that this Board will faithfully and in an able manner perform its duties, and thus it will become a real blessing to our state, not only at the present time, but long after every member of it has died. It will assuredly be such if we, the necessary originators of its various details, only look at our duties in the light of the broadest philanthropy and, as far as in us lies, the wisest statesmanship, and finally with all the knowledge that modern science can at present give us.

In making these introductory remarks, I have done only what seemed to be proper; but I hope that others will speak what seems to them good, so that starting on our new career with understanding minds and buoyant and willing hearts, we may vigorously inaugurate State Medicine in Massachusetts.

II

THE PUBLIC HEALTH

[This circular letter was issued by the State Board of Health in October, 1869, and sent to the Mayor and Board of Health of every city, to the Selectmen of every town, to every member of the Legislature of 1869, and to every clergyman and physician in Massachusetts. *First Annual Report*, 1870, pp. 15–17. — G. C. W.]

THE undersigned have recently been appointed by the governor and council to constitute the "State Board of Health," under an Act passed by the last Legislature.

In entering upon our duties, which are rather advisory than executive, we desire to establish such communication with the local boards having this important subject in charge, that all may work together for the common advantage of the people, for the prevention of disease, and for the prolongation of life.

We believe that all citizens have an inherent right to the enjoyment of pure and uncontaminated air, and water, and soil; that this right should be regarded as belonging to the whole community; and that no one should be allowed to trespass upon it by his carelessness, or his avarice, or even by his ignorance. This right is in a great measure recognized by the state, as appears by the General Statutes.

If these were strictly and impartially enforced, we should have a condition of public cleanliness, and of public health, which would make Massachusetts a model for all other communities. That this has not been done depends upon many causes, some of general, and others of purely local operation.

It has been doubted, whether the public mind is sufficiently aware of the dangerous elements around us; whether the connection between filth and disease is as yet proved to the public satisfaction; whether the people are convinced that undrained land is unwholesome to live upon.

All these doubts of the public intelligence have impeded the operation of our laws.

It is thought also that local and private interests have often been so strong as to paralyze the action of the health authorities.

But we hope and believe that a better time is coming; and we confidently look to you to put in force the powers which the laws have placed in your hands.

Among these laws we would particularly call your attention to —

General Statutes, chapter 26, in which are comprised stringent provisions relative to the abatement of nuisances, to vaccination, to contagion, and to offensive trades.

Also, to chapter 49, section 151, relative to the sale of milk produced from cows fed upon the refuse of breweries or distilleries, and to the sale of milk rendered unwholesome by any cause.

Also, to chapter 166, in which the law is given relative to the sale of unwholesome provisions of all kinds, whether for meat or drink; the corruption of springs, wells, reservoirs, or aqueducts; the sale of dangerous drugs, and the adulteration of drugs of every sort.

It will also be seen, on reference to chapter 211 of the Acts of the year 1866, that it is in the power of any person, aggrieved by the neglect of the board of health of any city or town to abate a nuisance, to appeal to the county commissioners, who can in that case exercise all the powers of the board of health.

Chapter 253 of the Acts of 1866 authorizes boards of health to seize and destroy the meat of any calf killed when less than four weeks old.

Chapter 271 of the Acts of 1866 authorizes boards of health to appoint agents, to act for them, under certain restrictions.

The Legislature of 1868 passed two Acts of great importance to the public health, to which we would respectfully and earnestly ask your attention. The first, chapter 281, 1868, applies only to the city of Boston, and relates to tenement and lodging houses, placing them under very strict regulations, for the public good.

The second, chapter 160, is of general application. It provides that in any city or town, lands which are wet, rotten or spongy, or covered with stagnant water, so as to be offensive, or injurious to health, shall be deemed a nuisance, to be abated by the board of health of such city or town. In case they refuse to act, appeal may be made, by persons aggrieved, to the superior court or any justice thereof, who may appoint three commissioners with powers equal to those possessed by boards of health.

We confidently look to you for the enforcement of these laws.

We believe that public opinion will fully support you in so doing.

We will give you all the help in our power.

There is a great work before us, which, if carried out in the letter and spirit of the laws referred to, we cannot doubt will justify the wisdom which framed them.

In making this our first communication to the boards of health of the various cities and towns of the Commonwealth, we sincerely hope that it may serve as the opening of friendly and helpful relations between us, and that it will lead to reforms, the effects of which will be evident in the improved condition of public health.

Communications addressed to our secretary, Dr. George Derby, State House, Boston, will be at once acknowledged, and will be laid before the State Board of Health at their next meeting.

Very respectfully, your obedient servants,

HENRY I. BOWDITCH,
GEORGE DERBY,
ROBERT T. DAVIS,
RICHARD FROTHINGHAM,
P. EMORY ALDRICH,
WARREN SAWYER,
WILLIAM C. CHAPIN,
State Board of Health.

III

INTEMPERANCE IN THE LIGHT OF THE COSMIC LAW

By Dr. Henry I. Bowditch

[Summary of the principal subjects considered in a letter of Dr. Henry I. Bowditch to the State Board of Health on Intemperance as seen in the light of cosmic law. *Third Annual Report*, January, 1872, pp. 72–73, 109–112. — G. C. W.]

In our *Second Annual Report* is printed a correspondence on the use and abuse of alcoholic stimulants among foreign nations, and a comparison of the same with our own country in this particular. I think this correspondence is unique not only for the extent of the surface of the globe that it embraces, but likewise for the character of our correspondents. Last year, owing to want of time, the letters were printed without comment, except a most imperfect analysis of them.

I have thought that they should receive more attention from us, and that all their essential truths or apparent truths should be sifted out and brought more clearly into view. I have had this end in view while preparing this communication for you.

I cannot perhaps hope to gain the unanimous consent of the Board to all the propositions I may feel justified in laying down after a fair consideration of the various letters. But I trust you will believe that I have endeavored to get at the exact truth.

In commencing the correspondence as your representative I had no other object in view than to get the opinions of able correspondents, most of them either American ambassadors to different courts or consuls from the American government stationed in all the various important countries of the world to which our commerce extends. My questions embraced two main ideas. They were put briefly, because I believed that if I asked a few questions containing seminal principles, I should get ampler responses than if I should ask a greater number, which would necessarily require a longer time and perhaps much study to answer correctly.

The two ideas were, *First* — to learn the nature and character of the stimulants used (if any were so used) by the inhabitants of countries to which said correspondents were accredited, and the influence of such indulgence on the health and prosperity of the people.

Second — the relative amount of intoxication in said countries compared with that known by such correspondents to exist in the United States.

The papers were sent to thirty-three resident American ambassadors and one hundred and thirty-two consuls and a few other non-official personages and friends whose opinions I knew would be of great value if obtained.

Among these correspondents are many of our most distinguished citizens, some of whom are well known for their eminent intellectual and moral qualities. Usually they have resided for some years in the places from which they write, and are of course generally well acquainted with the habits of the people, not only of the cities from which they reply, but also with those of the people of the districts or countries in which these cities are situated. Most of them write as if they knew well the habits of the people, and also those of our own nation in reference to the use and abuse of stimulating drink. Hence their opinions on that subject are of great value.

Summary of the Principal Subjects Considered in this Letter

1. Stimulants are used everywhere, and, at times, abused by savage and by civilized man. Consequently, intoxication occurs all over the globe.

2. This love of stimulants is one of the strongest of human instincts. It cannot be annihilated, but may be regulated by reason, by conscience, by education, or by law when it encroaches on the rights of others.

3. Climatic law governs it. The tendency to indulge to intoxication being not only greater as we go from the heat of the equator towards the north, but the character of that intoxication becomes more violent.

4. Owing to this cosmic law, intemperance is very rare near the equator. It is there a social crime, and a disgrace of the deepest dye. Licentiousness and gambling are small offences compared with it. To call a man a drunkard is the highest of insults. On the contrary, at the north of 50° it is very frequent, is less of a disgrace, is by no means a social crime.

5. Intemperance causes little or no crime toward the equator. It is the almost constant cause of crime either directly or indirectly at the north above 50°.

6. Intemperance is modified by race, as shown in the different tendencies to intoxication of different peoples.

7. Races are modified physically and morally by the kind of liquor they use, as proved by examination of the returns from Austria and Switzerland.

8. Beer, native light grape wines and ardent spirits should not be classed together, for they produce very different effects on the individual and upon the race.

9. Light German beer and ale can be used even freely without any very apparent injury to the individual, or without causing intoxication. They contain very small percentages of alcohol (4 or 4.5 to 6.50 per cent). Light grape wines, unfortified by an extra amount of alcohol, can be drunk less freely but without apparent injury to the race, and with exhilaration rather than drunkenness. Some writers think they do no harm but a real good if used moderately. They never produce the violent crazy drunkenness, so noticeable from the use of the ardent spirits of the North.

Ardent spirits, on the contrary, unless used very moderately, and with great temperance, and with the determination to omit them as soon as the occasion has passed for their use, are almost always injurious, if continued even moderately for any length of time, for they gradually encroach on the vital powers. If used immoderately, they cause a beastly narcotism which makes the victim regardless of all the amenities and even the decencies of life, or perhaps they render him furiously crazy, so that he may murder his best friend. While those who live in the tropics merely sip slowly ardent spirits from the tiniest of glasses, with the slightest appreciable effect, the denizen of the frozen North swallows half tumblers full of the same to the speedy production of intoxication.

10. Races may be educated to evil by bad laws, or by the introduction of bad habits. England's taste for strong drinks has been fostered by legislation, and by wars of nearly two centuries since. France and parts of Switzerland are beginning to suffer from the introduction of absinthe and of schnapps. Especially is this noticeable since the late Franco-Prussian war. By classifying all liquors as equally injurious, and by endeavoring to further that idea in the community, are we not doing a real injury to the country by preventing a freer use of a mild lager beer, or of native grape wine instead of the ardent spirits to which our people are now so addicted?

11. A race, when it emigrates, carries its habits with it, and, for a time at least, those habits may override all climatic law.

12. England has thus overshadowed our whole country with its love of strong drinks, and with its habits of intoxication, as it has more recently covered Ceylon, parts of the East, and Australia.

13. This influence on our own country is greater now than it would have been if our forefathers, the early settlers, had cultivated the vine, which would have been practicable, as seen by the recent examples of Ohio and California, and from the fact that the whole of the United States lies in the region of the earth's surface suited to the grape culture.

14. If these early settlers had done this, our nation would probably have been more temperate, and a vast industry like that of France, of Spain and of Italy and Germany, in light native wines, would long ago have sprung up.

15. The example set by California and Ohio should be followed by the whole country, where the vine can be grown. As a temperance measure it behooves every good citizen to promote that most desirable object. We should also allow the light, unfortified wines of Europe to be introduced free of duty instead of the large one now imposed. Instead of refusing the German lager beer, we should seek to have it introduced into the present "grog

shops," and thus substitute a comparatively innoxious article for those potent liquors, which now bring disaster and death into so many families.

16. "Holly Tree" branches for the sale of good food, tea and coffee chiefly to the people, should, by the benevolent co-operation of the community, be made to take the places of the numerous grog shops now open for the sale of ardent spirits.

17. The moral sense of the community should be so aroused to the enormity of the evils flowing from keeping an open bar for the sale of ardent spirits, while those for the sale of light wines and of lager beer should not be opposed, except for the sale to habitual drunkards, after due notice from friends. Sellers violating such law might be compelled to support for a time the family of their victim.

18. The horrid nature of drunkenness should be impressed by every means in our power upon the moral sense of the people. The habitual drunkard should be punished, or if he be a dipsomaniac, he should be placed in an inebriate asylum for medical and moral treatment, until he has gained sufficient self-respect to enable him to overcome his love of drink. These asylums should be established by the state.

19. The appendix contains various letters on intemperance in this and other countries, on reciprocity treaties for introduction of European wines, etc.

In the sincere belief, gentlemen, that this analysis of our correspondence will, eventually at least, tend to help onward the most excellent cause of temperance everywhere, and in the hope that none will be offended at the expression, at times, of my own individual opinions, which in the course of the discussion I have deemed it my right and duty to give, I remain,

Your colleague and friend,

HENRY I. BOWDITCH.

IV

PREVENTIVE MEDICINE AND THE PHYSICIAN OF THE FUTURE

By Dr. Henry I. Bowditch

[Reprinted from the *Fifth Annual Report*, 1874, pp. 31–38 and 59–60. This article, in the form of a letter to his colleagues, was written after being chairman of the Board for five years. — G. C. W.]

In my earliest communication with you I endeavored to express in a few words some general views of the great and benign objects presented before us, and the correlative public duties that devolved upon us, by our appointment as members of the State Board of Health. I wished then to give my highest ideal of those objects and duties, and I then expressed my belief that we should not fail of doing some service to the people of Massachusetts if, with simplicity of purpose and single-hearted devotion to that purpose, we should pursue, slowly, perhaps, but steadily, the path opening before us.

It is not my intention now to review what we have already done. I may, however, be allowed to say that the annual liberality of the Legislature in regard to our reports, and the fact that the example of Massachusetts has been followed by several states of this Union, who have established similar boards, is certainly gratifying. It would seem that our example has stimulated others to a like course of action in regard to Preventive or State Medicine, as it has been sometimes called, because the improvement of the public health and the prevention of disease among the people is the object of both. This object has now occupied us for five years, and we can, perhaps, see more clearly its tendency and noble scope. We can also, perhaps, prophesy more decidedly than before the beneficial results that will accrue to mankind when the world enters heartily into its objects, and when similar boards have been formed, and have worked for many years in every civilized community.

Preventive or State Medicine is of recent origin. It has been the natural outgrowth of modern thought and resources, stimulated by centuries of suffering and by the sacrifice of multitudes of human beings. Modern thought, later and more scientific methods of investigation, and more rapid means of communication of thought and of action have given this idea to the nations. It is true that Hygiene, or the science which would promote human health, has been discussed from earliest times, but commonly as applied to the individual man. The scientific study of the laws of disease as they affect large masses of men, and the voluntary efforts of great states to study those laws by means of boards of health, or of experts set apart for this special purpose, are strictly of modern origin. Hippocrates, wise as he was, could not, with the imperfect means of communication in his day, have inaugurated it. Moreover, in the earlier states, man as an individual never stood, in the estimation of his fellows, nor of the government, so high as he does at the present day under European or American civilization. Formerly his welfare was subordinated to that of the state. Now, the theory is exactly the reverse, and the state claims to have the tenderest interest in the welfare of each and every one, the humblest or richest of its citizens. Formerly, all persons believed, as many now believe, that prayer should be offered to the offended gods in order to stop plagues, famine and death. But now, most persons feel that, although prayer may avail much to enable an individual or a state to bear calmly some terrible calamity or to die bravely, if need be, in a great cause, it can never drive away fever, cholera, nor smallpox. It can never cure consumption, though it may help both sufferer and friends to bear it more patiently. To submit quietly to any remediable evil, as if to the will of Providence, is not now considered an act of piety, but an unmanly and really irreligious act. It is the part of error and stupidity which does not believe in the duty of studying into the physical causes of disease, and in at least endeavoring to crush out these originators of pestilence and of death.

Modern Preventive Medicine has been hinted at by Nature from the earliest time. Occasionally she has shown us how she can summarily strangle disease, and drive it forever from its usual haunts. The great fire in London, in 1666, burned up the greater part of that metropolis. With its great sorrows, trials and losses, it brought one of London's greatest blessings, viz.: the extirpation of the plague which had previously so often ravaged the inhabitants.[1]

Intermittent fever has ceased in certain parts of Great Britain and of this country under the influence of tillage and drainage of the soil. Till inoculation was brought from the East and taught to modern Europe, the physician could not mitigate smallpox.

Jenner, led by Nature's teachings, substituted the milder disease of vaccination for the fatal scourge of smallpox.

Private investigations in Europe and America have, in these later days, proved that residence on a damp soil brings consumption; and, second, that drainage of wet soil of towns tends to lessen the ravages of that disease.

We have been taught by Murchison and others that fevers are often propagated by contaminated drinking-water or milk. Our own Board investigations have proved that contaminated air may also cause it.

Still more recently cholera has been brought, in its origin and progress, under law, and we know how we could probably prevent it if proper precautions against its origin were taken. A neglect of proper sanitary regulations tends to propagate this scourge, year after year, over Europe.

These monitions given by Nature and individuals, as to our power of checking or preventing disease, have at last culminated in the fact that the state decides to use its moral power and material resources in aid of State or Preventive Medicine. England, in this respect, outranks all other countries. America, I think, stands next.

This appears to me the general course of events hitherto in regard to public health. I do not mean to assert, however, that nothing has ever been done before by the state. On the contrary, the Parliament of Great Britain and other European states and the legislatures of our various states have at times spasmodically

[1] 68,596 died of it in London, 1664–65.

and tentatively, for centuries past, given powers to local town boards of health. They have, moreover, at times, devised important plans for the health of the people and for the prevention of the spread of certain diseases. But all these were trivial compared with the present position of England and of some states of this Union where state boards of health have been established.

Again, physicians have heretofore devoted themselves chiefly not to the prevention, but to the "cure" of disease. How utterly impotent have commonly been their efforts to cope with great epidemics! The giving of medicine during a disease, not the prevention of it, has been their chief aim, and the community now generally believes that the physician is simply an administrator of drugs. How rarely is a physician called upon to mark out the course a man should pursue to prevent their use! Nevertheless, modern times will bear ample witness to the zeal with which some of the most distinguished of our number have protested against the too free use of medicine, and have declared that our art must be pursued more in accordance with Nature's laws, and not in total neglect of them, as was too frequently the case in former days. Some few even, though I would protest against it, have carried their skepticism so far as to lead one to believe that they think the practice of Physic hitherto has been an unmitigated evil.

With one accord I believe it may be said that the whole profession has cordially greeted the advent of State or Preventive Medicine. What, it may now be asked, will be the effect upon the public and the profession after two or three centuries of growth of the principles of Preventive Medicine? I look forward with high hopes for the future of this young idea, founded as it is on the duty of the state to investigate the laws of all diseases so that, as far as possible, all shall hereafter be prevented. I think that idea cannot fail of making a stalwart growth. It may make many errors, but it must make yearly progress in the knowledge of the more hidden causes of disease. At least three good results will arise from it: —

1. The profession will learn that a system of therapeutics, dependent on materia medica simply, is much less valuable

than that which seeks to defend its patients from the insidious approaches of the causes of disease.

2. The people will themselves learn to avoid many evils into which they now fall, because of their ignorance of the laws of health. They will have less faith in drugs, more in nature; more in anticipating and preventing evil than in curing it after it has begun.

3. The knowledge of the precise effects of special drugs, and of their various compounds one with another, will become more and more accurate under the teaching of modern experimental physiology, and still more under clinical experience. Though it may take centuries to develop, even to a small extent, the future materia medica, the future physician will use each article with a finer knowledge of the precise effects of each drug and of its combinations, than it is possible for us now to have. We can scarcely foresee the time that will be required for this materia medica to become even tolerably perfect. In fact, the knowledge of the special action of drugs at the present day, compared with what we have yet to learn upon this important subject, is a mere trifle.

Meanwhile, as the profession of medicine becomes more thoroughly scientific, the people will also gradually learn that all filth, physical, moral or intellectual, is absolute poison; that no violation of physical, moral or intellectual law can be made, even momentarily, without injury to human comfort and life, and possibly without causing premature death. It will learn that it is not only worse than useless, but a vile wrong to one's self, to use various articles as incautiously as they are generally now used.

But it may be asked, What is to become of the physician and his practice, when the public takes care of its own health more than it does at present? Will the profession be useless? Far from it. It will stand higher than ever. It will be the prophet of the future, and will direct men how to govern their own bodies in order to get the full amount of work and of joy that is possible out of each body that appears in life. I feel sure that more than at the present day will the wise adviser and practitioner of medicine be then needed, whenever misfortune or wilfulness or carelessness, folly or crime, shall have brought disease and perhaps a tendency to early death into a family. It will be the physician's duty to show the way out of such impending evil. He will take the child at its birth, and will cast its horoscope from the past and present of its family tendencies, and its actual surroundings. Having well considered these data he will lay down the rules of life which should rigidly be pursued by parents and by himself in order to gain possession of as much of perfect health as he is capable of having. As the dentist now undertakes to modify and to guide the various processes of dentition from earliest childhood to old age, so the physician will be the monitor and guide for the entire body from birth to death. The dentist is, philosophically speaking, in advance of the physician of the present day, inasmuch as in his own specialty he oftener acts on the principle of Preventive Medicine. It must be admitted, moreover, that however wise a prophet the physician may be, and however skilled in hygienic law the people may become, there will always be a very wide margin of ignorance, folly and of adverse circumstances on the part of the public, which must be met, and, if possible, remedied by the professors of our art.

To be able to aid in inaugurating such a future state of professional and lay knowledge is surely an object worthy of our highest effort. It is satisfactory to me, and I hope also to you, to think that we are allowed to advocate this noble cause in Massachusetts. It is my hope that by the efforts of the Board the state will annually become more alive to its best interests, and to its duties towards the people. Hygienic laws will be enacted and they will be obeyed by the many, if from no other motive, from self-interest. May we not hope that our country homes will be more carefully guarded from the many causes of disease that now, through ignorance beset them. I trust that in our cities large tenements for the poor, in which there are common corridors and water-closets or privies for two or three hundred people, in which the comforts of home and all the amenities of human life are set at naught, in which it is impossible to educate a family in decency, and where disease and crime prevail, will be declared public nuisances and pest-houses. I look forward to the time when a city government will be considered criminal which, like the city of Boston, allows, year after year, sewers to be introduced as unwisely as they are at present, and its sewage to be thrown broadcast about its borders, thereby at times overwhelming its inhabitants with a tainted atmosphere. The same government will, I trust, feel the importance of having proper administration of the laws about drunkenness, guarding itself alike against the futile waste of time of attempting to enforce a general prohibition, or the allowing, as at present, of unbridled license in the sale of liquor. When Preventive Medicine has full sway, men will not be allowed day after day to disturb the public peace or the comfort of their own families by beastly drunkenness. The authorities of that day will promptly decide whether it be the result of disease or of crime, and will seclude the wrong-doer either in a drunkard's sanitarium or a prison. I feel sure, moreover, that the time will come when the selling of rum to an avowed and well-known drunkard will be deemed one of the most dreadful of crimes, inasmuch as drunkenness strikes at the root of the physical, moral and intellectual health of the people. These are only a few of the blessings that will arise when Preventive Medicine shall have its full sway over our people, and when individuals and laws shall have been gradually moulded by it.

As an example, imperfect though it must be, of what I think will be the relations of physicians and the community compared with those which they respectively hold at present, let me imagine the following: Suppose two parents have hereditary tendencies to consumption, and they are desirous of knowing how best to manage their child that has just been born. They wish that it may have the best chance of arriving at a good old age after a life of health. Let us suppose that both parents have this ancestral tendency to that disease of the lungs which is known as consumption. According to some modern writers, it has many antecedents or causes, but we shall probably know it for centuries to come, as it has been known in the past, as the one disease of the lungs that slays a large percentage of all who die in New England. There are certainly some general topics, even with our present knowledge of its antecedents, which would naturally and physiologically come under discussion in replying to the inquiries. Among them are some which are generally applicable to all human beings, whether in health or disease, viz.: residence, nutrition, clothing, care of the skin, bathing, etc., recreations, education, profession, exercise, walking, running, dancing, horseback exercise, driving, gymnastics, bowling, rowing, swimming. Let me try to give most briefly some general ideas on each of these topics.[1]

I have thus given you my views of the grand scope of Preventive Medicine, and, as a most imperfect illustration of its future usefulness, I have run through a series of recommendations that I think any experienced physician might even now give, according to the principles and rules of action that will weigh with the physician of the future. And I believe that if these recommendations, with others that might be added by any family physician, should be *thoroughly* carried out by the parent during childhood, and by the man or woman when arrived at adult life, many that will die of consumption would escape that calamity.

In saying this I do not mean to intimate that during the whole period no other remedies, strictly so called, might not be necessary. Doubtless they would be; and of the exact mode of application of those remedies physiological experiment and clinical experience of physicians are teaching us more and more every day. I contend, therefore, that the physician of the future will stand higher than ever, as Preventive Medicine advances. In this statement I take a position exactly the reverse of that assumed by President Barnard in his late address before the Health Association at its recent meeting in New York. That gentleman quietly informed his medical hearers that their doom was sealed under the steady advance of modern science. Their services would become less and less necessary, and would finally be no longer needed by the laity. I think he is wrong and that my views are correct, because, while human free agency and human imperfection exist, while accidents, moral and physical, occur, there will always be some occurrences tending to injure health which no skill in prophecy can foresee. The wise physician will

[1] Discussion of these topics is omitted from this abstract.

therefore be summoned to act immediately on important cases of disease or threatened death. These he will meet not only by wise preventive regulations for the future health of his patient, but likewise by a careful administration of medicine, properly so called, during the actual attack.

HENRY I. BOWDITCH.

V

THE FILTRATION OF POTABLE WATER

By Professor William Ripley Nichols

[At the time when this paper was written the filtration of water was practiced but little in the United States, although filters had been in use in London for over twenty years. Professor Nichols discussed the subject in a scholarly and scientific manner and those familiar with the subject will appreciate his keen powers of observation. He did not then have a knowledge of bacteria and the germ theory of disease and this accounts for his view that filtration will not purify polluted water. Reprinted from the *Ninth Annual Report*, 1878, p. 139. — G. C. W.]

Prominent among the requirements of various commissions, which have been busied in different places with the matter of water-supply, is the statement which needs no commission to establish; namely, that a good drinking-water should be free from all suspended matter, and as far as possible free from color.

Comparatively few towns can congratulate themselves on having in their possession, or even within their reach, a supply of water which shall correspond in all points to the ideal drinking-water. Often the question must be decided between an extravagant expenditure of money, and a water which is of inferior quality although not actually unwholesome. In theory, financial considerations stand behind sanitary considerations; yet in practice there is always a limit which cannot reasonably be exceeded.

It is not proposed at this time to enter into any discussion as to what may be, theoretically, the best source from which the supply of water for town or city use should if possible be taken: in actual practice it is often found necessary to choose as a source of supply a river or pond, which, although it may not have become unfit for use by reason of pollution, is of inferior quality owing to the presence of suspended particles of vegetable or mineral matter, or to excessive hardness, or to coloring matter of vegetable origin in solution. In such cases it is possible to improve the quality of water which in its natural condition is not well suited for use. It may, however, be regarded as a principle in sanitary science, that a water which is polluted by admixture of substances known or generally suspected to be injurious, to such an extent as to require actual purification, should be rejected at once as a source of domestic supply; but a water too hard for use may be softened by Clark's process, which is applicable on the large scale;[1] and a water containing matter in suspension may be clarified by some process of filtration, to be preceded as a rule, in the case of running streams, by subsidence. It is the purpose of the present paper to consider, in the light of American and foreign experience, artificial filtration on the large scale, especially with reference to the conditions which obtain in our own state; and, on account of its intimate connection with the same subject, we shall also consider the so-called natural filtration method of water-supply, and the filtration of water in the household.

Before beginning upon the subject proper, attention is called to certain definitions, which to some will seem, no doubt, very elementary. There is, however, a great deal of confusion in the minds of even well-educated people, as to the use of the terms in solution, and in suspension, as referred to waters; a great deal of confusion, also, with reference to the distinction between clear and colorless, ideas which are by no means synonymous. The accurate use of the terms can probably best be made plain by illustrations. If, for instance, we put some common salt into a quantity of water, after a time the salt disappears, the ultimate particles being distributed through the water so that they are no

[1] The so-called hardness of water is due in the main to the presence of compounds of lime and magnesia in solution. These compounds are generally the sulphates and bicarbonates. When the hardness is due to the bicarbonates of lime and magnesia, the water becomes softer on boiling, because the bicarbonates are decomposed into carbonic-acid gas, which escapes, and the carbonates of lime and of magnesia, which are insoluble in water. Practically the same effect as that produced by boiling may be brought about by the addition of a proper amount of milk of lime. The lime unites with the bicarbonates to form simple carbonates, which are deposited as a white powder, incidentally removing at the same time most of the suspended matter which the water originally contained, and often removing more or less coloring matter. There is no serious difficulty in applying this process on a very large scale.

longer distinguishable by the eye, even aided by the most powerful microscope: the salt cannot be removed by simple filtration; and, although the solution is somewhat less mobile than water, it is still transparent. This is a case of solution. Suppose instead of the salt we take a quantity of blue vitriol (sulphate of copper). The phenomena would be similar, but the blue color of the compound would show itself in the solution. If the solution were saturated, i. e., if the water had dissolved as much as it could, the transparency of the liquid would be diminished on account of the depth of color; it would be easy, however, to take a very thick layer of the solution, and satisfy one's self of its transparence. Such a liquid is colored, but is also clear.

Suppose, now, we take some clay, shake it with water, and then allow it to settle. The grosser particles will subside to the bottom of the vessel, but the finer particles will remain in suspension. Very finely divided clay will refuse to settle for weeks, and sometimes even for months. In such cases the liquid appears somewhat turbid and opaque; and although the individual particles are too fine to be readily removed by ordinary filters, and too small to be distinguished as particles by the eye, still the clay has not dissolved, and the very turbidity or opacity of the liquid shows the presence of solid particles, although they are extremely minute. Such an appearance is not to be described as being colored, although finely divided clay and other material may be suspended in a liquid which does of itself possess a distinct color. One often meets with the expression, and that too in standard works, " the water is discolored by clay," when really it is a question of a colorless water carrying particles in suspension. The water in many of our New England streams is at seasons highly colored by vegetable extractive matter in solution, while the water may at the same time be perfectly clear and transparent. On the other hand, our pond waters are often decidedly green; but simple filtration gives a colorless water, and shows the green color to have been due to particles of green (vegetable) matter which were suspended in the liquid.

Artificial Filtration on the Large Scale

The filtration of water on the large scale has been practiced in England and on the Continent of Europe for many years, and has become very general in cases where the supply is taken from streams or ponds. From statistics which were laid before the Düsseldorf meeting of the German Public Health Association, in 1876, by Engineer Grahn, it would seem that in Germany since 1858 there has been no town of considerable size supplied with unfiltered river water, while the increase with reference to other sources of supply may be seen from the following data: —

Table I

Total Number of Inhabitants in Eighty Towns of Germany, German-Austria, and Switzerland

Supplied With	1858	1876
Unfiltered river water	460,000	460,000
Filtered river water	1,060,000	1,697,000
Spring and ground water (by gravitation)	25,000	1,519,000
Spring and ground water (by pumping)	45,000	1,719,000

In the United States the practice of the filtration of water on the large scale is but just beginning to come into use. In the year 1866, James P. Kirkwood, C.E., went to Europe in the interests of the city of St. Louis to study the clarification of river waters used for the supply of cities; and his elaborate report [1] on the subject of filtration in general is almost the only book on the subject which is at all comprehensive. Full details of European practice are there given, as well as plans and suggestions for filtering-beds for St. Louis. St. Louis has not yet adopted any system of filtration, but several other cities of smaller size have done so with more or less success: namely, Poughkeepsie, N. Y., in 1871; Hudson, N. Y., in 1874; Columbus, Ohio, in 1874; Toledo, Ohio, in 1875. The necessity of filtration is, however, in many places felt, and would no doubt have been long since undertaken were it not for the additional outlay required for subsiding-basins and filter-beds, and the expense of maintenance.

[1] Kirkwood, "Filtration of River Waters." New York, 1869.

Object and Results of Filtration on the Large Scale

Having considered the method of filtration in common use we may now profitably inquire more closely into the object which it aims to accomplish, and the results which are actually obtained.

Although, as we shall see later, something more is incidentally accomplished, filtration in its strict sense is simply a mechanical operation, and consists in causing a liquid containing suspended particles of solid matter to pass through some material, the pores of which, although large enough to permit the passage of liquids, are still too small for the passage of the solid particles suspended in the liquid. The suspended matter which by its presence in our water-supplies makes filtration desirable is somewhat various in character. Most rivers are liable, particularly at times of freshet, to carry a greater or smaller quantity of mineral matters in suspension; this may be, first, of such a character as to settle quite readily by virtue of the comparatively high specific gravity of the particles, as will be the case of the mineral matter consisting of sand, mica, etc. Such material as this is readily removed by filtration; but it is generally more economical to subject the water to a process of sedimentation first, and settling-basins are quite universally regarded as a necessary preliminary to successful filtration. It is evident that without sedimentation a slower rate of filtration must be employed, and the sand must be cleaned more frequently.

The suspended matter may obstinately refuse to settle, as is the case of rivers rendered turbid by the presence of clay in suspension; in which case it is almost impossible as a rule to filter the water slowly enough to obtain good results if the turbid water without previous sedimentation is put directly upon the filter-beds. Even with sedimentation the result is not always as good as might be desired. The following table, taken from the *Sixth Report of the Rivers Pollution Commission*, will give an idea of the efficiency of the filtration as practiced by the various London companies. The observations being made on monthly samples, the statements of the table will perhaps hardly give a just idea of the results obtained day by day; but they will serve to indicate the fact that the mere possession of filter-beds does not secure perfectly clear water at all times.

TABLE 2

THAMES AND LEE WATER. COMPARATIVE EFFICIENCY OF DIFFERENT RATES OF FILTRATION DURING THE YEARS 1868 TO 1873, INCLUSIVE

Name of Company	Maximum Rate of Filtration Expressed in Inches Per Hour	Number of Monthly Occasions When —			
		Clear	Slightly Turbid	Turbid	Very Turbid
THAMES					
Chelsea	7.27	49	15	5	6
West Middlesex	4.71	75	..	..	..
Southwark and Vauxhall	6.00	41	24	5	4
Grand Junction	6.97	55	14	7	..
Lambeth	12.00	42	11	12	10
LEE					
New River	5.00	70	4	..	..
East London	3.85	51	18	3	2

In speaking of suspended matters it is hardly necessary to allude to fish and small animals, or to chips and sawdust and other such substances, intentionally thrown into running streams, or to leaves and other fragments of vegetable matter which have fallen from the trees and forests along their banks. Most of such floating matter can be arrested by suitable screens, which would be without effect as far as removing the finer particles is concerned.

We have spoken of the turbidity of many streams: ponds are less liable to be turbid from the causes alluded to, being, in fact, settling reservoirs; and in the case of old ponds with sandy or gravelly sides and bottom there is seldom anything to complain of or to necessitate filtration. Ponds are, however, particularly liable to other sorts of suspended matters: namely, to growths of minute vegetable organisms. This trouble concerns so intimately the water-supplies of this region, where the water is quite commonly taken from natural or artificial ponds, that we may dwell upon it somewhat in detail.

No natural water which is exposed to the air and light, whether in pond or river, is ever entirely free from vegetable growth.

The non-professional and non-botanical observer might very likely divide the various plants found growing in the water into three classes: 1st, and most readily recognized as plants, are those commonly known as eel-grass, pond-weed, pickerel-weed, lilies, etc., which have roots and leaves, and also, at the proper season, flowers; 2d, and less readily recognized as plants, are the confervoid growths,[1] as they are often called, of filamentous structure, grass-green or in some cases bluish-green in color, forming tangled masses readily removed from the water, and, when so removed, shrinking enormously in apparent bulk, and drying away to a grayish or colorless mass, in some cases looking almost like coarse paper. Plants of this character grow in almost all reservoirs, or other bodies of water exposed to the light and air, both in still and running water; they either float in masses in the water, or grow attached more or less firmly to the rocks and stones of the bottom of the pond or reservoir. By their growth they do no harm to the water in which they flourish; and as they are readily arrested by ordinary wire screens, or easily removed by rakes or scoop-nets, their presence causes no serious inconvenience in water used for town-supply.

The third division of the non-professional would include, if indeed they were recognized as plants, those minute organisms which appear as greenish specks, or minute straight or curved threads, diffused through the water, visible enough if a large quantity of water be looked at, but perhaps almost escaping notice in the small quantity which would be taken up in a single glass. It is true that the individual plants are in some cases distinguishable by the naked eye, but their form and structure can be made out only by use of the microscope. If collected together as a scum, which often happens, especially on the windward shore of a pond, the scum is not coherent, is easily broken up, either by a wind setting in the opposite direction, by a shower of rain, or by

[1] These, as well as those mentioned below, belong to the class of cryptogamous (non-flowering) plants, which the botanists call *algae*, — plants which grow in the water, or in moist places, and usually contain chlorophyll (green coloring matter), or some allied substance. To their number and variety there is almost no end.

artificial agitation. The appearance has been sometimes described as that of meal or of fine dust scattered through the water. The number of individuals is almost infinite, and under favorable conditions they increase with great rapidity. Their presence gives a decidedly green or greenish-yellow tinge to large bodies of water; and their death and decay often cause considerable offence to the sense of smell of those sojourning in the neighborhood, and to the sense of taste of those obliged to drink the water.

While very many species of the minute algae present this general appearance, as far as my own observation and information extend, the number of species which are known to increase to such a great extent as to completely fill the waters of ponds of many acres in area, and to cause sensible inconvenience, is comparatively small; the most common in this neighborhood (New England) seeming to be the *Clathrocystis æruginosa*, but certain plants referable to the *Nostochineæ* are not uncommon alone, or in company with the *Clathrocystis*.[1]

The inconvenience caused by the presence of the plant is felt first by those who use the water for town-supply, and, secondly, by those who cut ice upon the pond. While the plant is alive and growing, there is little taste or odor given to the water, hardly noticeable if the water is iced. When the plants enter into the first stage of decay, the water acquires a peculiar taste and odor. Light and a certain degree of temperature are requisite for the normal growth of these algae, and the decay often takes place in the mains and service-pipes; it will not infrequently happen that the water in a reservoir or pond will have almost no taste, while the water as delivered to consumers will have a decided taste. By the settling of the green growth to the bottom in a more or less decayed state, the ponds are generally cleared before the cold weather sets in; but, in several cases which have come under my observation, the material floats up to

[1] It may be interesting to note, with reference to the chemical effect of the presence of these algae, that they are highly nitrogenous. A sample collected in the Ludlow Reservoir was dried, and was found to contain 11.18 per cent of nitrogen. The sample consisted mainly of the *Clathrocystis*, but of course it was impossible to separate the microscopic animal organisms from the vegetable.

the under surface of the ice, and is frozen into the ice, making it unmarketable.

Among the various questions which are often propounded with reference to the matter are the following:

1. What is the cause of the trouble?
2. Is it injurious to health?
3. Can anything be done to prevent it?

(A) *The Cause of the Trouble.* — Although there is no doubt that the trouble is caused by minute vegetable organisms, of whose life-history a good deal is known to botanists, various suggestions have been made as to the cause of its appearance. By many it has been supposed to be a sort of fermentation, a process of purification.[1] In some cases, this abundant appearance of the green matter has seemed to follow the apparent increase of sewage and other impurities discharged into the pond. I have within the last few years examined a great many ponds affected in this way, and cannot satisfy myself that there is any connection between such discharge of sewage and the growth of these algae: the amount of soluble nitrogenous matter, of ammoniacal salts, of phosphates, and of other mineral compounds necessary for their growth, are everywhere present; and it would be unsafe to prophesy the security therefrom of any pond. Although it would seem that ponds recently made by flowing marshy or cultivated land were peculiarly liable to the trouble, especially if shallow, my observations have led me to make even this statement less emphatic than I was at first inclined.

Although these plants are not all killed by a considerable degree of cold, still they thrive only in warm weather. Observations on this point are incomplete; but such as I have been able to collect would seem to point to a temperature of 70° F., or thereabout, below which the trouble is not likely to begin. Extended observations on this point are much needed.

[1] I have often found that residents (farmers and others) on the banks of large ponds are familiar with what they call a "fomentation" in the pond, taking place with some regularity at certain seasons of the year, which phenomenon is, in some cases at least, a growth of these minute algae.

I have been unable to satisfy myself that the presence of aquatic plants at the margins of the ponds has other effect than that of entangling and holding masses of scum, which if then exposed to a hot summer sun rapidly enter into decay.

(B) *Is the Matter Injurious to Health?*—The observations as to the effect on the human organism of water containing these algae, are not, of course, very definite or complete. In some places, however, where the only source of supply is thus affected, opportunity for observation is afforded. I have not been able to obtain any evidence of the unwholesomeness of the water from a supply which is in other respects of good quality. When the algae are alive and fresh, horses and cattle drink the water readily, in preference to spring water: when decay has taken place, the water sometimes becomes so offensive that they refuse to drink it. In this condition it is manifestly unsuited for domestic use.

(C) *Can Anything be done to prevent the Trouble?* — As far as our present knowledge extends, nothing.

Various plans of local applicability are pursued in different places, by which the annoyance is lessened. Sometimes while the vegetable matter is a scum, water may be wasted from the surface of the reservoir, at a point where the material has collected; and sometimes the pond may be left to itself, and an alternate supply made use of.

There is no difficulty in removing the vegetable matter completely by sand filtration, although of course the filters become rapidly clogged. This clogging is aided also by the development upon the beds themselves of confervoid growth, which in uncovered beds becomes so abundant and vigorous as to form a sort of carpet on the surface of the sand, which can be raked off in coherent sheets, or rolled up. If the vegetable matter in the water, or that which grows in the beds, enters into decay, and communicates an unpleasant taste to the water, the filtration may be unable to remove the taste completely.[1]

[1] I would be distinctly understood as not asserting that all bad tastes and odors to which water-supplies are subject are due to the presence of these or other algae. They are the real cause of a real trouble. The occurrence of a fishy, musty, cucum-

It also seems that filtration through sand does not remove the germs or spores of the plants; so that if the filtered water be stored in open reservoirs, exposed to light, it is again liable to vegetable growth. For this reason, such water, when once filtered, should be delivered at once into the distribution-pipes; or, if storage is necessary, it should be stored in covered reservoirs, preferably of such size as to be readily emptied and cleaned if occasion require.

Conclusions

I will here bring together the general conclusions reached from a study of the practice and results at home and abroad, and from my own experiments.

1. No material has yet been brought into practical use for artificial filtration on the large scale, except sand.

2. With our present knowledge we have no evidence that sand filtration can be regarded as an efficient means of purification of polluted water; although it may, if properly carried out, lessen the liability of ill effects.

3. All visible suspended particles, and an appreciable proportion of organic matter actually in solution, may be removed by properly conducted filtration through sand.

4. For the present, at any rate, it will be best to regard artificial filtration mainly as a means for the removal of suspended matters, although under the management of a person of intelligence, education, and experience, the simple sand filter is capable of producing sensible improvement in respect to the organic matter which is dissolved in the water. In ordinary practice, however, it is quite certain that sufficient care will not be taken to secure such results; and, in view of what is actually accom-

ber, green corn, or other peculiar odor or taste, may be due to the presence or decomposition of certain algae; but it may be produced by the decay of more highly organized plants, or by causes of which we are ignorant. For instance, the cucumber taste which affected the Chestnut Hill Reservoir of the Boston Water Works in 1875 was traceable to no such cause, nor, indeed, to any assignable cause, although careful examinations were made from a chemical, from a botanical, and from a zoölogical standpoint. Other cases also have come under my observation, where no algae, fresh or decomposed, could be found in sufficient quantity to account for the unpleasant taste, which was very noticeable.

plished in existing works, it seems to be best to regard the removal of color and unpleasant taste as incidental, and likely to vary very much according to the condition of the filter.

As the public mind becomes educated in the matter, a higher standard of efficiency may be exacted; but for the present it should not be held out to towns and water-boards as a result which will follow filtration through sand, that a water which is naturally strongly colored by vegetable extractive matter will be rendered colorless in ordinary practice, although it is true, that, starting with an entirely new filter, the first portions of water filtered may be deprived of color, and such an experiment has often led into error.

5. It is not worth while to introduce a system of sand filtration in the case of any town-supply unless there is the willingness to make such outlay for construction and maintenance as shall render the scheme thorough and efficient. This will involve properly constructed filter-beds and generally settling-basins of sufficient size; it will involve intelligent supervision, and frequent cleansing and renewing of the material of the filter. It should also involve, in the construction, the covering of the filter-beds; and for the best effect the filtered water should be delivered at once to the consumers. There should be at least duplicate beds, so that there can always be one in use. If on account of lack of duplicate beds, or for other reasons, it seems necessary to store the filtered water, this should be done in covered reservoirs of small size, which can be readily emptied and cleaned if occasion require. It cannot be said too emphatically that sand filters, or indeed filters of any description, are not automatic, and that the effect obtained depends not only on the construction of the filters, but also, and even more, upon the care with which they are managed. I believe that money expended on a scheme for filtration is practically wasted unless a sufficient outlay is made to secure certain efficiency. It is possible to store the filtered water under such conditions that it shall become as bad as before filtration. A desire for economy in original outlay may lead to a scanty area of settling-basins and filter-beds; but a subsequent larger demand than the plant can meet will necessitate either

too rapid filtration, by which imperfectly filtered water will be obtained, and the beds fouled throughout; or an admixture of unfiltered water, which, even if necessary for a short time only, will foul the pipes, and undo the subsequent work of the filter.

I should not recommend any town to undertake the artificial filtration of their water unless they were willing to face the probability of its costing from two dollars and fifty cents to three dollars per million gallons in addition to the original outlay for the works.

VI

ON SOME IMPURITIES OF DRINKING-WATER CAUSED BY VEGETABLE GROWTHS

By Dr. W. G. Farlow

[This was probably the first paper in the United States to discuss adequately the character of the microscopic organisms which cause tastes and odors in water. *Supplement to First Annual Report, Board of Health, Lunacy and Charity*, 1879, p. 131. — G. C. W.]

The object of the present paper is to present in a popular form a statement of what is known with regard to the effect of the growth of different plants upon the water in the ponds, streams, and basins which supply the cities and towns of the Commonwealth. In this connection the subject will be discussed from a botanical point of view; and we can only consider certain striking properties, such as smell and taste, with relation to the particular species of plants which produce them, without taking into account the more subtile changes which can only be detected by chemical analysis. It is desirable that all who, in any sense, have charge of the public health, should have some familiarity with the common forms of plants likely to pollute drinking-water; because, as the matter now stands, the public are at the mercy of any person, who, armed with a compound microscope and a supply of Latin and Greek names, chooses to alarm the neighborhood by the announcement of the appearance in the water-supplies of plants whose injurious nature is supposed to be in direct proportion to the length and incomprehensibility of their names. The public are now beginning to read about the germ-theory of disease; and hearing that fevers may be produced by germs, and being told that germs are found in water, they very naturally but illogically infer that any small bodies found in the water are the germs of disease. Whatever of truth there may be in the germ-theory of disease, there is no doubt that designing persons impose on the credulity and fears of the public by representing as germs of disease microscopic plants which could not possibly have caused any of the diseases which have been supposed by scientific men to be produced by germs of a vegetable nature.

The most striking plants which are found in fresh water are those which are commonly called weeds; as, for example, pond-weed, pickerel-weed, eel-grass, etc. They all have distinct stems and leaves, and produce flowers, using the word in a botanical sense. In some cases, as in the pickerel-weed and pond-lilies, the flowers are striking, and readily recognized as such; but in most of the water-weeds they are small and obscure, and pass unrecognized by the public. The mass of the water-weeds of this region belong to a comparatively few botanical genera; e. g., *Myriophyllum*, *Ceratophyllum*, *Callitriche*, *Utricularia*, *Anacharis*, *Potamogeton*, *Naias*, *Vallisneria*, etc. They all start from roots at the bottom of ponds and streams, and may attain a length of several feet. Late in the season, and especially when the water has been disturbed by strong winds, they break from their attachments, and are washed ashore often in large heaps.

The Lemnae, or duck-weeds as they are popularly called (*see* Plate I, Figs. 4, 5), although classed by botanists with flowering-plants, differ in habit from our other common water-weeds. Instead of growing from the bottom, and having stems and leaves, they float in immense numbers on the surface of the water, forming a scum, as may be seen in the ponds of the town of Winchester, and at other points in the Mystic Valley. The duck-weeds have no distinct stem and leaves, but consist merely of more or less roundish, grass-green disks, not usually more than a quarter of an inch in diameter, from the under side of which delicate roots project into the water. All the flowering plants commonly included under the name of water-weeds. whether they grow from the bottom, as is usually the case, and have distinct stems and leaves, or, as in the exceptional case of the duck-weeds, float on the surface in the form of a scum, may, under ordinary circumstances, be considered harmless as far as any direct effect produced on drinking-water is concerned.

They may, however, be sources of trouble in two ways. In the first place, they may cause a mechanical difficulty, when growing luxuriantly, by choking up small streams or bodies of shallow water. This difficulty is not so likely to arise in bodies of water used as water-supplies as in the small sheets of water used for ornamental purposes. In the latter case, it not infrequently happens that the means taken for avoiding a growth of plants, such as cementing or stoning the bottoms and margins of small ponds, seem to encourage the growth of certain species of weeds which do not flourish to any very great extent in natural basins. In an artificial pond supplied by a brook in the neighborhood of Boston, the water was completely filled, and the pond disfigured, by a growth of the common water-starwort, *Callitriche verna*, which in this region rarely grows in large quantities in brooks. We may here refer to the well-known case of the plant known in England as Babington's curse, because it was introduced into that country from America by Professor C. C. Babington of Cambridge University. It is the species known to American botanists under the name of *Anacharis Canadensis*, which, although not at all rare in this country, is not so common as to prove a nuisance, or at least has not been so until within a comparatively few years. Introduced into England, and thence transferred to the Continent, it grew so luxuriantly as to choke small water-courses, and thus became a great pest. Even in this country, the species is becoming more common, and that, too, in places where special efforts are made to keep the water clear of weeds. We may instance as an example Fresh Pond, now used as a source of water-supply for the city of Cambridge, in which the *Anacharis* has become so abundant that the pond has to be periodically dredged. Just why certain species increase in bodies of water which have been artificially stoned or embanked is not clear. It may be that, by removing the larger weeds, a better chance is given to the smaller species, among which *Anacharis* is included. It may also be true, in the case of small pieces of water, that the lime or other ingredients of the stones and cement used may make the water better adapted to the growth of some species at the expense of others.

A second source of danger from the presence of large masses of weeds, especially in basins liable to frequent changes in the height of the water-level, lies in the fact that they may serve as places of attachment or shelter for some of the injurious small plants to which we shall have occasion to refer presently.

We have said, that, under ordinary circumstances, no direct trouble is likely to arise from the growth of any of the larger weeds in our water-supplies. By the expression, "under ordinary circumstances," we mean to presuppose that the plants are living and flourishing. The question still arises as to the effect they would produce in decay. The answer to this question falls rather within the province of a chemist than that of a botanist; but it is safe to say that no danger is to be anticipated from the death of vegetation in the autumn, certainly provided the water for immediate use is stored for a time in a receiving-reservoir.

The case of masses of plants suddenly killed by the lowering of the water in the heat of summer may be different. Here it is possible that trouble might arise; but we have no direct evidence to show that decided injury has resulted in any particular case from drinking water coming from ponds or streams in which were decaying plants of the group which we have characterized as weeds. Neither can we say that any well-defined odor or taste marks the water containing merely weeds in a state of decomposition. As we shall see, the extremely disagreeable tastes and odors are produced by plants which cannot be included in the group which we are now considering, — plants of a very different appearance and structure.

Let us begin a more detailed study with an examination of some of the typical forms of the *Nostoc* family, which are represented in Plate II. The figures 4 and 5 represent respectively *Cœlosphærium Kuetzingianum* and *Clathrocystis æruginosa*, two species found diffused in the water, or forming scums upon the surface. These two species consist of a mass of jelly, in which are embedded the cells, which are bluish-green. We speak of such collections of cells as colonies, because, in a certain sense, each cell is capable of living by itself, and the dependence of the different cells on one another is not essential, as it is in the case of the cells which form the higher plants. The cells of the *Clathrocystis* are spherical; but those of the *Cœlosphærium* are oblong, and all have their longer axes directed towards the centre of the mucus in which they are embedded. The last-named species may be found in its earlier stages attached to the leaves and stalks of water-plants; and, in that condition, the colonies are small and nearly spherical. When found floating on the surface, they are generally lobulated as in Fig. 4, and are surrounded by a colorless film of mucus, which can hardly be well shown in a drawing. The film is often fringed by a halo of very short colorless filaments, or rather rods. The rods have no direct connection with the *Cœlosphærium* itself but are caused by the action of small parasites, species of *Bacillus* and *Vibrio*, on the mucus in which the cells are embedded. A section through the *Cœlosphærium* colonies would show that the colored cells are confined to the surface, and that the interior is a mass of mucus or jelly traversed by bands of a denser substance than the rest of the interior. The *Clathrocystis*, Fig. 5, begins as a small solid body resembling the young *Cœlosphærium*, except in the size and shape of the cells composing it. The outer cells increase rapidly by dividing into two parts, each part growing to the size of the original cell. By repetitions of this process, the plant which was at first solid becomes a hollow mass of spheroidal shape. Certain portions of the surface then bud out from the rest, and the whole mass becomes lobulated and irregular. The projecting buds or lobes then separate from the rest of the colony; and, as a result, we have what is represented in Fig. 5, a net-shaped bag of irregular outline. The lobes or buds which have fallen off so as to leave holes in the mother colony form new colonies; and the same mode of increase and budding is repeated in them.

The question as to the exact amount of harm caused by the excessive growth of *Cœlosphærium* and *Clathrocystis* in the water-supplies is to be answered by physicians and sanitarians rather than by botanists. The water immediately affected becomes too offensive to drink; and the only practical question is, whether the disagreeable properties are conveyed any considerable distance. During the period of the trouble in Horn Pond last summer, great complaint about the water was made in East Boston, which is supplied by the Mystic system. Something is perhaps to be attributed to the imagination, as rather terrifying accounts of the state of Horn Pond were published in the papers at the time. But beyond this there was undoubtedly a real repugnance to the water. As to the possibility of purifying the water by filtering, and allowing it to stand some days in a reservoir, much good may be accomplished; but, judging from the experience of last summer, the water cannot be entirely purified by these means.

In one respect, the fears of the public may be set at rest. The theory that certain diseases, as fevers, are produced by germs of some low forms of plant-life, whether true or not, has no bearing on the present case. On the one hand, although we know that the species described in the present article do cause the disagreeable pig-pen odor, and do render the water at times unfit to drink, we know, on the other hand, that they do not cause the specific diseases whose origin is considered to be explained by the germ-theory. The germs, so called, are all species of bacteria, distinct from the *Nostoc* family and much smaller. The public should receive with very great caution any statements about the dangerous effect of bacteria in our waters; and, instead of worrying over the subject, had better leave the matter entirely in the hands of scientific people, who, at the present day, are the only persons who can be expected to follow the complicated and obscure relations of this difficult question.

In conclusion, we must mention one or two species which possess an interest in connection with those already described. One finds on the submerged iron of almost all water works a rusty-colored, slimy plant. This is *Lyngbya ochracea*, or, as it is more frequently called, *Leptothrix ochracea*, a very much more delicate species than the *Lyngbya* shown in the accompanying plate. It does no harm to the water, as far as injury to its drinking properties is concerned; but it is a great pest to paper manufacturers, who require water free from all coloring matter.

We must also mention a small group of plants, the *Beggiatoæ*, classed by some writers in the *Nostoc* family; although they are white, not bluish-green, when seen with the naked eye. The species of *Beggiatoa* are filamentous, and look something like a *Lyngbya* destitute of a sheath. They are characterized by the rapid vibrations of their filaments, and by the fact that they give off an odor of sulphuretted hydrogen. They are common in house-drains and sluggish ditches near factories, especially where the water is made warm by discharged steam or hot water. They are also found along the seashore, and abundantly in hot springs, and appear to the naked eye like very fine white films. Under the microscope the filaments are seen to oscillate, at the same time advancing or retreating; and in the cells themselves are dark granules which consist of sulphur.

From a botanical point of view, the floating *Nostocs* are very interesting; but it is usually difficult to get good material for study unless one is on the spot. The species of *Anabæna* are especially prone to break up and decompose when sent by express, and the various preservative fluids are of little use. To determine the species one should have the spores and heterocysts in position. The best way of preparing specimens is, by means of a pipette, to drop some of the water containing the plants upon a piece of mica or glass, and let it dry. The specimens can then be sent any distance; and, on re-moistening, the filaments swell up so that they can be well studied. If they do not at once recover their form, a little ammonia or potash may be added. Information about the winter condition of the vegetation is very much wanted; and especially do we need an accurate chemical knowledge of their relation to the water in which they grow.

EXPLANATION OF PLATES

Plate I

All the species figured in this plate are grass-green, and produce no injurious effect on drinking-water.

Figs. 1–3. — *Chara coronata*, var. *Schweinitzii*, A. Br. Fig. 1, life size; Fig. 2, branch with antheridia, *a*, and sporangia, *b*, magnified slightly; Fig. 3, sporangium containing spore magnified 50 diameters.

Figs. 4, 5. — *Lemna polyrrhiza*, L. Fig. 4, life size; Fig. 5, the same seen from the under side, and slightly magnified.

Figs. 1–5 were drawn from life by Mr. C. E. Faxon.

Fig. 6. — *Cosmarium Botrytis*, Menegh. From Ralf's British Desmidieæ. *a* and *b* are two unicellar individuals, which are represented in *c* and *d* respectively as having ruptured, their contents having united to form the spore, *s*. Diameter of spore, $\frac{1}{870}$ of an inch.

Fig. 7. — *Spirogyra* from Luerssen's Handbuch. *c*, chlorophyl-bands in the cells; *s*, spores formed by the union of the contents of two cells. Magnified 240 diameters.

Plate II

All the species figured in this plate are of a bluish-green color, and in decay give off a pig-pen odor.

Fig. 1. — *Cœlosphærium Kuetzingianum*, Naeg., and *Anabæna Flos-aquæ*, var. *circinalis*, Kirchner. From the surface of Basin No. 3, South Framingham, October, 1879. Magnified 300 diameters.

Fig. 2. — The same, showing details of *Anabæna*. *a*, spores; *b*, heterocysts.

Fig. 3. — A portion of Fig. 2, magnified 600 diameters.

Fig. 4. — *Cœlosphærium*. From Fig. 1, magnified 600 diameters. A gelatinous halo is usually found round the colonies when seen with this power.

Fig. 5. — *Clathrocystis æruginosa*, Henfrey. From Fresh Pond, Cambridge, October, 1879. Mature colony magnified 400 diameters.

Fig. 6. — *Lyngbya Wollei*, Farlow. From Horn Pond, Woburn. A portion of two filaments magnified 400 diameters, showing the bluish-green disk-shaped cells, surrounded by a colorless sheath.

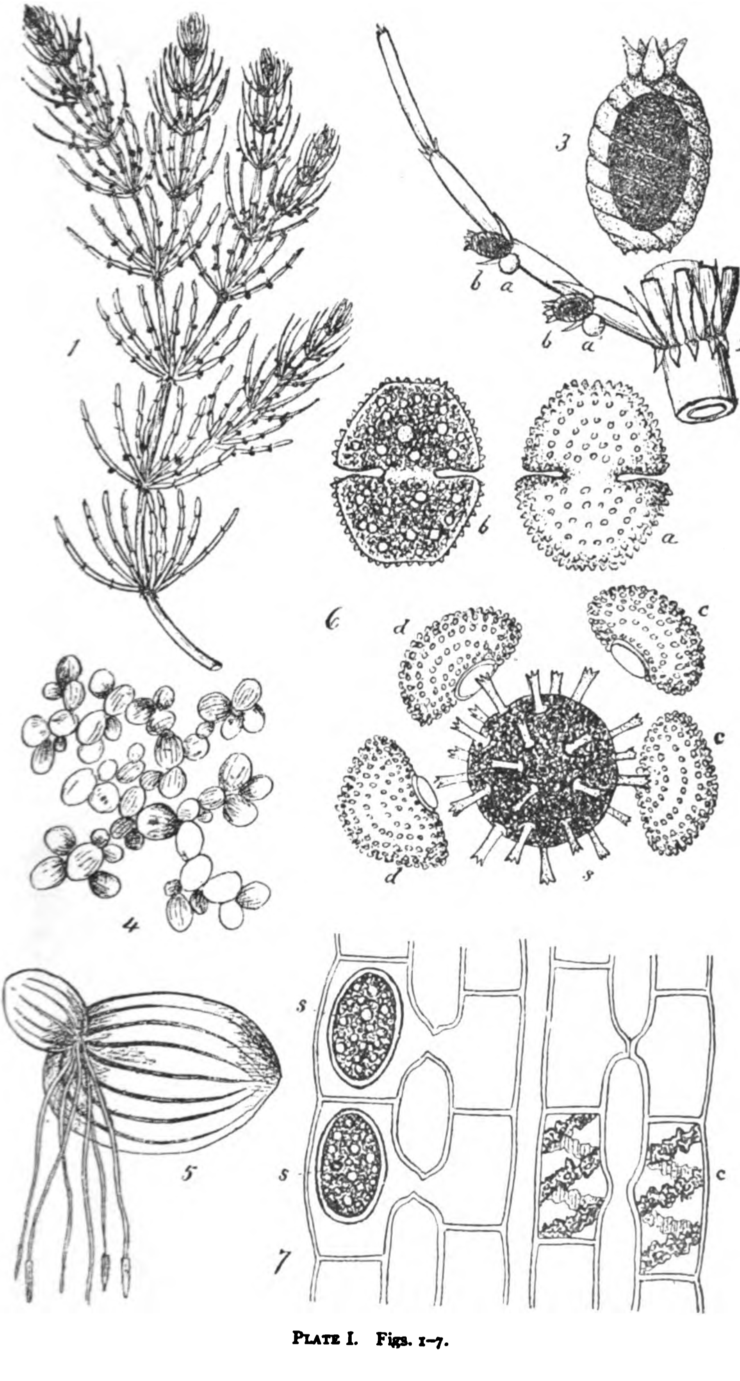

Plate I. Figs. 1–7.

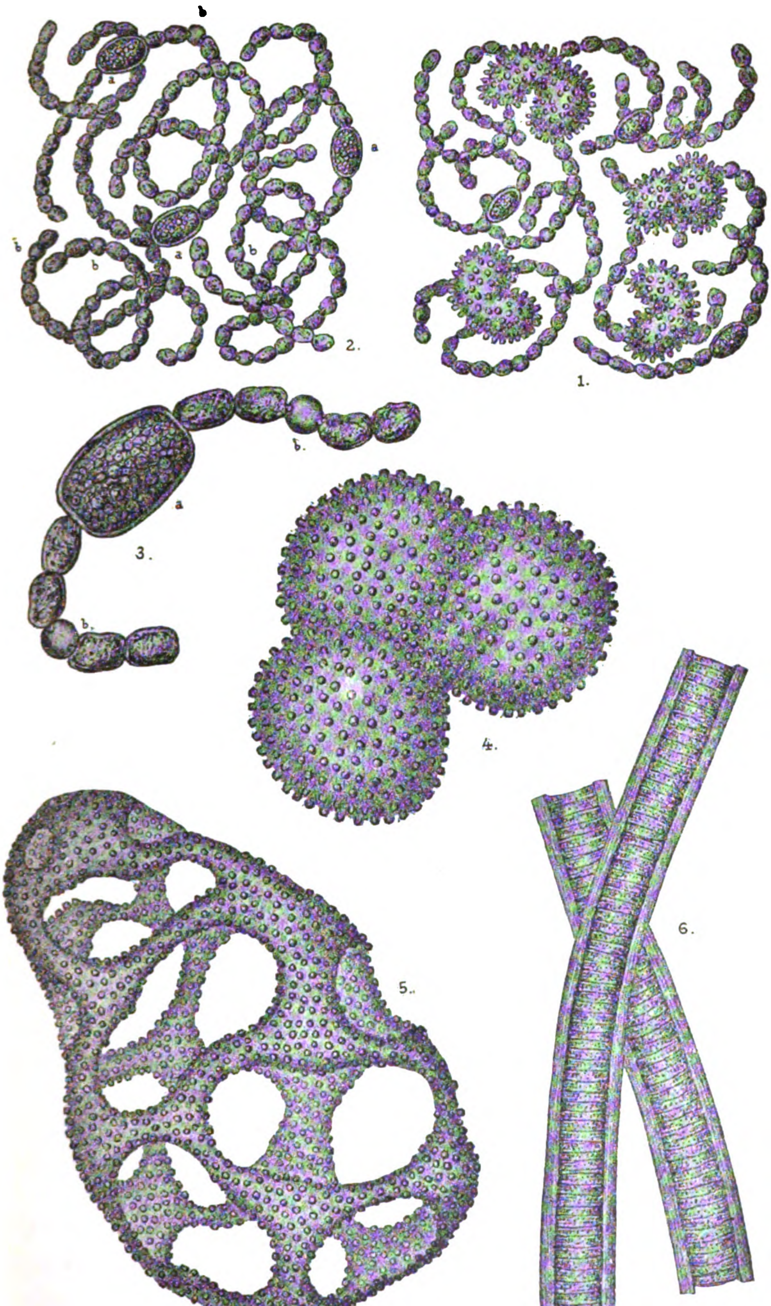

Plate II. Figs. 1–6.

VII

A STUDY OF THE RELATIVE POISONOUS EFFECTS OF COAL AND WATER GAS

By William T. Sedgwick and William Ripley Nichols

[This paper was written at a time when there was a vigorous legislative contest over the subject of water gas, instigated by rival business and political interests. The object of the investigation was to obtain the scientific facts as a basis for a proper settlement of the question. In spite of the findings, the water gas interests won, and this gas has been widely used in recent years. Reprinted from *Supplement to Sixth Annual Report of the State Board of Health, Lunacy and Charity*, 1884, p. 275. — G. C. W.]

The recent extensive employment for illuminating purposes of the so-called " water " gas, derived from the decomposition of steam by the action of incandescent coal and enriched with the vapor of naphtha, has excited a vigorous discussion of the question whether this gas is, or is not, more dangerous to the public health when distributed for the purposes of illumination, than the ordinary " coal " gas derived from the destructive distillation of bituminous coal. Up to the present time, although opinions, chiefly *a priori*, have been freely expressed in the affirmative, and especially in the negative, in answer to the question, very little experimental evidence has been available.

In view of the possibility of the general substitution of water gas for the coal gas now in common use in Massachusetts, the question has assumed a large public importance, and accordingly, under the instruction and direction of the State Board of Health, Lunacy and Charity, an investigation was undertaken by us, in the hope of obtaining facts which might serve to answer the question.

At the outset an experimental room was built to imitate in size and closeness an ordinary sleeping-room of medium size. It was originally our intention to place in this room animals of different kinds (in order, by learning the effects upon animals in general, — since it was not possible to experiment upon men, — to infer concerning the effects upon man himself), and then to introduce into it, through one or more burners, at a known rate, coal gas or water gas in successive experiments. This room was readily supplied with coal gas, and it was supposed that it would not be difficult to obtain and control a supply of water gas sufficient for our use. But in this we were disappointed, and after several attempts and many annoying delays it became evident that it would be easier and in some respects better to visit places supplied with water gas and there make comparative experiments.

Accordingly, we visited Middletown, Conn., and Athol, Mass., both of which were supplied with water gas, and there made several experiments. Afterwards we remodelled the original room supplied with coal gas — at Newton Centre, Mass. — and there concluded our experiments upon animals. More recently, one of us has made a special experiment in a room in his own house, and has also studied the influence upon coal gas of its passage through artificial soils. For the special details of most of these experiments reference must be made to the appendix[1] to this paper. There also will be found the description of the methods employed in sampling, in analysis, etc. In the present place it will suffice to state the results to which our experiments have led us, and also certain practical conclusions which naturally follow.

I. With ordinary gas fixtures it is generally difficult to get more than three per cent of illuminating gas into an ordinary room. By using one burner alone it is difficult to exceed one per cent.

The explanation of these facts is very simple and depends upon the rapid leakage and diffusion — the " natural " ventilation — which is all the time going on through the walls, ceiling and floor, and through the " cracks " about the doors and windows. The rate at which this goes on keeps pace in a general way with the amount of inflow, increasing as the inflow increases, so that no extensive accumulation can take place. Rather, a balance, so to speak, is struck if the inflow be constant, between the amount flowing in and that flowing out, so that a tolerably definite quantity is always in the room. But as the outflow

[1] Not here reprinted.

increases more rapidly in proportion, in order to raise to any great extent the amount that shall remain in the room, it is necessary that a very much larger amount shall flow in. For example: with six feet per hour it is difficult to keep one per cent in a small room, but it would be much more difficult to reach two per cent with twelve feet per hour, and quite impossible (under ordinary circumstances) to reach six per cent with thirty-six feet per hour.

II. With coal gas it is a matter of some difficulty to get into an ordinary apartment through the ordinary burners gas enough to produce upon healthy animals distinctly poisonous effects. With water gas, on the contrary, it is comparatively easy to get into an ordinary apartment, through the ordinary burners, gas enough to produce poisonous and even fatal effects.

This is not because water gas flows in more freely, or accumulates in any way, in the room. For the percentages present under similar circumstances, after the lapse of the same time, do not materially differ with the two gases. The only explanation which we have been able to discover is, that under the same circumstances water gas is considerably more poisonous than coal gas.

There is little doubt that in order to produce poisoning by either gas, a certain percentage of carbonic oxide must be present. And upon this view the facts are readily interpreted, for water gas contains enough of carbonic oxide to supply under these circumstances a dangerous amount while coal gas does not. It must certainly be accounted a curious fact, though it appears to be true, that in the combination of ordinary apartments, ordinary gas fixtures and ordinary coal gas, there happens to be comparative safety, while in the combination of ordinary apartments, ordinary gas fixtures and ordinary water gas, there is comparative danger.

III. It does not follow that because one illuminating gas contains three, four or five times as much carbonic oxide as another it is therefore only three, four or five times as dangerous to life.

A little consideration will show that no such simple relation can possibly exist. For it is not conceivable that a gas containing ninety per cent of carbonic oxide would be exactly twice as dangerous to inhale as one with forty-five per cent: both would be extremely dangerous. Nor would pure carbonic oxide be merely one thousand times as dangerous, if inhaled, as a mixture of air and carbonic oxide in which the latter amounted to 0.1 per cent: it would be infinitely more dangerous. Again, a mixture of air and illuminating gas might be inhaled for a short time, which contained only 0.001 per cent of carbonic oxide, but to say that this was precisely half as dangerous as a mixture containing 0.002 per cent would be obviously absurd: neither would be noticed at all.

From the experiments of others, and from our own work, there is no doubt that atmospheres containing eight per cent or more of either coal gas or water gas will destroy life very quickly, and that atmospheres containing 0.2 per cent or less of either gas may be breathed for a long time without producing distinctly poisonous effects. But, between these limits, there is for each gas a percentage (different in the two gases and always a lower percentage with water gas than with coal gas), above which the danger increases, and below which it diminishes, very rapidly. This percentage is known as the "danger-line," or "threshold," and varies widely with individuals, sex, physical condition, etc. In terms of carbonic oxide it is probably never very far from 0.5 per cent for the human species.

The reason why water gas is so much more dangerous than coal gas appears to be that this danger line is comparatively easily reached or overstepped with water gas, rich as it is in carbonic oxide, while the comparative poverty of coal gas, in this respect, brings it well below the line into the region of comparative safety.[1]

IV. Our experiments confirm the work of Gruber and others who claim that carbonic oxide is not a cumulative poison. That is, the breathing of a small quantity for a long time is not equiva-

[1] In these particulars carbonic oxide is not different from many other poisons. Thus a grain of morphia generally proves fatal to a healthy adult. A quarter of a grain is generally harmless. Obviously, the grain is not merely four times as dangerous. But between the quarter and the whole there must be some quantity which is a sort of limit of safety, and above which danger becomes imminent, while below it safety rapidly increases.

lent to the breathing of a large quantity for a short time. A similar conclusion may be drawn for all the constituents of illuminating gas.

This, however, does not preclude the possibility, which can hardly be doubted, that even small quantities produce their proper physiological effects, though these may not be immediately perceptible.

From the fact that carbonic oxide is not a cumulative poison and from the considerations mentioned before concerning the rapid increase of danger above, and the decrease of it below the "danger line," it follows that, within certain limits, the less carbonic oxide there is in illuminating gas the safer it is for public use. For about the danger line a very moderate decrease of carbonic oxide may very greatly enhance its safety, while a moderate increase may very greatly multiply the dangers arising from its use. Nevertheless, with very high percentages of carbonic oxide and with very low ones this does not hold good, because far above and far below the danger line, the effect of slight variations is very little.

We may now illustrate the foregoing conclusions by examples drawn from our own experiments and more fully described in the appendix.[1] And first, as to the difficulty of charging rooms heavily with illuminating gas.

A room containing 1,140 cubic feet of space was supplied with four ordinary burners. Through these there entered the room at a tolerably constant rate during 24 hours, 1,200 feet of coal gas. Yet at the end of the 24 hours the top of the room just above the burners contained a mixture of gas and air of which the former composed only three per cent, while the lower portions of the room showed less than one per cent. Again, a room holding about the same amount of air received 55 feet of water gas during 1½ hours. At the end of that time the largest amount discoverable in the room was 1.1 per cent of gas in the whole mixture of gas and air.

To illustrate the second conclusion, viz., that it is somewhat difficult to get in enough gas by the ordinary fixtures to kill, if the

[1] Not included in this volume.

gas be coal gas, but relatively easy if it be water gas, it is only necessary to note the effects of the two experiments just quoted. In the former (coal gas) after 24 hours the animals though somewhat drowsy and stupefied were not seriously affected, while in the latter, after 1½ hours only, similar animals showed most alarming symptoms and one was dead from the effects of the gas. From other experiments it is certain that had this experiment been long continued, others, and probably all the animals would soon have perished.

Similar considerations illustrate the third conclusion, for it is impossible to say that in the latter case the animals were only four or five times worse off than in the former. It is plain that as their lives were in imminent danger and as they were vomiting and in distress, it is not possible to express their relative danger mathematically. The first experiment just mentioned also indicates that carbonic oxide is not cumulative, for exposure to a small amount for 24 hours led to no serious consequences.

As to the time required to produce poisoning: this seems to be merely the time required to attain a poisonous percentage of carbonic oxide; and this clearly depends on the rate of inflow, the size of the room, the leakage, etc. Nevertheless, owing to the peculiar fact already mentioned that the danger line for both kinds of gas probably lies between 0.2 of one per cent and eight per cent of gas in a mixture with air (though always lower with water gas than with coal gas), and that with ordinary rooms and ordinary fixtures such percentages are liable to be obtained, it becomes interesting to compare the time relations in such apartments.

The following experiments illustrate this, besides showing how, under certain circumstances, a very moderate inflow of the two gases may lead, respectively, to totally different consequences:

By means of partitions, two rooms — one in Newton and one in Athol — were made as much alike as possible, both as to shape and cubic space. Each room had a capacity of about 700 cubic feet, which was somewhat larger than a room in Middletown in which a fatal case of poisoning from water gas actually occurred. Three dogs, two cats and two rabbits were placed in the room in

Athol, and the water gas in use there, containing about thirty per cent of carbonic oxide, was allowed to flow in from a single ordinary burner, at the rate of six feet per hour. The experiment began at 11.15 A.M., and at 12.45 P.M. vomiting, delirium, convulsions, etc., had already been noted. Half an hour later, all the animals were unconscious, or apparently so, failing to respond to calls and to vigorous knocks upon the walls. At 2.30 P.M., or about three hours from the start, two cats were dead, and the other animals were prone and quite unconscious. The dogs died at 3, 4, and 6.30 o'clock, respectively, — the rabbits, also, at 6.30. In a word, symptoms of poisoning were well developed in an hour and a half. Deaths began to occur in a little more than three hours, and all were dead within eight hours.

In the corresponding experiment at Newton, made with coal gas containing about seven per cent of carbonic oxide, two dogs, two cats, two rabbits and two pigeons were placed in the room, and the gas was introduced from an ordinary burner, as before, and at the same rate, — six feet per hour. The experiment began at 8 A.M., and for three and one-half hours no symptoms of consequence were observed, and then only drowsiness and general anxiety, with salivation in one case. At 4 P.M., i. e., after eight hours, at the end of which time in the other experiment all the animals were dead, nothing more than a gradual exaggeration of the symptoms had occurred. Recovery, apparently, would have been still possible and even easy, at this time.

After 24 hours, i. e., at 8 A.M. of the next day, one cat and one rabbit were dead, but the others though stupefied were not unconscious, being still responsive to knocks and calls. There is little doubt, moreover, that as the night was extremely cold (below 0° F.) and the rabbit was young it was somewhat chilled by the cold and thus succumbed the more readily to the gas.

In view of the foregoing conclusions based upon experimental evidence herewith presented, it seems to us that it must be admitted by all that water gas with its thirty per cent, more or less, of carbonic oxide is a more dangerous substance than coal gas with its six per cent or seven per cent of carbonic oxide, and that the only question that can be raised is, How much practical importance is to be attached to this more poisonous character? It will help to answer this question if we consider under what circumstances accidents are likely to occur as a result of the general distribution of gas for illuminating purposes.

There are five principal ways in which such injuries are likely to arise, as follows: —

1. By suffocation: as when workmen are overpowered in the trenches by large quantities of gas escaping from broken or leaky mains.

2. By the formation of explosive mixtures with air, owing to the escape of the gas in any manner.

3. By poisoning during sleep, from the escape into the sleeping-room of gas from the burner because, owing to defective fixtures, to accident, intention or ignorance, the light has been put out while the gas is still allowed to flow in.

4. By the slow and obscure poisoning (especially of feeble or anaemic persons) owing to leaks in or about pipes or burners in ordinary dwelling-rooms.

5. By poisoning, especially at night, when doors and windows are generally closed, with gas escaping from broken (street) mains into the earth, afterwards passing through drains or through the soil to the basements of dwellings, and thence upwards throughout the house.

The question has been raised, whether the gas in passing for some distance through the ground might not lose its odor and thus escape into houses or other buildings without being perceived. Everyone knows that the ground in the vicinity of leaky gas pipes becomes impregnated with the characteristic odor; we should therefore infer that the gas must lose some of its odorous ingredients. It may, however, be the case, that the amount lost by any given volume of the gas is proportionally too small to make a noticeable difference in the gas itself, although the continued passage of the gas makes the soil decidedly odorous. The experience of those connected with gas distribution has shown that leaks may occur in the mains without the facts being discovered by the odor of escaping gas, and, in fact, it was determined by the experts of the Berlin gas works, some years since, that a leak of not more than 0.2 cubic meter in 24 hours would not attract observation. It seems to be generally agreed that there is a peculiar and characteristic odor which may be removed if the gas passes for a sufficient distance through the ground, but the gas does not, as a rule, become perfectly odorless, and probably persons who were not experts would pronounce the odor that of gas.

The gas which escapes through the ground is also noticed to be less luminous than before. This may be due in part to its being mixed with air, for it is possible to diminish the illuminating power very considerably, by an admixture of air (especially ground air with its higher proportion of carbonic acid), without producing an explosive mixture. The generally conceived idea is that, in passing through the ground, the gas loses a greater or less portion of the heavy hydrocarbons — the illuminants — along with the peculiar odorous substance or substances, the exact nature of which is not known.

The only experiments with which we are acquainted, where analyses were made of the gas before and after passing through the soil, are those of Biefel and Poleck, who passed gas slowly through a pipe 2.35 meters (say seven and one-half feet) long, and five centimeters (say two inches) in diameter, filled with sandy loam. The pipe was connected with the gas main between the purifiers and the gas holders. The analysis of the gas before and after its passage through the soil gave the following results: —

TABLE 3

	Before	After
Carbonic acid	3.06	2.23
Oxygen	0.00	6.55
Illuminants	4.66	0.69
Carbonic oxide	10.52	13.93
Marsh gas	31.24	17.76
Hydrogen	49.44	47.13
Nitrogen	1.08	11.71
	100.00	100.00

These analyses are not altogether satisfactory, and it would appear that the air originally in the pipe had not been entirely displaced when the issuing gas was taken for analysis.

We have made some experiments in the same direction. A galvanized iron cylinder, ten feet long and eight inches in diameter, was filled with the material under examination; the gas was passed slowly in at one end through a quarter-inch tube, and issued at the other end through a similar tube. If gas be introduced into such a pipe it does not force the air out bodily before it, but mixes with it more or less, at first, and we think that in some experiments which have been made with reference to this matter, the diminished odor and illuminating power of the gas may have been partly due to the fact that it contained air mixed with it. In our experiments the gas entered at the top of the cylinder which was placed vertically in order to take advantage of the lower specific gravity of the gas and avoid mixing as much as possible; the gas was allowed to flow slowly (one cubic foot in from twenty-five minutes to two hours), and samples of the air or gas which escaped from the bottom of the cylinder were taken at intervals. If, after the air was entirely displaced, the issuing gas was not different in composition from that which entered, an end was put to the experiment; if there was a marked difference, the gas was allowed to flow for a longer period. For two materials which might be regarded as most likely and least likely to absorb the heavy hydrocarbons, we employed fine, pure, siliceous sand (kindly furnished by the Berkshire Glass Sand Company, Cheshire, Mass.), and ordinary coal ashes such as are frequently used in filling low land. We also employed a mixture of dry clay with three times its bulk of sand.

The general results may be briefly expressed as follows: The capacity of the cylinder was approximately three and one-half cubic feet, about two-thirds of which would be occupied by the substance of the filling material, and one-third, say one and one-sixth cubic feet, would at the beginning of the experiment be filled with air. When gas was introduced, at the rate of one cubic foot in from twenty-five minutes to two hours, the issuing mixture would begin to burn as soon as from 1.2 to 2 cubic feet had entered the apparatus; the air was not, however, displaced completely until about four cubic feet of gas had flowed in. What escaped thereafter was either gas, or gas robbed of some portion of its constituents. With clean, siliceous sand, or with a mixture of sand and dry clay, the gas did not seem to be affected to any appreciable extent. When, however, the cylinder was filled with coal ashes such as are used in " making " land, the results were very different. The passage through only ten feet of this material at the rate of one cubic foot in fifty minutes, the temperature being about 70° F., was sufficient to cause an almost complete removal of the heavy hydrocarbons, and with them of a great deal of the odor and of the illuminating power. It is thus evident that coal gas (and the case would be the same with water gas) in passing through the ground may lose its odor to a great extent, and it would appear that land made by filling in with ashes (where, owing to settlement, leaks would be likely to occur) would be particularly liable to unnoticed escape of gas.

VIII

REPORT OF A COMMISSION TO CONSIDER A GENERAL SYSTEM OF DRAINAGE FOR THE VALLEYS OF THE MYSTIC, BLACKSTONE AND CHARLES RIVERS

By Dr. Henry P. Walcott

Published as a separate document in 1886.

[This report, while not found in the annual reports of the State Board of Health, is important as it laid the foundation for the work of the Board in connection with the Purity of Inland Waters. Its forceful and eloquent words have been the inspiration of Massachusetts engineers for more than thirty years, and should continue to give inspiration for all time to come. The portion of the report quoted is said to have been written by Dr. Henry P. Walcott. — G. C. W.]

The undersigned commissioners appointed to consider and report systems of drainage for the Mystic, Blackstone and Charles rivers, and for some other purposes recited in a resolve of the Legislature, which received your official approval on the twenty-eighth day of May, 1884, beg leave to state that they have attended to the duty assigned them, and desire to submit the following report: —

We think it very desirable that there should be some expert authority to consult with towns and cities looking for pure and adequate water supplies, or searching for unobjectionable methods of sewerage.

The difficulties in these directions are becoming greater each year and the resultant confusion and complication more embarrassing. In the two years eighty-three and eighty-four alone, some fifty or sixty towns came up to the State House for leave to take or increase a water supply, and more than two score of private companies obtained similar privileges, and the indications are that these applications will show little diminution for many years to come. Each one of these towns, and many others in like case will, in no long time, find that water supply and sewerage are for the most part inseparable companions. Then, instead of a carefully prearranged plan of sewers, a piecemeal, hand to mouth sort of a makeshift device is likely to be improvised from day to day, entailing unnecessary expense and danger, and finally total loss. And again the scramble for the best and most accessible waters is responsible for a good deal of avoidable contention and imperfectly matured legislation. There is water enough for all if it be equitably shared. But the Legislature is annually besieged by importunate suitors who are bound to disregard all claims but the needs of their own constituents. It would be far better, in our opinion, if there were some competent board where all these jostling demands could be calmly considered and systematically adjusted. We have accordingly inserted a section in one of the subjoined forms of statute conferring such discretion upon a board as we think will tend to promote scientific sewerage and a fair and judicious distribution of pure water. Once more disclaiming any design on our part to attribute any especial propriety to the forms of legislation which we submit and which we wish to be regarded as auxiliary suggestions rather than settled conclusions, we approach the end of these observations.

Coming to the final division of our report, we have again preferred to enlarge rather than restrict the scope of the jurisdiction which can be strictly derived from the bare text of the resolve. We " may consider and report upon the needs of any other portion of the Commonwealth as to the disposal of sewage and the protection of the public water supplies therein." We have determined to regard the whole remaining body of the state, and not any particular division, as the " other portion " as to which we are at liberty to submit our views upon the propriety of throwing further safeguards about its supplies of drinking water and attempting greater system in the disposal of its sewage. This interpretation brings within the purview of our commission the whole subject of water pollution and its restriction or prevention within the state.

We take it that no one will controvert the general proposition of law that every holder of property, however absolute and unqualified be his title, holds it under the implied liability that his use of it may be so regulated that it shall not be injurious to the rights of the community.

In the exercise of its undoubted prerogative to watch over the general welfare and to guard the public rights by the ample police powers with which it is armed, the Legislature may make exactly such rules respecting the pollution of streams and ponds or other inland waters as it may judge requisite and necessary for the public welfare. It may absolutely prohibit, under suitable penalty, any contamination of any water within the borders of the Commonwealth, if it so please. It is a question always of expediency what degree of interference with individual liberty is required by the circumstances. Thus far the Legislature has been content to forbid any pollution of waters used directly or indirectly for a water supply by any city or town within twenty miles above the point of taking, provided this prohibition be not held to impair rights granted by statute before July 1, 1878, or prescriptive rights of drainage, to the extent to which they lawfully existed on that date. The Merrimack and Connecticut rivers and so much of the Concord as lies within the city of Lowell are also exempt from this rule. Nor can any person save those employed in getting ice or hauling lumber drive a horse on any pond used as a water supply for domestic purposes by a city or town. Neither is bathing permitted in any such pond. The Legislature seems to have drawn the line at drinking-water. Water dedicated to household uses is protected, within certain limits and to a certain degree, by a speedy, peremptory and effectual process. Municipal authorities may obtain an injunction at any time, from any justice of the Supreme or Superior Court, to restrain any person from violating the 80th chapter of the General Statutes, which we have recited above. But all other waters are left to the ordinary rules of the common law. We think that a comprehensive knowledge of all the facts will satisfy any unbiased inquirer that under this kind of customary guardianship of no one in particular the general condition of our waters has suffered a steady degradation, or, to borrow the language of the State Board as long ago as 1876, " any defence against the impurities which so conveniently flow into our waters from the settlements and works on their banks has thus far been merely nominal; that is, the law can be used to prevent a nuisance from continuing to be poured into the river, but it is not used, because the process is too slow, cumbersome and expensive." The lapse of nine years has only served to point and emphasize this commentary. The growth of population, the spread of modern refinements of living, the increase in industrial establishments, and all the indefinite multiplication of incidents appertaining to a prosperous and progressive community, must naturally and perhaps inevitably tend to vitiate the water of its rivers and lakes. But even if a certain degree of taint be unavoidable, there is a vast amount which is wanton and preventable. A cursory glance at the report of Mr. Clarke[1] will convince anyone that there is no necessity whatever for a large part of the abuse to which our water courses are subjected. It is a question of time only, and that not a long time either, when, if we hold to the path we are traveling, we shall find ourselves face to face with a state of things as intolerable as that of England twenty-five years ago, when the Sewage of Towns Commission denounced it as an "evil of national urgency requiring the earliest and most serious attention." The condition of many of its important and frequented streams had become so filthy and disgusting, that a universal protest arose, and large sums of money had to be expended in haste to mitigate the extremity of the offence. Meanwhile untold misery and mischief had been inflicted. Now preventive measures are far less costly and much more effective than remedial expedients. We think it is high time that some steps should be taken here to arrest the progress of rivers pollution at the point it has reached today in Massachusetts, and gradually to retrieve some portion, at least, of the ground we have carelessly yielded. Impressed with this conviction, we yet consider it impracticable to ask for a summary enforcement of the extreme right of the community in its waters now for the first time. Apart from technical points of law, and taking it upon broad, equitable grounds, it would be felt to be unfair for the community suddenly to insist upon a rigid exaction of its abstract right to clean waters after so many years of license and neglect. Even if it be law that no one can prescribe for a public nuisance, it does

[1] Eliot C. Clarke.

not necessarily follow that it is policy to abate all nuisances forthwith. And supposing such a project of law to have been enacted, we do not believe that the statute could or would be enforced. Certainly the existing law is not, then why should one so much more severe? We therefore cast about a good deal to hit upon some principle of classification, some scheme of discrimination, or even a mere frame of fixed regulations to guide the steps of a guardian of public waters. It was suggested that schedules might be made of streams which could be allowed a certain kind and amount of pollution, to be carefully defined, either in general or for each individual case. Certain others might be set apart and reserved for the standard purity expected for drinking-water. While possibly a few might be left to take care of themselves, at least for the present. It was held to be reasonable to forbid certain more dangerous or offensive trades from seating themselves in future at or near the fountain heads of rivers or brooks. It was urged that there would be no hardship in compelling a new-comer, whose labors must grievously deteriorate the quality of the water, to go below the industries which already depended upon the water as they were getting it, and could not endure without suffering any additional impairment of its purity. These expedients and many like them were canvassed and weighed in turn, but to all there seemed to be grave objections. After much consideration it was decided to propound a plan of action which seemed to fit the exigency as well or better than any which occurred to us. It had besides the strong recommendation of shaping itself in exact conformity with precedents which have stood the test of time and have proved themselves to be valuable working agencies. In the year 1879 the Legislature intrusted the care of "the lands, flats, shores and rights in tide-waters belonging to the Commonwealth," and the supervision of "all its tide-waters and all the flats and lands flowed thereby," to a Board whom it empowered "to prevent and remove unauthorized encroachments" or whatever "in any way injures their channels." Every work done within tide-water, not sanctioned by them or authorized by the General Court, where a license is required, is declared to be a nuisance, and the Board may order suits on behalf of the Commonwealth to prevent it or stop the removal of material from any bar or breakwater of any harbor. This legislation is strictly in line with that we offer. It is, indeed, almost identical with it. Alter its wording but a little and it would suit our purpose exactly. Precisely the same principle which enjoins a watchful care over the exterior waters of the state would seem to call for at least an equal solicitude concerning the abuse of its interior waters. But mindful of the tenderness with which Massachusetts has always treated her industrial classes, we think it would be wise to embrace in the enactment one peculiarly characteristic feature borrowed from the act establishing a Railroad Commission, and which has proved strong enough to enforce amply all the rights of the public in that class of highways called railroads. This distinctive trait is the use of advisory as distinguished from mandatory power. We think it would be well, then, for the Legislature to designate some one or more persons to look after the public interests in this direction. Let these guardians of inland waters be charged to acquaint themselves with the actual condition of all waters within the state as respects their pollution or purity, and to inform themselves particularly as to the relation which that condition bears to the health and well-being of any part of the people of the Commonwealth. Let them do away, as far as possible, with all remediable pollution, and use every means in their power to prevent further vitiation. Let them make it their business to advise and assist cities or towns desiring a supply of water or a system of sewerage. They shall put themselves at the disposal of manufactories and others using rivers, streams or ponds, or in any way misusing them, to suggest the best means of minimizing the amount of dirt in their effluent, and to experiment upon methods of reducing or avoiding pollution. They shall warn the persistent violator of all reasonable regulation in the management of water of the consequences of his acts. In a word, it shall be their especial function to guard the public interest and the public health in its relation with water, whether pure or defiled, with the ultimate hope, which must never be abandoned, that sooner or later ways may be found to redeem and preserve all the waters of the state. We propose to clothe

the Board with no other power than the power to examine, advise and report, except in cases of violation of the statutes. Such cases, if persisted in after notice, are to be referred to the Attorney-General for action. Other than this, its decisions must look for their sanction to their own intrinsic sense and soundness. Its last protest against wilful and obstinate defilement will be to the General Court. To that tribunal it shall report all the facts, leaving to its supreme discretion the final disposition of such offenders. If such a Board be able to commend itself by its conduct to the approval of the great court of public opinion, it will have no difficulty, we think, in materially reducing the disorders and abuses which are threatening to give great trouble in future if not speedily checked. If, however, we err in this expectation, and more drastic measures prove indispensable, the mandate of the state can always be invoked to re-enforce its advice.

In conclusion, it may be well to explain, in order to avoid misconception, that we do not regard the form which we suggest as very material. We wish it understood that although we propose a fresh commission to build the Mystic or the Charles River sewers, we do not deny that they can very possibly be as well done by the Governor and Council, by the city of Boston, or some other agency, if the Legislature prefer, and when we recommend that the prevention of rivers pollution be assigned to a Board, we do not intend to prejudge the question whether that Board shall be an existing Board or a fresh creation. It seems to us comparatively immaterial by what instruments our ends are wrought, provided only the work be done economically and speedily, and above all, be done well.

John Q. Adams,
Solomon B. Stebbins,
Edmund W. Converse,
Edward D. Hayden,
Leverett S. Tuckerman.

December 24, 1885.

IX

MICRO-ORGANISMS IN THE AIR OF THE BOSTON CITY HOSPITAL

By Greenleaf R. Tucker, S.B.

[The use of solid-culture media for quantitative bacteriological investigations began in 1881 with the work of Dr. Koch. During the next few years various adaptations of it were made. Professor Sedgwick and Dr. Tucker studied its application to the determination of bacteria in the air. The method suggested in this paper is with some modifications still in use. The original paper is here much abridged, statistical results being largely omitted. Reprinted from the *Twentieth Annual Report*, 1888, p. 161. — G. C. W.]

In compliance with a vote of the State Board of Health which was passed in March, 1888, the writer of the following paper was requested to make an investigation relative to the quality of the air of hospital wards, which should have for its special objects to determine the number and distribution of micro-organisms in the air of such wards; the causes which affect their number and distribution; and as far as possible to determine their character. A study of the germs themselves was soon found to be impracticable, and it was thought advisable to reserve this part of the subject for future investigation. Transfers of colonies from the air of the wards, to the number of about two hundred, have been made and preserved for this purpose. It is believed that these cultures will represent most of the forms habitually present in the air of these buildings.

The experiments to be described began in November, 1888, and were continued uninterruptedly for a period of three months. Some regret is felt that a portion of the work at least could not be conducted under the conditions of weather to be expected at that time of year. The winter was exceptionally mild, and the ground practically free from snow.

The investigation of indoor air began by taking samples in the afternoon, between two and three o'clock; the time being so chosen because the wards are then in their normal condition, only such work being done as the necessities of the sick demand. On Monday, Tuesday, Thursday and Saturday of each week, friends of patients are admitted from 2 to 3 P.M., usually to the number of two to three hundred, and distribute themselves throughout the various wards, the number of visitors in each ward being often equal to the number of patients; this afforded opportunity to observe the effect upon the air of increased numbers of people over those habitually present. It was found necessary to limit the number of experiments each day to five, including the outside air. The total number of wards being eighteen, four or five days elapsed before a return could be made to a given point; and the entire month was necessary to accumulate sufficient data for each ward, from which to draw conclusions.

During December, samples were taken mornings, generally between eight and ten o'clock, the wards at that time being in a more or less disturbed condition, — beds are made, floors swept, surgical dressings changed, and the general comfort of the patients attended to. By following this plan, two series of results were obtained, showing the condition of the air under quiet and disturbing influences. The month of January and part of February were devoted to special investigation, which the previous work had shown to be necessary.

Methods employed in the Quantitative Determination of Micro-organisms in the Air

The introduction by Koch in 1881 of a solid-culture medium for the study of micro-organisms has resulted in methods by which we can determine with facility, and approximately, if not with accuracy, the number of micro-organisms in the air. Koch himself exposed plates coated with a solid nutrient gelatine, upon which aërial microbes settled, and could be counted after development. Hesse, however, was the first to apply this principle quantitatively to investigations of the air, and in 1883 published the well-known method bearing his name. Petrie, in Germany, and Frankland, in England, have proposed methods, which, while retaining the solid-culture medium of Koch, differ essentially from the method of Hesse and from each other, in detail. In this country, also, some new methods of culture have been practiced by the writer, in conjunction with Professor Sedgwick, in a series of investigations conducted at the Massachusetts Institute of Technology.

Hesse's Method

Hesse makes use of the fact previously ascertained, — that micro-organisms rapidly settle out in a quiet atmosphere. He employs a long glass tube of large bore, coated inside with sterilized nutrient gelatine. The tube is fastened to a photographic tripod in a horizontal position, and, by a suitable connection with two aspirator-bottles, a slow current of air (one liter in three minutes) is drawn through the tube. The germs are all supposed to settle out during the passage of the air through the tube, and remain fixed by the moist, solid gelatine, where they become visible after several days as isolated colonies.

Frankland's Method

This method consists in aspirating a known volume of air through a glass tube containing two sterile plugs of glass-wool alone, or glass-wool and fine sugar-powder; after which the germ-laden filter is transferred to a flask containing melted sterilized nutrient gelatine, the two thoroughly shaken together, and solidified upon the sides of the flask by cooling, where the colonies which develop can be counted.

Petrie's Method

Petrie uses fine sand as a filter, packed in a small glass tube, and held in place by disks of wire gauze. After drawing through sufficient air by means of an air pump, the sand, with its occluded germs, is poured into several small double dishes of glass, containing nutrient gelatine, the object being to distribute the sand and germs over a considerable surface, so that the colonies may be more readily counted.

The method employed in the present investigation was first used by the writer, in association with Professor Sedgwick,[1] in a

[1] The complete paper was presented to the National Academy of Sciences at Washington, April 18, 1888, under the title, "A New Method for the Biological Examination of Air: with a Description of an Aërobioscope."

series of experiments in 1887, and will be described somewhat in detail.

The actual requirements of a quantitative method for the bacteriological examination of air, briefly stated, are as follows:—

First. — A means of collecting and accurately measuring the volume of air to be examined.

Second. — A suitable filtering medium for holding back the micro-organisms contained in the air.

Third. — A solid-culture medium, in which the germ-laden filter can be diffused, and where, on cooling and incubating for a sufficient length of time, the germs may develop and be counted as isolated colonies.

The apparatus consists essentially of three parts: (1) A glass tube of special form, to which the name of aërobioscope has been given; (2) a stout copper cylinder of about sixteen liters capacity, provided with a vacuum gauge; (3) an air pump. The aërobioscope through which the air is aspirated is six inches long, and one and three-quarters inches in diameter at its expanded part; the upper end of it is narrowed somewhat to a neck one inch in diameter and one inch long. To the lower end is fused a piece of glass tubing six inches long and three-sixteenths of an inch in bore, in which to place the filtering material.

Preparation of the aërobioscope: Upon the narrow part of the tube, two inches from the lower end, a slight mark is made with a file, and a little roll of brass gauze is inserted, which serves as a stop for the filter to be placed above it. Beneath the gauze stop is placed a small plug of cotton wool, and the open ends are then plugged with cotton wool; the tube is now placed in a sterilizer, and subjected to a heat of at least 150° C. for one or two hours. When cool, the non-sterilized cotton-wool plug is carefully removed from the neck, and sterilized No. 50 granulated sugar is poured in, until it just fills the four inches of narrow tube above the gauze stop. This column of sugar weighs one gram and is the filtering material employed to engage and retain the micro-organisms. The cotton-wool plug being replaced, the tube is again placed in the sterilizer, and re-sterilized for several hours at 120° C.

Taking the air sample: In order to measure the amount of air used, the value of each degree on the vacuum gauge is determined in terms of air, by means of an air meter, or by calculation from the known capacity of the cylinder. This fact ascertained, the negative pressure indicated by the needle on exhausting the cylinder shows the volume of air which must pass into it to fill the vacuum. By means of the air pump, one exhausts the cylinder until the needle reaches the mark corresponding to the amount of air required. A sterilized aërobioscope is attached to the cylinder, in an upright position, by means of a clamp; and, to establish communication between the two, they are joined together by means of a rubber tube attached to the lower end of the aërobioscope and to a stop-cock on the cylinder. For removing and protecting the sterilized cotton-wool plug while the air is being drawn through the tube, a very simple device is used. A glass shield with a neck slightly larger than the neck of the aërobioscope, and bearing a rubber finger-cot, is pushed down over the cotton-wool plug; when, by compressing the rubber, the plug can be removed (inside the shield), and remains suspended there. The plug removed, the cock is opened, when air will pass through the aërobioscope, leaving its germs in the sterilized sugar filter.

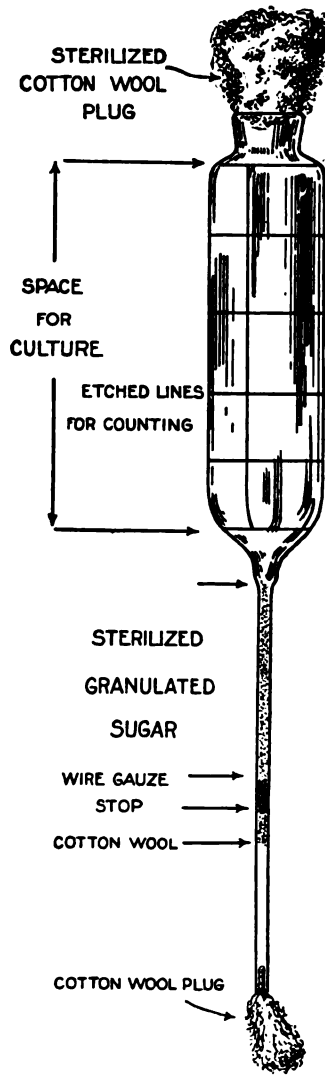

FIG. 1. AËROBIOSCOPE

Cultivation of the germs: The aërobioscope, after the air has been drawn through, is taken to the culture room for further treatment. The tube being held in a nearly horizontal position, the sugar (with the contained germs) is made to run into the body of the tube, by a gentle tapping. Melted sterilized nutrient gelatine (25 c.c.) is now added, under proper precautions, and

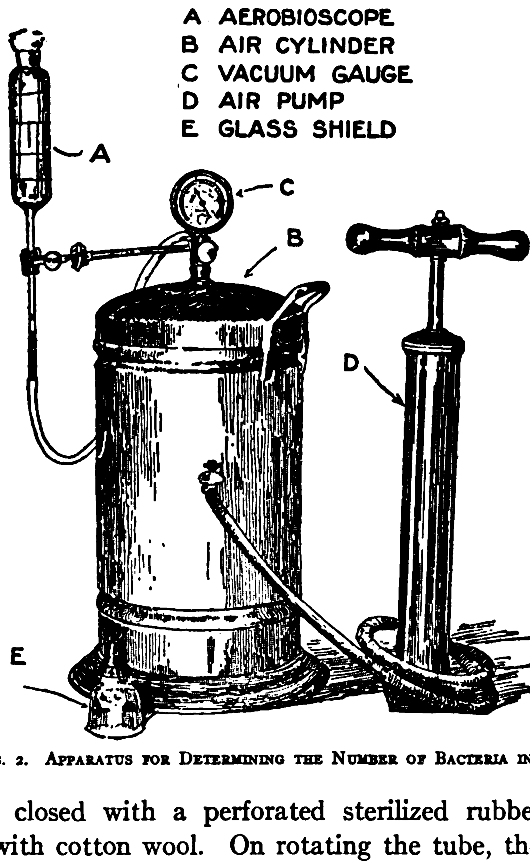

FIG. 2. APPARATUS FOR DETERMINING THE NUMBER OF BACTERIA IN AIR

the neck closed with a perforated sterilized rubber stopper, plugged with cotton wool. On rotating the tube, the sugar all dissolves in the gelatine, leaving the germs uniformly distributed through it. The gelatine is now congealed in an even film upon the inside of the tube, where, after four or five days, the colonies will develop, and can be counted by the aid of squares engraved upon the glass.

The illustration above shows the apparatus set up ready for use.

This method has several advantages not to be found in other methods. In the first place, the use of a vacuum cylinder permits a known volume of air to be aspirated with great ease, and the rate of flow through the filter is controlled to a nicety. The advantage of a soluble filter (sterilized granulated sugar), leaving only the germs imbedded in the gelatine, cannot be overestimated; for any insoluble substances seriously interfere with the counting. Again, the aërobioscope, quite apart from the filter, constitutes an important advance, since it obviates the necessity of transferring the filter (and contained germs), thereby avoiding accidental loss or gain of germs. The whole apparatus is portable, and the method, as compared with others, is exceedingly rapid of execution.

Outside Air

In order to have data for comparison with the work done indoors, the outside air was examined nearly every day during this investigation. The results are of some value in themselves, as showing the condition of the air of Boston in a rather secluded place, but in the immediate vicinity of its traffic.

The samples were all taken at the same place, at the foot of the surgical steps, four feet from the ground, on the north side of the hospital, except on rainy days, when the apparatus was moved under the steps, to avoid annoyance from the rain. The direction and strength of the wind, temperature, time of day, and any disturbing influences likely to affect the results, were observed. The ground was free from snow and the weather was mild throughout, while the prevailing winds were strong. The general averages for the months of November and December, 1888, and January, 1889, are shown in the following table: —

TABLE 4

Date	Number of Experiments	Average Number of Bacteria	Average Number of Moulds	Ratio of Bacteria to Moulds
November, 1888	19	10.4	6.8	1.5
December, 1888	22	14.5	5.6	2.6
January, 1889	15	13.2	3.5	3.8

All figures representing bacteria and moulds are for 10 liters of air.

The average numbers of bacteria are thus seen to be about the same for the three months, and representing, as they do, less than two per liter of air, must be considered small. Carnelly (*Phil. Trans. of the Royal Society of London*, vol. 178) found recently in the town of Dundee, in quiet places, as a mean of fourteen experiments, less than one bacterium per liter of air; while, in certain streets where the ratio of bacteria to moulds was very high, the total number of organisms was 17.5 per liter of air.

A comparison between the numbers of organisms found on clear and on rainy days is shown in the next table:—

TABLE 5

Condition of Weather	November			December			January		
	No. of Determinations	Average No. of Bacteria	Average No. of Moulds	No. of Determinations	Average No. of Bacteria	Average No. of Moulds	No. of Determinations	Average No. of Bacteria	Average No. of Moulds
Rain	5	7.6	7.8	3	9.3	6.3	2	2.5	3.0
Clear	14	11.4	6.4	18	15.0	5.4	9	19.0	3.5

The number of bacteria present in the air on clear days is greater than on rainy days, but the number of moulds remains the same; i. e., rain washes out bacteria from the air, but does not

TABLE 6

	November			December			January		
	No. of Determinations	Bacteria	Moulds	No. of Determinations	Bacteria	Moulds	No. of Determinations	Bacteria	Moulds
Wind slight ...	2	2.5	18.0	6	12	9.3	2	4.5	3
Wind strong ..	15	11.0	4.3	15	15	4.4	10	17.0	4

remove moulds. Both bacteria and moulds were more numerous on rainy days than was expected; and this is perhaps accounted for by the fact that the experiments were made under some stone steps, near a basement door frequently opened by employees.

No deductions could be drawn from the effect of the direction of the wind upon the micro-organisms, owing to the position of the buildings. The quarter from which the wind blew was taken from a neighboring weather-vane; but the direction, as felt by the observer, seldom coincided, being generally either easterly or westerly. The effect of the strength of the wind is, however, worthy of notice, being to increase the numbers of bacteria.

Conclusions

The results obtained from buildings of the hospital group occupied by employees, investigated for the sake of comparison with the wards, taken together with the results furnished by outside air, furnish abundant proof that the air of the hospital is remarkably free from micro-organisms. Whether the numbers found are greater or less than would be found in similar institutions is not known. So far as I am familiar with the work of other investigators in this field, the results show that hospitals of this class, as compared with other buildings, will take first rank in the freedom of their air from micro-organisms.

This is as it should be: bacteria, in a way, represent so much dirt. In a well-managed hospital, one has an approach to an ideal degree of cleanliness, and in no class of buildings is the same care taken to secure freedom from dirt as is taken in such a hospital. Undoubtedly, the systematic, thorough renovation which is going on continually in the hospital is of great importance in removing accumulations of germs, which must inevitably occur in the wear and tear of a building. This hospital is particularly fortunate in this respect; with its large tent service, wards in turn can be vacated during the summer months, and put in thorough repair, to an extent not otherwise possible.

In this connection, it will be interesting to reproduce some valuable tables prepared by Professor Thomas Carnelly and his colleagues,[1] showing the number of micro-organisms in the air of clean and unclean buildings in Dundee.

[1] I take great pleasure in referring the reader interested in this subject to the work of Carnelly, it being the first attempt, so far as I am aware, to systematically determine the number of micro-organisms in the air of buildings.

TABLE 7

	Bacteria in 10 Liters of Air
One-roomed houses, clean	180
" " dirty	410
" " dirtier	490
" " very dirty	930
Naturally ventilated schools, cleaner	910
" " " average cleanliness	1,250
" " " dirtier	1,980
Mechanically ventilated schools, cleanest	30
" " " clean	160
" " " less clean	300

These results leave no doubt that the cleanliness of rooms and of persons also is of the greatest importance in preventing accumulations of micro-organisms. It will be noticed that the numbers found in mechanically ventilated schools are far less than for those ventilated naturally; but the results as a whole, both in schools and dwelling-houses, are enormous, as compared with those obtained in this hospital. On the other hand, Carnelly found in the wards of the Dundee Royal Infirmary, between 4 and 5 o'clock P.M., from 10 to 20 bacteria. Neumann made thirty-five experiments by Hesse's method. At different elevations, from 1.40 to 3.20 meters, about the same number of organisms were found. In the morning, after sweeping, 10 liters of air gave from 80 to 140 bacteria, while four consecutive determinations at the same height showed a gradual decrease; the last examination, at 8 P.M., giving from 4 to 10 bacteria.

The results obtained in both the above hospitals are in perfect accord with those obtained in this investigation.

The extent of vitiation which the air of dwelling-houses may reach is further shown by determinations made by Carnelly, on one, two and four-roomed houses, between 12.30 and 4.30 A.M.

	Bacteria	Moulds
One-roomed houses	580	12
Two-roomed houses	430	22
Four-roomed houses, and more	160	10

When it is remembered that the air of the Boston City Hospital is practically free from bacteria at the hour of midnight, the above results, representing the condition of the air breathed by human beings, is certainly startling, and goes far to show the value of the information furnished by such determinations. The atmosphere of a building vitiated by micro-organisms can be so readily brought at least to a moderate state of purity, by a proper degree of cleanliness and oversight, that there is no legitimate reason why the air of public buildings should reach the condition of vitiation shown by Carnelly's experiments, in certain buildings in Dundee.

In any comparison of the number of micro-organisms found in the air of a hospital with those of other buildings, allowance must of course be made for the fact that a very small number of organisms found in hospital air, if pathogenic, might be more dangerous than large numbers of non-pathogenic forms found elsewhere. The great majority of micro-organisms found in air are probably harmless; but their functions as yet are so imperfectly understood, that it would seem unwise to consider them entirely harmless. Many of them evince a power in the decomposition of the various culture media, which is suggestive of what might happen in or upon the human system, should they find there a suitable nidus for development. Although no attempt was made in this investigation, except in a very general way, to determine the character of the germs present, it was found that the same species which occurred in the outside air were met with in the hospital; but certain species were met with in the hospital that were not found in outside air. In the ward devoted to diphtheria, species were always fewer in number than elsewhere, and the colonies were not unlike those obtained from the material furnished by the patients themselves, although no proof of their identity was obtained. The presence of pathogenic bacteria has frequently been demonstrated in the air of hospital wards; for example, Cornet, of Koch's Hygienic Institute, found bacilli tuberculosis in fifteen out of twenty-one wards in seven hospitals in Berlin, and out of ninety-four animals inoculated, twenty died of tuberculosis. Von Eiselsberg in an erysipelas room of the hospital found erysipelas cocci; also, in a surgical ward, where wounds were treated under aseptic precautions, the presence of staphylococcus pyogenes aureus was demonstrated. Emmerich not only found erysipelas cocci in the air of an old dissecting room, but also in the plastering and walls and ceiling.

In this connection, it should be stated that the ordinary methods employed in the cultivation of the germs of the air would fail to reveal the presence of certain pathogenic bacteria, as, for example, bacilli tuberculosis; such forms, however, are not difficult to determine by special means. Pathogenic bacteria are as likely to exist in this hospital as in any other, and probably do exist; but it is worthy of note that the general health of employees is excellent, that contagious diseases are seldom contracted by them, or by patients themselves, although isolated cases occasionally occur.

The importance of obtaining definite information regarding the dangerous or innocuous character of micro-organisms found in the atmosphere is evident; but, until methods are so amplified that species can be identified with a greater degree of certainty and far less expenditure of time than at present, we must be content with a determination of the number and distribution of bacteria in the air of buildings.

Carnelly has proposed a standard for the air of dwellings and schools; i. e., twenty micro-organisms per liter, or two hundred per ten liters (excess over outside air), — numbers so greatly in excess of all results obtained in this hospital as to make evident the necessity of standards for various classes of buildings.

The air of this hospital compares favorably with the external air. In the absence, then, of a standard of purity for hospital air, it would not be unreasonable to require that the number of micro-organisms in the air of a ward should but slightly exceed the numbers found in outside air.

X

POLLUTION OF ICE SUPPLIES

[In this report we see the joint application of sanitary chemistry and bacteriology to a practical public health problem. Although a short report it is typical of the manner in which such questions have been answered by the Massachusetts State Board of Health, that is, by securing the facts in the case, using the best available methods of procedure. At the time this report was written relatively little was known about the effect of freezing on the quality of ice, or the relation between ice and the public health. *Twenty-first Annual Report*, 1889, p. 143.— G. C. W.]

By chapter 84 of the Resolves of 1888, the General Court directed the State Board of Health to " make a special investigation with reference to the pollution of ponds, lakes, streams or other bodies of water used as ice supplies in this State, especially with reference to the effect of such pollution upon the healthfulness of such ice for domestic use."

In accordance with this direction, the State Board of Health sent to every city and town in the state printed circulars, — to the local boards of health, to physicians, or to persons known to have an interest in the subject, asking their co-operation and their replies to the following questions: —

1. Names of companies, firms or individuals who cut or sell ice in your city or town, and sources from which such ice is obtained.
2. What contaminating causes, if any, pollute the sources from which ice is cut ?
3. Have any cases of illness come to your knowledge from the use of ice cut from such sources ?
4. What remedies do you suggest for the prevention of such pollution ?

In the responses to these circulars from one hundred and eighty-nine cities and towns, sources of pollution were noted in thirty. The answers to the third question were generally, " No." A few cases were, however. noted, where the ice supply was suspected of being the cause of illness, but none appeared to be so definitely connected with this cause as to give promise of additional knowledge if investigated further.

From the thirty sources where contaminating causes of pollution were noted there were selected twelve which appeared to be the most polluted; and in October, 1888, samples of the water from each of these sources as it then existed, and samples of the ice in ice houses adjacent, were examined, with the following average result: —

TABLE 8

AVERAGE OF ANALYSES OF WATER AND OF ICE FROM POLLUTED SOURCES IN OCTOBER, 1888

(Parts per 100,000)

	Color	Loss on Ignition	Fixed Residue	Ammonia		Chlorine	Nitrates	Nitrites	Bacteria
				Free	Albuminoid				
Water	0.24	1.65	6.94	0.0143	0.0206	1.18	0.0343	0.0009	..
Ice	0.00	0.24	1.00	0.0022	0.0027	0.01	0.0045	0.00005	138
Per cent ..	..	15.00	14.00	15.0000	13.0000	..	13.0000	6.0000	..

One sample of ice from an unpolluted source gave the following: —

	0.0	0.20	0.20	0.0000	0.0000	0.00	0.0050	0.0000	0

The samples of ice from the twelve most polluted sources, obtained from ice houses in October, when compared with the waters of the various ponds, as they were in October, showed that the color and salt had been removed, and that all but about thirteen per cent of the other impurities of the water, as shown by chemical analyses, had been removed.

The number of bacteria in the ice averaged 138, being increased by one sample of snow ice that contained 1,246 per cubic centimeter, while the clear part of the same cake had but 6. Two samples had none; three had less than 10; three others had between 10 and 100, and two had 199 and 433 bacteria per cubic centimeter.

A single sample of clear ice from an unpolluted source was found to be nearly as free from organic impurities as distilled water.

These preliminary examinations indicated, as had been found by Dr. T. M. Prudden,[1] in examining Hudson River ice, that different parts of a cake of ice may differ much in quality; and it was concluded to follow Dr. Prudden's method of making separate examinations of transparent and of snow ice. This classification was used in examinations of the ice crop of 1888–89. Experiments were planned by which the qualities of ice found under differing circumstances could be determined; but the short season in which ice formed, — limited to the latter part of February and the first of March in 1889, — and the almost entire failure of the ice crop in 1889–90, have prevented the carrying out of these investigations; so that the Board, while presenting the facts that have been obtained and some of the conclusions to which these lead, is unable to present demonstrations of all of the interesting problems that enter the investigation required by the resolve.

As has been stated, examinations were first made of water and ice from the twelve sources which by the reports appeared to be those most polluted. On continuing the investigation other sources were included, making in all fifty-eight localities, some of which were from excellent water.

The results are all included in the tables given below. In these tables are given chemical analyses of 76 samples of water and 236 samples of ice. Most of the samples were also examined for microscopic organisms and for bacteria.

In tabulating the results of microscopical examinations, the figures represent the number of thousands of organisms in 200 cubic centimeters of water or of ice. The smallest figure given is 0.1, which expresses 100 organisms in 200 c.c. of water or of ice; where the number observed was less than 100, they are said to be "present."

The figures under bacteria express the actual number found in one cubic centimeter of the water or ice.

The number of bacteria was found to vary much in different parts of a cake of ice. The division adopted in the first season

[1] "On Bacteria in Ice and their Relations to Disease, with Special Reference to the Ice Supply of New York City." By T. Mitchell Prudden, M.D. New York. 1887. *The Medical Record*, Vol. 31, Nos. 13, 14.

into snow ice and transparent ice made one important distinction, but others were found necessary; and in the second season three divisions were made; viz., snow ice, bubbly ice and clear ice, also top ice and bottom ice; and in the tables the remarks at the right of the columns often indicate that the chemical analysis was made from snow ice or from the top or bottom of the cake, while the columns for bacteria show that two or more samples from the same part of the cake were examined, because there were portions of clear ice and of bubbly ice in each.

In the earlier examinations, when all of the samples were included in snow ice and transparent ice, the latter included much that was bubbly; and, when clear and bubbly ice took the place of transparent, the clear ice included some which was somewhat bubbly. If the ice crop of the present season had not failed, the Board would have made other distinctions to include the circumstances under which the ice is formed.

From the examinations that have been made, it appears probable that, when ice first forms on the surface of a pond or river, a considerable part of the impurity in the water near the surface is entangled in the first inch or less in depth, and that the ice that forms below this first inch contains but a very small percentage of the impurities of the water. If snow falls upon the thin ice, causing it to sink, so that water from below saturates the snow, it will freeze without purification; or, if rain falls upon the snow and freezes, the ice thus formed contains the impurities of the snow and of the rain water, and whatever else may have settled out of the air. The method, often pursued, of flooding the ice of a pond or river, by cutting holes through it, gives a layer of ice as impure as the water of which it is formed.

From all of the analyses of water and of ice taken at the same time, so that they can be fairly compared, twelve have been selected in which the sum of ammonias in the water indicated the greatest pollution, and the principal results of analyses are given in the following table: —

Table 9

Millbury. — Blackstone River

(Parts per 100,000)

	Color	Residue on Evaporation		Ammonia		Chlorine	Nitrogen as		Bacteria per c.c.	
		Loss on Ignition	Fixed Residue	Free	Albuminoid		Nitrates	Nitrites	Water or Ice	Snow Ice
Water.....	0.5	3.00	11.30	.1680	.0440	0.74	.0150	.0018	3762	..
Snow ice...	0.0	1.70	2.90	.0448	.0306	0.10	.0020	.0003	..	1586
Ice........	0.0	1.10	2.15	.0252	.0176	0.10	.0050	.0003	241	..
% Snow ice.	..	57	26	27	70	14	13	17	..	42
% Ice	..	37	19	15	40	14	33	17	6	..
Northbridge. — Pond Fed by Blackstone River										
Water.....	0.3	..	..	.0600	.0370	0.50	.0200	.0006	74	..
Ice........	0.0	1.65	0.85	.0006	.0030	0.01	.0030	.0001	43	..
Per cent....	..	..	..	1	8	2	15	17	60	..
Lowell. — Black Brook										
Water.....	0.0	..	..	.0686	.0142	0.40	.0600	.0003	107	..
Snow ice...	0.0	1.40	2.50	.0184	.0128	0.04	.0060	.0001	..	39
Ice........	0.0	0.55	0.45	.0036	.0040	0.01	.0050	.0000	3	..
% Snow ice.	..	..	..	27	90	10	10	33	..	37
% Ice	..	..	..	5	28	2	8	0	3	..
Jamaica Pond										
Water.....	0.05	..	..	.0120	.0664	0.86	.0450	.0002	147	..
Ice........	0.00	0.35	1.10	.0034	.0060	0.00	.0040	.0001	1	..
Per cent....	..	..	..	28	9	0	9	50	1	..
Worcester. — Crescent Street Pond										
Water.....	0.15	..	..	.0356	.0356	0.70	.0850	.0007	1200	..
Snow ice ...	0.00	..	..	.0046	.0094	0.03	..	..	..	58
Ice........	0.00	0.45	1.10	.0006	.0026	0.01	.0060	.0000	16	..
% Snow ice.	..	..	..	13	26	4	..	..	..	5
% Ice	..	..	..	2	7	1	7	0	1	..

TABLE 9 — *continued*

BRIGHTON. — HOLLIS POND

	Color	Residue on Evaporation		Ammonia		Chlorine	Nitrogen as		Bacteria per c.c.	
		Loss on Ignition	Fixed Residue	Free	Albuminoid		Nitrates	Nitrites	Water or Ice	Snow Ice
Water	0.1	..	..	.0354	.0296	1.59	.4000	.0031	20000	..
Ice	0.0	0.30	0.60	.0012	.0022	0.00	.0030	.0000	702	..
Per cent	..	..	..	3	7	0	1	0	3	..

DORCHESTER. — KING'S POND

Water	0.2	..	..	.0314	.0262	1.19	.0800	.0013	412	..
Ice	0.0	0.50	1.10	.0028	.0044	0.01	.0030	.0000	6	..
Per cent	..	..	..	9	17	1	4	0	1	..

NEWTON. — HAMMOND'S POND

Water	1.1	..	..	.0038	.0450	0.54	.0040	.0003	115	..
Ice	0.0	0.20	0.55	.0000	.0012	0.00	.0030	.0000	8	..
Per cent	..	..	..	0	3	0	75	0	7	..

ARLINGTON. — LITTLE SPY POND

Water	0.2	..	..	.0058	.0390	1.70	.1750	.0020	1029	..
Ice	0.0	0.68	2.68	.0026	.0068	0.02	.0020	.0000	11	61
Per cent	..	..	..	45	17	1	1	0	1	6

MELROSE. — ELL POND

Water	0.2	..	..	.0240	.0202	0.94	.0650	.0009	..	..
Ice	0.0	0.68	2.20	.0020	.0028	0.02	.0050	.0000	2	11
Per cent	..	..	..	8	14	2	8	0	..	..

CAMBRIDGE. — FRESH POND

Water	0.05	..	..	.0230	.0180	1.00	.0300	.0008	11	..
Ice	0.00	0.56	0.80	.0022	.0030	0.02	.0020	.0000	3	..
Per cent	..	..	..	10	17	2	67	0	27	..

TABLE 9 — *concluded*

WOBURN — HORN POND

	Color	Residue on Evaporation		Ammonia		Chlo-rine	Nitrogen as		Bacteria per c.c.	
		Loss on Ig-nition	Fixed Residue	Free	Albu-minoid		Ni-trates	Ni-trites	Water or Ice	Snow Ice
Water.....	0.25	..	..	.0172	.0210	0.67	.0200	.0007	327	..
Ice.........	0.00	0.25	0.60	.0010	.0028	0.02	.0000	.0000	3	..
Per cent....	..	..	..	6	13	3	0	0	1	..

The chemical results are given in parts per 100,000.

The bacteria are indicated by the number found in a cubic centimeter.

The percentage of each substance of the water that remained in the ice or in snow ice is given.

These waters all contain more ammonias than are desirable in drinking waters; but the ice formed from these waters contains from three to twenty-one per cent as much as the waters, averaging eleven per cent. The amount of ammonias contained in the ice, except in the one containing the largest amount, would not cause them to be condemned as drinking waters; neither would the number of bacteria, except in the case of ice from the Blackstone River and from Hollis Pond in Brighton. But we cannot depend upon numbers alone. A large number of bacteria of one kind may be harmless, and a small number of another kind may communicate a most serious disease. It is known, from these experiments as well as from others, that many kinds of bacteria survive a long season in ice; and it has been shown by Dr. Prudden that the bacillus of typhoid fever will live in decreasing numbers in ice for three months at least. It is, then, the quality of the bacteria rather than the quantity that we are to consider, and the best judgment in regard to this includes the source from which they came. If the source is one which is liable to be polluted by disease-producing bacteria, as is likely to be the case wherever sewage enters, this fact should have much more weight than the small number of bacteria found.

The purifying effect of freezing is greater upon substances that are in solution than it is upon those in suspension. For example, upon freezing the upper part of a body of sewage to the depth of one inch, the substances in solution were reduced as given below: —

TABLE 10

	Sewage	Ice	Per Cent Remaining in Ice
Loss on ignition	10.4	1.8	17
Fixed residue	19.6	2.2	11
Free ammonia	1.646	0.184	11
Albuminoid ammonia	0.250	0.012	5
Chlorine	4.20	0.52	12
The parts in suspension were affected as follows: —			
Loss on ignition	2.8	1.9	68
Fixed residue	2.3	1.6	70
Albuminoid ammonia	0.130	0.036	28

Of the parts that were in solution in the sewage, the freezing process caused to be removed all of the impurities except from five to seventeen per cent, while of the much smaller parts which were in suspension there remained in the ice from twenty-eight to seventy per cent.

The unfrozen sewage under the ice contained the impurities which the ice had expelled.

It appears that the parts that are in suspension, particularly particles that have some buoyancy in water, are not so easily expelled as the parts that are in solution. This is confirmed by the fact that a large part of the organic matter, one-half or three-quarters and sometimes more, that is found in good ice is of particles in suspension, and is readily removed by filter paper.

The inch in depth of frozen sewage contained ten per cent of the organic impurity of the sewage, as indicated by the sum of ammonias; and from other experiments we have reason to conclude that, if another inch in depth had formed under the first, it would have contained a still smaller percentage of organic impurity; but if the first inch had been pressed down, and the sewage had risen above it and then frozen, this last layer would have been as impure as the sewage. This is an extreme case of impurity of the source.

Taking an average of all of the water and ice used for ice supplies, which we have examined, we find that the organic impurities of the snow ice, as shown by the sum of ammonias, amount to sixty-nine per cent of those of the waters; that the organic impurities of all the ice except the snow ice amount to twelve per cent, and those of what we have called clear ice amount to six per cent, of the impurities of the waters. The color of the waters was entirely removed, and the salt that they contained was nearly all removed, by the process of freezing.

There were eighty-one per cent as many bacteria in the snow ice as in the waters; ten per cent as many in all other ice, and two per cent as many in the clear ice, as in the waters.

While the Board, as before stated, was unable in these warm winters to make the experiments desired to settle many points of the inquiry, the results obtained lead to the conclusions that, while clear ice from polluted sources may contain so small a percentage of the impurities of the source that it may not be regarded as injurious to health, the snow ice and any ice, however clear, that may have been formed by flooding, is likely to contain so large a percentage of the impurities of the source, and with these impurities some of the disease germs that may be in the source, that the Board feels bound to warn the public against using ice for domestic purposes that is obtained from a source polluted by sewage beyond that which would be allowable in a drinking water stream or pond; and that in general it is much safer to use, for drinking water and for placing in contact with food, that portion of the ice that is clear.

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State Board of Health.

XI

REPORT OF THE STATE BOARD OF HEALTH UPON THE SEWERAGE OF THE MYSTIC AND CHARLES RIVER VALLEYS

[This report relates to the establishment of the North Metropolitan System of sewers. It contains an interesting account of filtration experiments made to determine the feasibility of disposing of the sewage of Boston on the Saugus Marshes. *Special Report*, 1889. — G. C. W.]

THE Resolves of the General Court, under which the State Board of Health has made investigations relating to sewage disposal, and has made designs for a system of sewerage for the Mystic and Charles River valleys, are as follows: —

[Chap. 95.]

RESOLVE RELATING TO SEWAGE DISPOSAL IN THE MYSTIC AND CHARLES RIVER VALLEYS

Resolved, That the state board of health is hereby authorized and directed to consider and report a general system of drainage and sewerage for the relief of the valley of Mystic river, and so much of the valley of Charles river, if any, whose relief in the opinion of said board is to be sought in conjunction with the Mystic valley system, and for such cities and towns, or parts of cities and towns as may, in the opinion of said board, be best relieved by the use of said system; and so much of the report of the commissioners appointed under resolve approved May twenty-eighth, in the year eighteen hundred and eighty-four, as relates to the cities and towns, or parts of cities and towns, which said board shall incorporate in the system to be reported under this resolve, is hereby referred to said board for its further consideration, and it shall be the duty of said board, —

First. To designate the cities and towns, and parts of cities and towns, which shall be tributary to and embraced in the district and system so to be reported, and to define the same by their report, with plans and maps.

Second. To define and show, by suitable plans and maps, such trunk line and main branches as it shall recommend to be constructed, with outlet.

Third. To define the methods by which said cities and towns, or parts of any city or town, may utilize said trunk line and main branches as an outlet of a system of sewerage and drainage for said respective cities and towns, and said parts of cities and towns, and to show the same by plans and maps.

Fourth. To cause such surveys and levels to be made as will enable said board to determine with accuracy the location and grades of said trunk line and main branches, and also such surveys and levels in said cities and towns and parts of cities and towns as will enable said board to determine with accuracy the methods by which said cities and towns and parts of cities and towns may respectively utilize said trunk line and main branches and to report such methods by plans showing the main lines by which each may so provide for itself a system of sewerage and drainage with its outlet into said trunk line or main branches.

Fifth. To define the size and capacity of said trunk line and main branches and the materials of which they should be constructed and manner of construction, and such other particulars as will enable said board to determine the probable expense thereof.

Sixth. The expenses of surveys, maps and plans made to show the method by which any city or town, or part of city or town, may utilize said trunk line and main branches shall be separately kept, and the same, showing the amount expended in each, together with the expenses of the location and grade, maps and plans of said trunk line and main branches, together with all other expenses in the premises, and the items thereof, shall be reported to the governor and council, and all such costs and expenses shall be paid out of the treasury of the Commonwealth, on bills to be approved by the governor and council.

Seventh. Each city or town which wholly or in part said board shall consider should form a part of the territory to be embraced in the system to be reported shall be notified thereof by said board as soon as said board shall determine the cities and towns and parts of cities and towns which shall constitute said sewerage and drainage district. Said notice shall contain the names of the cities and towns wholly, and shall designate the portions of the cities and towns not wholly but in part, incorporated therein, and each of such cities and towns may confer with said board in respect to such drainage and sewerage system, and on request in writing be heard by said board on matters relating to the method of its utilizing said trunk line and main branches and the surveys, levels, maps and plans to determine and show the same, and under the superintendence of said board may, at its own expense, make its said surveys, levels, maps and plans for the use of said board; but all questions upon which any city or town shall desire to be heard shall be submitted to said board in writing with such request.

Eighth. Said board shall also consider whether any city or town within such district can more advantageously provide for itself a system of sewerage and drainage by itself and not as a part of said general system, and shall hear such city or town thereon if it shall so request, and shall also make report thereof.

Ninth. To ascertain and report the cost of the construction of said trunk line and main branches and outlet, and of the annual expense of operating the same, and also what cities and towns, or parts of cities and towns, would be obliged to pump their sewage or any part thereof, at what places, the cost of the works therefor and the annual expenses thereof: provided, however, the whole amount expended under the provisions of this resolve shall not exceed the sum of ten thousand dollars;[1] and reports under the same shall be made by the state board of health to the general court on or before the first Wednesday of January, in the year eighteen hundred and eighty-nine. [*Approved June 16, 1887.*

[1] In 1888 the further sum of fifteen thousand dollars.

[Chap. 63.]

RESOLVE PROVIDING FOR FURTHER INVESTIGATIONS RELATIVE TO SEWAGE DISPOSAL IN THE MYSTIC AND CHARLES RIVER VALLEYS

Resolved, That the state board of health be requested to designate some method for the disposal of the sewage of such cities and towns as are embraced within the lower valley of the Charles river, in the report of the commissioners appointed under chapter sixty-three of the resolves of the year eighteen hundred and eighty-four, as they may not include in their report under chapter ninety-five of the resolves of the year eighteen hundred and eighty-seven, and so much of said report as relates thereto is hereby referred to said board for its further consideration. Such designation shall be made as a part of the report required by chapter ninety-five of the resolves of the year eighteen hundred and eighty-seven, and the expense thereof charged to the appropriation provided for in chapter forty-two of the resolves of the year eighteen hundred and eighty-eight. [*Approved April 24, 1888.*

The territory whose relief is, under these resolves, to be considered by the State Board of Health, includes an area of one hundred and thirty square miles, and contains one-sixth of the population of the state.

Some of the cities have more or less complete local systems of sewerage, discharging sewage at their borders, where it is offensive to their own citizens and to their neighbors, and has become, or is rapidly becoming, dangerous to the public health. Others of the cities and the more populous towns have little or no sewerage systems, and are waiting, with solicitude for the health of their people, the action of the General Court in arranging for a common method of disposal of their sewage, being prohibited by statute, or by considerations of public health, from pouring it into the streams which are the natural drains of their territory; and still other towns, sparsely settled, see less need for disposal of their own sewage, but are much concerned for the health of their communities, because of the pollution of streams upon their borders by the sewage of their neighbors.

To devise the most efficient systems of relief for these communities, and to present plans which, upon careful consideration, would meet their approval as the best that can be adopted, required that the problem should be solved in all of the three practicable methods of solution that have met with favor elsewhere.

These methods are: —

(1) The method of discharging crude sewage into a strong tidal current that will convey it to sea, whence it cannot return.

(2) The method of partial purification by filtration upon the bed recommended by the Massachusetts Drainage Commission by report of December 24, 1885, or upon some other bed or beds.

(3) By chemical precipitation and discharge of the clarified effluent into outgoing tide at one or more points.

The Board concluded that the general consideration of each of these methods should be committed to a thoroughly competent engineer, skilled in the particular method to be planned by him, and that he should take time to investigate the whole subject in its relation to this locality, and work up the best plan for his method of disposal.

The Board selected Mr. Howard A. Carson, civil engineer of Boston, who had been the superintendent of construction of sewers of the Boston Main Drainage System, and went abroad with Mr. Davis to study the discharge of sewers into tidal currents, to make the investigations, plans and estimates by the first method, which plans and estimates for sewers, modified to meet the peculiar conditions, are used in the estimates of cost by the other methods; Mr. Phinehas Ball, civil engineer of Worcester, to make the investigations, plans and estimates appropriate to the second method; and Mr. Charles H. Swan, civil engineer of Boston, to make the investigations, plans and methods appropriate to the third method.

After careful examination of the possible localities for disposal of the sewage, Mr. Carson concluded that the best outlet for the discharge of crude sewage is a little west from the Beacon which is one-third of a mile south from Deer Island. Mr. Ball found that territory including and in the vicinity of that selected by the Massachusetts Drainage Commission of 1885 is the only available territory where any considerable portion of the sewage of Mystic valley can be treated by filtration; and Mr. Swan selected as the most favorable for the chemical precipitation process an area in Everett, on the north bank of Mystic River, between Malden Bridge and Island End River.

A system of intercepting sewers was first designed and located upon the ground, and estimates of cost made, for receiving and conveying to each of these points of disposal the sewage from Woburn, Stoneham, Winchester, Arlington, Belmont, Medford, Melrose, Malden, Everett, Chelsea and East Boston, and one-fifth of Somerville and one-ninth of Cambridge, containing a population estimated to be 150,000 in 1890 and to increase to 300,000 in 1930, the sewers being of sufficient capacity to serve the population of 1930.

With the estimated cost of these systems of sewers by Mr. Carson, and the estimates of Mr. Swan for the process of disposal by the aid of chemical precipitation, the chief engineer and the consulting engineer of the Board made for the use of the Board a comparative estimate of the cost and yearly running expenses for each of the three methods of disposal, which comparative estimate is given in the table on the following page to indicate the steps by which the Board has reached its final conclusions.

These estimates show that the amount to be paid on the cost and maintenance of works, and yearly running expenses for the forty years for which the systems were designed to be adequate for the territory embraced, is more than fifty per cent greater for the method of disposal by chemical precipitation at Island End River and discharge of the clarified sewage there on the out-going tide, than for the method of discharge of crude sewage into tidal currents at Deer Island Beacon.

When we consider a larger population than the 300,000, and find that the cost of chemicals and their application and the removal of sludge will be as much as fifty cents per inhabitant a year, while the whole yearly running expenses by the method of discharge at Deer Island are but one-half this amount, we must conclude that if a larger territory as favorably situated in respect to the outlet at Deer Island be included in a system discharging there, the resulting cost will to a much greater degree be in favor of the Deer Island outlet.

This result, though not anticipated by the Board, was received with satisfaction, because the effluent from chemical precipitation

TABLE II

COMPARATIVE ESTIMATE OF COST OF SEWERS FOR MYSTIC VALLEY FOR A PROSPECTIVE POPULATION OF 300,000, USED AT FIRST BY A POPULATION OF 150,000

	If Crude Sewage be Discharged Continuously into Tide Water at Deer Island Beacon	If Sewage be Filtered on Saugus Marshes	If Sewage be Precipitated by Chemicals at Island End River, and Effluent be Discharged at Ebb Tide
First cost	$2,726,995	$2,654,626	$2,384,503
Yearly running expenses and maintenance	$55,760	$66,700	$132,800
Interest and sinking fund at 4¾ per cent	129,532	126,095	113,264
Total yearly cost	$185,292	$192,795	$246,064
The same sewers used by a population of 300,000			
First cost	$2,792,995	Filtering area insufficient for so large a population	$2,835,651
Yearly running expenses and maintenance	$72,020		$222,300
Interest and sinking fund at 4¾ per cent	132,667		134,693
Total yearly cost	$204,687		$356,993

in England has been found to contain nearly one-half of the putrescible material of the sewage, and in some cases it has been found necessary to still further purify it by filtering it through land before turning it into streams. In this case it is to be turned into a large body of salt water, upon which it will tend to float, and, on the first ebb, will be carried down to Fort Point channel, and with the returning tide backed into the Mystic, Chelsea and Charles rivers: in the first river, nearly to the starting point, and in the last, about up to Craigie's Bridge. On the second ebb, the new discharge of clarified sewage will mingle to some extent with water containing the former discharge, so that, as Mr. Swan shows, there will always be the effluent from as much as one and one-half days' sewage in the waters about the principal wharf fronts of Charlestown, Chelsea, East Boston, East Cambridge and Boston.

This effluent is expected to be nearly colorless and clear when discharged, and will probably not be recognized as sewage after being in the river an hour. It will probably be mingled, to some extent, with the water of the river and harbor throughout its depth, but, being lighter than the salt water, will, during its passage back and forth past the wharves of these cities, probably be mingled to the greater extent with the water at and near the surface. In calm, moist weather we can but anticipate a marked effect of this surface water containing putrescible matter in adding to the discomfort of the great number of people who breathe the muggy air which has slowly moved over these waters.

Intercepting the sewage that now enters these waters, collecting it, — together with large additions from the surrounding country, — treating it with chemicals which remove the objectionable appearance and present odor of sewage, but still leaving in it one half, more or less, of the constituents which chemically distinguish sewage from pure water, and pouring this back, in ever-increasing quantity, into these rivers, surrounded by so dense a population, is a scheme to which the State Board of Health would be unwilling to give its approval, until satisfied by experiments which have not yet been made that the results would not be detrimental to the public health. Moreover, finding the cost of removing the sewage beyond all habitations and turning it into the ocean to be decidedly less than the cost of the questionable method by chemical precipitation, the Board is relieved from further investigation of the latter method, and dismisses it as inapplicable to the present circumstances.

The ordinary quantity of sewage to be pumped daily we have concluded to regard as 110 gallons per inhabitant, when serving a population of 150,000, and 120 gallons per inhabitant when this population grows to be 300,000, — making 16,500,000 gallons per day to be pumped presently after the completion of the works, and 36,000,000 gallons to be disposed of forty years later.

The area required to filter these quantities of sewage varies within a very wide range, depending upon the character and the porosity of the filtering material and the disposal to be made of the effluent.

The Board has made very extended experiments upon the Saugus Marshes to determine the quantity of water that will go down through the surface when kept constantly covered with one or two inches of water, and underdrained at the depth of six feet, and the water in the drains kept from three and a half to five feet below the surface.

Experiments have also been made to learn the quantity that would pass through where the surface was kept covered but a part of the time.

These experiments were in charge of Mr. Ball from their commencement in April till the latter part of July, when owing to ill health he found it necessary to discontinue work, and they were continued till the first of October in charge of Mr. Frederick Brooks, civil engineer of Boston.

At each of four different places on these marshes two circular beds were arranged with underdrains, and dikes to prevent overflow by the tide. One of these beds retained the surface of turf; the other had the turf to the thickness of four inches removed and the surface spaded up as if to be planted.

Upon these beds, about fifteen feet in diameter and separated from the surrounding marsh by a low embankment, water was applied to the depth of two inches. Outside of this embankment, a few feet away, was a second encircling embankment; and outside of this, a third embankment. Between these embankments water was kept, as near as practicable, at the same height as in the interior area.

At one place, intermediate between two others, a single bed ten feet by twenty feet was built, with the three lines of encircling embankments; in this bed the surface of turf was retained.

Arranging the beds in the order of the depth of peat, we give in the following table the quantity of water that passed through the surface of each when kept continually covered with water, while the water in the underdrains was kept from three and a half to five feet below the surface: —

TABLE 12

Depth of Peat	Quantity of Water Passing Through the Surface when Continually Covered — In Gallons per Acre per Day	
Feet	Natural Surface with Turf	Turf Removed and Surface Spaded
1.5	39,000	34,000
1.7	40,000	....
2.1	100,000	32,000
3.5	21,000	23,000
5.0	3,500	3,800

Experiments were made at six of the beds on the marsh to see the effect of allowing the surface to remain dry, after each application of water, as long a time as it took for about two inches in depth of water to disappear. The result of this intermittent treatment, with intervals of one to two days, continued for ten days or two weeks, was, that very little increase of capacity to transmit water followed such intermission; so that during a month when the surface is covered with water half the time, but little more than half the quantity of water will flow through if it be kept constantly covered.

The experiments of the Board upon the filtration of sewage by other material than peat show that the amount of sewage that can be filtered, month after month, is very much less than the amount of clear water that will continually flow through the material of the filter.

Most of the good filtering materials with which the Board has experimented will allow from ten times to one thousand times as much clear water to flow through them as the marsh surface, and will filter, giving an effluent suitable to turn into Pines River near a bathing beach, from less than one per cent to more than six per cent of the amount of clear water that will at first flow through them. But the material, not peat, which has filtered satisfactorily, and which is most nearly comparable with the marsh material, is composed of fine and coarse sand and a little fine gravel, overlaid by about twenty inches in depth of yellow loam and brown soil. This material allowed three times as much clear water to pass through it as the average of the marsh, and for a time filtered satisfactorily for the purpose there required one-third as much sewage as it at first passed of clear water; but this quantity of sewage grew less by the choking of the surface, until but one-twentieth as much would pass as originally of clear water. Then the surface was scraped off to the depth of half an inch, when it filtered readily and satisfactorily a quantity of sewage equal to one quarter of the original quantity of clear water; but this quantity gradually grew less and in one month filtered but one-eighth of the original quantity of clear water.

These results induced the Board to make experiments to determine, as near as practicable in the time at its disposal, the amount of sewage that can be filtered by material taken from the marsh at the location of the four double beds above described. When digging the drain between the two beds at each place a pillar of the material two feet square and five feet high was left; and this was carefully cut in layers six inches deep and placed in order in boxes, which were taken to the experimental station at Lawrence; and each layer was carefully cut to a circle twenty inches in diameter, and the bottom layer was placed in a galvanized iron tank twenty inches in diameter, upon a bed of six inches of coarse and fine gravel and coarse sand, which served as an underdrain; and each layer from the marsh was placed above this, in its order, filling the tank to the depth of five feet. Four tanks, filled in this way, represented as nearly as practicable the actual condition of the material in the marsh at the four localities.

Sewage has been applied to the peat in these tanks in such quantities as it would receive, for six and seven months, with results which are given in much detail because of their importance in deciding the question of the practicability of filtering sewage through a layer of peat.

Tank No. 1 of material from Saugus Marsh, having one and a half feet in depth of peat, with the peaty sand and clear sand below, making a total depth of five feet, being completely underdrained, was supplied with sewage, keeping the surface covered continually with a depth of about five inches, for three months, with the following result: —

During the first month the flow from bottom of tank was at the rate of	22,000 gals. per acre per day
During the second month, at the rate of..	16,000 " " " " "
During the third month, at the rate of...	9,200 " " " " "

During the fourth month the sewage on the surface, five inches deep, was allowed to settle away and disappear, which it did in twenty-eight days. The quantity flowing out decreased to 5,000 gallons on the fifth day, and on the day before sewage disappeared from the surface the quantity flowing was but 2,400 gallons per acre. For the next three weeks about the quantity which came out was applied intermittently, allowing the surface to become uncovered after each application, and the quantity flowing out decreased to 1,200 gallons per acre per day. At the end of this time the surface dried sufficiently for the mass of peat to shrink away from the sides of the tank, leaving a crack through which liquid could flow down freely for some distance, so that the quantity increased for a week to 11,000 gallons per acre per day; but by keeping the surface continually covered, the peat again swelled and the crack filled with slime, and the average daily outflow for the sixth month was 5,200 gallons, decreasing in the latter part of the month to 3,600 gallons, and during the seventh month the average daily flow for three weeks was 3,000 gallons, decreasing to 2,400 gallons per acre per day.

It is evident that the sewage came through this material, for the chlorine from the salt marsh decreased in the first two months from 1,200 parts in 100,000 to 75 parts, and has since decreased to 31 parts. The ammonias, being in the first sample 0.10 parts in 100,000, decreased nearly in proportion to the decrease in flow in two months to 0.02 parts, and have since increased and averaged during the past month 0.26 parts.

The effluent is now suitable to turn into an arm of the sea near a bathing beach, but as no nitrification takes place it is probable that the filtering material is storing up ammonia that will come out later, rendering the effluent objectionable. Keeping the surface continually covered with sewage, as in the earlier experiments, the surface becomes covered with a disagreeable slime, which, on account of the very slow percolation of the liquid, accumulates rapidly, and, no doubt, has the effect to close up the interstices of the peat and cause the amount flowing through to decrease so rapidly. But the choking of the surface appears in the later experiments to be more complete when the water is allowed to drain out of the slime after it has been deposited.

The experiments upon this material prove to the Board that an area of sand covered with peat to the depth of even one foot is unsuitable to be used for a filtration area. They indicate that if so used the surface will become covered with a slime which will prove a nuisance; that sewage applied to such an area in winter will have to remain so long upon the surface that it will freeze and the whole become inoperative; that under the most favorable circumstances the quantity of sewage which can flow through the peat is so small, and the effluent so little improved by passing, that it is not expedient to use it for this purpose; and that the only way to render such an area suitable for filtration is to remove the peat entirely from the sand and apply the sewage directly to the sand.

To remove peat from the marsh surface to the depth of one foot would cost as much as four hundred dollars per acre, which indicates that it would be unreasonable to consider the practicability of using the marsh for filtration where there is more than one foot in depth to be removed.

The whole area of the Saugus Marshes, where the depth of peat is not more than one foot, is about four hundred and twenty-eight acres, of which about sixty acres are in detached pieces, and the remainder is in three distinct areas.

One of these, southwest of Pines River, near Linden Station, contains about one hundred acres with peat six inches to a foot thick, underlaid with sand. Over about one-half the area the sand is very compact, and allows water to percolate very slowly.

Another section, in the vicinity of, and including the Franklin Trotting Park, contains about one hundred and twenty acres, with peat from six inches to a foot deep, much of which is underlaid with perhaps six inches of peaty sand, below which over three-quarters of the area is open sand, which alone at a proper height above tide water would be good filtering material. The other quarter of the area has, beneath, a compact material which allows water to percolate very slowly.

The third section contains about one hundred and fifty acres and is on either side of Bristow Street but mostly north of it. This area is of better material than the others, about thirty acres of it being from two to four feet above the marsh level and covered with soil containing some peat, with very open sand below. This could be used advantageously for filtering, but it is also valuable for agriculture, for which it is said to be worth three or four hundred dollars per acre. Adjacent land is laid out into streets with sewers. This section of one hundred and fifty acres is subjected to a mean height of water greater than the remainder of the marsh, owing to the dam of the Newhall tide mill, which allows a range of water from high tide to only three or four feet below the surface of the marsh.

The cost of the land and the removal of peat from these tracts would probably exceed five hundred dollars per acre. Diking, underdraining, preparing carriers from the pumping station and returning drains to the pumping station, would probably exceed six hundred dollars more per acre. An indefinite, but considerable expense, must be incurred in diverting and pumping rainfall coming from surrounding higher land. The cost of pumping ground water and sewage effluent, after the sewage is filtered, would be much larger than was estimated when it was supposed that the marsh material would serve as a filter, and the whole was to be used in one area. And the most that can be expected of the three areas would be the filtration of 20,000 gallons a day per acre on 370 acres, or 7,400,000 gallons, which, at 110 gallons per inhabitant, would serve for 67,000 people.

The circumstances are so unfavorable that it is not necessary to carry the investigation further to see that the expense of preparation and yearly maintenance would be so great as to exclude the use of these areas for filtering the sewage even of the adjacent towns of Malden, Melrose, Everett, and Revere, which, in forty years, would tax the area to its full capacity.

We have to conclude, then, from the additional information obtained by the experiments and investigations of the past year, that the Saugus Marshes will not serve for a filtering area for the sewage of the Mystic Valley; and as there is no other area available for filtering this sewage, its disposal by filtration must be abandoned.

For the system now to be considered, including the towns of the Mystic Valley, together with Cambridge, Somerville, Charlestown, East Boston and Winthrop, which we designate the North Metropolitan Sewerage System, the only reasonably practicable method of disposal is, the discharge of crude sewage into the sea; for the method by chemical precipitation, which was too expensive for adoption, as compared with this method, when considering the smaller territory, would be so to a much greater degree when a territory containing double the population is included; and the method by filtration upon land cannot be adopted, because there is not sufficient land available to filter one-eighth of the sewage.

We have then first to consider where into the sea, and under what conditions, this quantity of sewage can be poured, at a reasonable cost, with the least resulting discomfort.

Careful study of the tidal currents has been made by running floats from Shirley Gut; from Faun Bar Beacon, which is three-quarters of a mile east from Deer Island; and from Deer Island Beacon, which is one-third of a mile south from the southernmost point of Deer Island and in the north edge of the main ship channel.

For the quantity of sewage to be discharged from the North Metropolitan District, the currents at Shirley Gut are of too short duration and would not carry the sewage beyond adjacent flats. Either of the other sites may be used, but more satisfactory dispersion of the sewage, — because of stronger currents, — and less cost in construction, render Deer Island Beacon preferable. From this locality floats have been run at all stages of the tide to determine the course that sewage will take if discharged here.

From the paths of these floats it is evident that sewage discharged in any desired quantity, from one hour before high tide to four hours after, will not approach any shore where it can give the least offence. It will be carried to sea through the north and south channels never to return.

Careful study has also been made of the results that may be expected if the sewage be discharged here continuously through the twenty-four hours. In this study observations were made upon the sewage discharged at Moon Island, where the rate of outflow during the time of discharge may be called fifteen times that of the continuous flow at Deer Island.

From Moon Island the sewage flows away with the tidal current at the speed of about one mile per hour and spreads to a width of about three thousand feet. One-fifteenth of this quantity discharged continuously at Deer Island, flowing with a tidal current having a greater velocity, will evidently spread to a much less width. If it spreads to one-sixth the extent, or to five hundred feet, the layer of sewage upon the salt water will be much thinner than that from Moon Island, and will more quickly become dissipated. Assuming this to be the width, plottings have been made to show, from the paths taken by twenty floats started at different times during the rising tide, the probable position of the successive areas of sewage starting from the proposed outlet on each hour before and after low water, as they would be at one hour from the time of starting and at two hours from the time of starting.

These plottings are presented upon a map[1] of the harbor, on which the darker shade represents the position of the sewage within the first hour, and the lighter shade the position within the second hour after starting. As the direction of the current continually changes, the sewage delivered between the hours will be distributed over the whole area between the paths of the floats started upon the hour, as shown by the dotted areas.

[1] This map is not reproduced here.

The front of the body of sewage at two hours from the time of starting will, from experience at Moon Island, be entirely obliterated, and no appearance of sewage can be recognized farther away than the shaded area upon the map indicates, unless it be an occasional grease-ball or some other small floating substance that has escaped through the racks above the pumping station.

At the Moon Island outlet of the Boston Main Drainage System the sewage collected in eleven hours is generally discharged in a body in about half an hour, and, as stated above, no sewage is to be found in the tidal current into which it enters two hours after it leaves the sewer. That we might make observations and reach just conclusions in regard to a stream of sewage discharging continuously, the officers in charge of the Boston Main Drainage Works kindly co-operated with the Board by discharging continuously, on a falling tide, for four hours, about 1,500,000 gallons per hour, the equivalent of 36,000,000 gallons per day, which is the amount estimated to be discharged at Deer Island outlet when the population is between 300,000 and 400,000.

When sailing in the stream of sewage, or on the leeward side of it, from near the outlet of the sewer and for a distance of half a mile along the stream, the odor of the sewage was disagreeable. Continuing in the stream of sewage beyond this distance the odor was noticeable for a time, but before reaching the distance of three-quarters of a mile from the outlet of the sewer the odor could not be distinguished. At this distance, however, the color of the water was distinctly different from the blue of sea water, — it was more opaque and browner. But there was nothing, at this distance, with wind blowing up stream toward the outlet of sewer, either in appearance or odor, that was in the least objectionable. The appearance of the water here was like that in the upper harbor in midstream, between the Cunard wharf and the New York and New England railroad docks.

By the color and stillness of the surface the area containing sewage could be distinguished for a quarter of a mile farther, or at a distance of one mile from the outlet; but no odor could be distinguished, and there was no disagreeable appearance.

At one mile and a quarter a narrow strip of smooth water and a slightly opaque character of the water, — seen only upon very careful examination, — indicated an effect from sewage; but at one and a half miles from the outlet no trace of the sewage could be seen, although floats which started with the sewage had gone far beyond.

To present this subject with more definiteness than can be conveyed by recording the observations of individuals, samples of the water taken from the middle of the stream of sewage were subjected to most careful chemical tests, in comparison with the adjacent salt water which was unaffected by this sewage, and with the salt water of the inner harbor.

Samples of the sewage throughout the stream of observable sewage and beyond were taken within eight inches of the surface, after the stream had flowed in nearly the same place for three hours, and were subjected to chemical analysis with the following results: —

TABLE 13

(Parts per 100,000)

	Free Ammonia	Albuminoid Ammonia	Sum of Ammonias	Chlorine
Salt water, up stream, from area containing sewage	.0056	.0098	.0154	1,675
Salt water, down stream, from area containing sewage	.0056	.0095	.0151	1,746
Water, within area containing sewage, at the following distances from outlet:				
400 feet	2.5000	.5310	3.0310	773
1,600 "	.1944	.0636	.2580	1,570
3,200 "	.0416	.0254	.0670	1,621
4,700 "	.0224	.0116	.0340	1,694
6,200 "	.0184	.0156	.0340	1,689
7,200 "	.0136	.0108	.0244	1,687
9,200 "	.0104	.0096	.0200	1,710
Water in mid stream at crossing of North Ferry to East Boston	.0480	.0154	.0634	1,581

From these analyses it appears that in the stream of sewage at four hundred feet from the outlet of the sewer the upper eight inches in depth was about one-half sewage. At 1,600 feet distant it contained about one-eighteenth of its bulk of sewage, and at 3,200 feet, or five-eighths of a mile distant from the outlet of the sewer, the ammonias indicated the amount of sewage added to be but one per cent of the volume of the water, and the same amount as found in mid stream at the crossing of North Ferry to East Boston. Beyond this distance the amount of ammonia added became about one-half of one per cent at a mile, and less than one-tenth of one per cent at one and four-fifths miles from the outlet.

These results confirm those of direct observation. With the ordinary wave motion at this place, a mile from the outlet, the amount of sewage remaining near the surface of the water is so small that no disagreeable appearance or odor can be recognized.

From these experiments and the position of the currents shown upon the map, it is evident that the sewage discharged continuously at Deer Island Beacon will not reach any shores, nor lodge upon any flats that are exposed at low tide, nor come into the neighborhood of any dwelling, nor of land that is capable of being used for dwellings in the future, unless it be on a portion of Deer Island.

To guard against deposits of heavy material near the proposed outlet, provision has been made in the designs, and the cost of operating included in the estimates, for removing at each of the pumping stations and at the river crossings whatever material of this kind may get into the sewers.

This material will come principally from the street washings of the cities which now have the combined system of sewers, and will be removed by sand pumps or other contrivances, from places where it has been allowed to settle.

The outlet at Deer Island Beacon is directly into a tidal current more than fifty feet deep, in which the velocity of more than two and a half miles per hour is much greater than that in the sewer, and the scouring effect of the currents, reversed twice daily, will readily remove everything which the sewer can bring there. This conclusion is confirmed by the experience at Moon Island, — where the maximum velocity of the tidal current is much less, — given in the report of the chief engineer of the Board.

As a result of this study, the Board has concluded that it is advisable to construct the sewage works to discharge continuously the comparatively small stream of sewage as it arrives at the outlet. Should the time ever come when such a discharge proves objectionable, and the objection can be removed by holding the sewage back for one, two, or three hours after low tide, the capacity of the sewer between East Boston and the outlet will for several years be sufficient to allow of such storage during the hours named; and if it becomes desirable to store the sewage through the incoming tide and discharge it only when the outgoing tide will carry it directly to sea, a reservoir can be then built on Deer Island as well as at the present time; but the Board does not anticipate the need of such a reservoir.

We have thought it unnecessary to dwell upon the vital importance of providing relief for the several communities included in the two populous districts, because the action of the General Court in directing this Board to consider, not whether such relief is required, but how it can be wisely accomplished, indicates that the people of the state have grown to appreciate the necessity of action, and desire only to be shown the best method of accomplishing the purpose.

To this problem we have devoted our energies with results which we are gratified to present. These show that complete relief can be reached by expenditures which can reasonably be made by the populous and wealthy communities interested in the healthfulness of this great metropolitan territory.

HENRY P. WALCOTT,
ELIJAH U. JONES,
JULIUS H. APPLETON,
THORNTON K. LOTHROP,
FRANK W. DRAPER,
HIRAM F. MILLS,
THEODORE C. BATES,
State Board of Health.

XII

SUGGESTIONS AS TO THE SELECTION OF SOURCES OF WATER SUPPLY[1]

By Frederic P. Stearns

[Mr. Stearns' paper described some of the fundamental principles relating to the storage of water and its relation to the yield of catchment areas. The data given have served as the basis of much recent work. The original paper included sections not here given on the quantity of ground water and the quality of surface and ground water. *Twenty-second Annual Report*, 1890, p. 335. — G. C. W.]

In selecting a source of water supply, it is essential that all water should be rejected which is seriously polluted with domestic sewage. There are other waters not so polluted, as for instance those having a disagreeable taste and odor or drawn directly from swamps, which are manifestly unfit for drinking. A water may also be rejected by reason of its extreme hardness, which makes it unsuitable for washing purposes and for use in boilers. Among the waters which may be used there is a large difference in quality, and this in connection with the quantity and cost should receive careful consideration in making the selection.

Sources may be divided into two general classes, those in which the supply is taken from the ground, known as ground waters, and those obtained from lakes, ponds, streams and storage reservoirs, known as surface waters.

The prominent characteristic of ground water is freedom from color and organic matter (including microscopic organisms), while surface waters are frequently colored with vegetable matter derived from swamps, and almost always contain a greater or less number of microscopic or larger organisms, which, when abundant, frequently impart to the water a disagreeable taste and odor.

With regard to the question of quantity, sufficient surface water can be obtained for the largest cities, and the amount which

[1] These suggestions are based mainly upon observations in Massachusetts, and, in some respects, will be inapplicable to other places where different conditions prevail.

can be obtained from a given watershed can be estimated in advance with a large degree of accuracy. Ground water supplies, on the other hand, are much more limited in quantity, and the amount to be obtained from any given place cannot be as accurately predicted.

As a whole we may say that when unpolluted ground water can be obtained in sufficient quantity from regions where the water does not dissolve much mineral matter and in this way become hard, it is very much to be preferred to surface water for the supply of a city or town.

With these general statements we will proceed to consider in greater detail the quantity and quality of water to be derived from surface and ground water sources, including among the ground waters those taken from wells and filter-galleries built beside streams and ponds, and deriving their water, in part, from these surface waters, by filtration.

The question of the quality of waters variously situated has been so fully treated in the Special Report of the Board, Part I, 1890, that the present article will give greater prominence to the quantity of water to be obtained under different circumstances.

Quantity of Surface Water

All sources from which water is obtained depend for their supply upon the rain which falls upon the area from which the water can flow over the surface or under ground to the point whence it is taken for use. In a great majority of cases this area coincides with the superficial watershed of the stream or pond utilized. We have, therefore, as very important factors affecting the quantity of water, the amount of the annual rainfall and the area of the watershed.

The whole of the rain which falls upon a watershed does not flow off into the streams, because much is lost by evaporation from the surface of the ground. The amount of this loss has been determined practically by comparing the quantity of water falling upon a given watershed (as deduced from the depth of rainfall and the area of the watershed) with the amount of water flowing off in the streams. Very valuable records of this character have been kept by the city of Boston for many years at Cochituate Lake, Sudbury River and Mystic Lake, and the results have been published in the annual reports of the Boston Water Board. From these we learn that the average percentage of rainfall collected from these three watersheds is as follows: —

TABLE 14

	Average Rainfall	Average Rainfall Collected	Per Cent Collected
	Inches	Inches	
Lake Cochituate (28 years' observations) ...	47.82	20.55	42.97
Sudbury River (16 years' observations).....	45.80	22.67	49.50
Mystic Lake (13 years' observations).......	44.11	20.22	45.84

In attempting to determine the quantity of water which can be made available for use from any given source, the above figures, representing the average results of many years' observations, have only a limited value, because there is a marked variation in the amount of rainfall in different years and a still greater difference in the amount of rainfall collected, the rule being that the percentage collected decreases with the amount of the annual rainfall; moreover, there is a vast difference in the amount of rainfall collected at different seasons of the year. In view of these differences it is obviously necessary to take into account the rainfall collected during dry periods of much less than a year's duration. This can be done by means of the records of the Boston Water Works above referred to. Of these the Sudbury River records are the most accurate and the most generally applicable to conditions existing at other places, and, on account of their value as a basis for water supply estimates, they are reproduced from the reports of the Boston Water Board in the following table.[1]

As has already been indicated it is necessary in estimating the capacity of sources of water supply to take into account the dryest periods which have occurred, and which consequently may recur; and for this reason it is the minimums recorded in the foregoing table which have the most value. These for periods varying in duration from one month to sixteen years have been carefully

[1] Owing to the length of this table it has not been reproduced here.

selected from the table, and are presented in more convenient form in the one which follows: —

TABLE 15

TABLE SHOWING THE AVERAGE DAILY FLOW FROM THE SUDBURY RIVER WATERSHED FOR DIFFERENT PERIODS, VARYING FROM ONE MONTH TO SIXTEEN YEARS, SELECTING IN EACH CASE THE DRYEST PERIOD OF THE GIVEN DURATION

Length of Period	Dates	Average Daily Flow of Watershed		
		Gallons per Day per Square Mile	Gallons per Day per Acre	Cubic Feet per Second per Sq. Mile
1 month	September, 1884	44,000	69	.068
2 months	Sept. 1, 1884 to Oct. 31, 1884	64,000	100	.099
3 months	July 1, 1883 to Sept. 30, 1883	95,000	148	.147
4 months	July 1, 1883 to Oct. 31, 1883	118,000	184	.183
5 months	June 1, 1880 to Oct. 31, 1880	131,000	205	.203
6 months	June 1, 1880 to Nov. 30, 1880	143,000	223	.221
7 months	June 1, 1880 to Dec. 31, 1880	147,000	230	.227
8 months	June 1, 1880 to Jan. 31, 1881	181,000	283	.280
9 months	May 1, 1880 to Jan. 31, 1881	219,000	342	.339
10 months	April 1, 1880 to Jan. 31, 1881	312,000	487	.483
11 months	Mar. 1, 1880 to Jan. 31, 1881	409,000	639	.633
1 year	Mar. 1, 1880 to Feb. 28, 1881	497,000	777	.769
2 years	Feb. 1, 1882 to Jan. 31, 1884	687,000	1,073	1.063
3 years	Mar. 1, 1880 to Feb. 28, 1883	764,000	1,194	1.182
4 years	Feb. 1, 1880 to Jan. 31, 1884	735,000	1,148	1.137
5 years	Jan. 1, 1879 to Dec. 31, 1883	769,000	1,202	1.190
6 years	Oct. 1, 1879 to Sept. 30, 1885	803,000	1,255	1.242
7 years	Jan. 1, 1879 to Dec. 31, 1885	839,000	1,311	1.298
8 years	Jan. 1, 1879 to Dec. 31, 1886	870,000	1,359	1.346
9 years	Jan. 1, 1879 to Dec. 31, 1887	902,000	1,409	1.396
10 years	April 1, 1878 to Mar. 31, 1888	944,000	1,475	1.461
11 years	Jan. 1, 1875 to Dec. 31, 1885	968,000	1,512	1.498
12 years	Jan. 1, 1875 to Dec. 31, 1886	978,000	1,528	1.513
13 years	Jan. 1, 1875 to Dec. 31, 1887	991,000	1,548	1.533
14 years	Jan. 1, 1875 to Dec. 31, 1888	1,042,000	1,628	1.612
15 years	Jan. 1, 1875 to Dec. 31, 1889	1,065,000	1,664	1.648
16 years	Jan. 1, 1875 to Dec. 31, 1890	1,079,000	1,686	1.670

With such a vast difference in the average daily flow during the dryest month and the dryest year, and also in the flow during the dryest year and a long series of years, it is obvious that the quantity of water which can be made available from a given watershed depends very much upon the amount which can be stored in seasons when water is abundant for use during seasons of drought.

It is feasible to deduce from the Sudbury River records a table which will show directly the amount of storage necessary to make available different quantities of water per day from each square mile of watershed,[1] where the conditions are similar to those

TABLE 16

TABLE SHOWING THE AMOUNT OF STORAGE REQUIRED TO MAKE AVAILABLE DIFFERENT DAILY VOLUMES OF WATER PER SQUARE MILE OF WATERSHED,[2] BASED UPON THE RECORDS OF THE FLOW OF SUDBURY RIVER FROM 1875 TO 1890, INCLUSIVE

Daily Volume per Square Mile	Storage required per Square Mile to prevent a Deficiency in the Season of Greatest Drought when the Daily Consumption of Water is as Indicated in the First Column	Dates when Greatest Draught from Reservoir would have occurred during the Period. 1875–1890			Length of Time Reservoir would have been below High Water Mark
		Beginning of Draught upon Reservoir	Lowest Point Reached	Reservoir Full Again	
Gallons	Gallons				
100,000	2,200,000	Sept. 1884	Oct. 1884	Nov. 1884	3 months
150,000	5,300,000	Sept. 1884	Oct. 1884	Dec. 1884	4 months
200,000	11,000,000	June, 1880	Dec. 1880	Feb. 1881	9 months
250,000	22,000,000	June, 1880	Dec. 1880	Feb. 1881	9 months
300,000	33,000,000	June, 1880	Dec. 1880	Feb. 1881	9 months
400,000	54,000,000	June, 1880	Dec. 1880	Mar. 1881	10 months
500,000	78,000,000	June, 1880	Jan. 1881	Mar. 1881	10 months
600,000	105,000,000	May, 1880	Jan. 1881	Mar. 1881	11 months
700,000	156,000,000	June, 1882	Dec. 1883	Mar. 1884	1 yr. 10 mos.
800,000	214,000,000	June, 1882	Dec. 1883	April, 1884	1 yr. 11 mos.
900,000	373,000,000	June, 1879	Dec. 1883	May, 1887	8 years
1,000,000	540,000,000	June, 1879	Dec. 1883	Mar. 1890	10 yrs. 10 mos.
1,024,000	596,000,000	June, 1879	Oct. 1885	May, 1890	11 years

which exist at Sudbury River. A table of this character is given above, which, in addition to the amount of storage required, gives the length of time the reservoir would have been below high water mark during the dryest period of the given duration, and

[1] The area of the Sudbury River watershed, as used for making up the records, includes both land and water surfaces.

[2] Including water surfaces amounting to 2.31 per cent of the land surface.

the date when the water in the reservoir would have reached its lowest level.

Having deduced from the Sudbury River records the facts given in the last table, we have next to consider to what extent they are applicable to other watersheds. It may be said in a general way that the dry weather flow of different streams per square mile of watershed, without artificial storage, is liable to differ greatly; but that the total yearly flow does not vary nearly as much. In many cases it will be found, by applying the Sudbury River records directly, that there is so great a difference between the estimated yield and the amount of water required that any further refinement is unnecessary. In other cases it is necessary to take into account everything which may affect the application of these records. The chief causes of variation in the yield of different watersheds per square mile, after taking into account the influence of storage, are: the amount of rainfall and its distribution throughout the year, the area of water surfaces, the character of the surface of the ground as regards topography and material, and the size of the watershed. There is also another feature which frequently requires consideration, particularly with small and steep watersheds; namely, the loss of water by leakage past dams and by filtration through the ground to a lower level.

The conditions which existed upon the Sudbury River watershed during the time included in the records were as follows: The area of the watershed from which the flow was measured was 77.764 square miles until the end of 1878, then 78.238 square miles until the end of 1880, and after that time 75.199 square miles. These areas include all water surfaces. From the beginning of the observations until the end of 1878, the water surfaces consisted of Farm Pond, Whitehall Pond (which was flowed in winter and drawn down in summer), several mill ponds, and the various streams. The area of these combined water surfaces was equal to 1.02 per cent of the land surfaces. The construction of artificial storage reservoirs has since increased the area of water surfaces. Three reservoirs were completed and filled in 1879, making the total area of water surfaces after this date, until 1886, 2.31 per cent of the land surfaces. In 1886, Reservoir No. 4 was added, increasing the per cent of water surfaces to 2.92. The dryest periods occurred between the years 1879 and 1886, and it may therefore be assumed that the water surfaces of Sudbury River which had the most effect upon the present records were 2.31 per cent of the land area.

The flow of the river past the lowest dam has been greatly modified by the use of the artificial reservoirs; but this does not appear in the records, because the amount flowing past the dam is corrected by the amount added to or drawn from storage. The object in making these corrections has been to eliminate the effect of the reservoirs and to present in the records the natural flow of the stream modified only by such storage as is furnished by ordinary mill ponds and by Whitehall Pond. It cannot, however, be said that the effect of the reservoirs is wholly eliminated, because the evaporation from the increased water surfaces is not taken into account; and the dry weather flows recorded are consequently less than they would be if these reservoirs did not exist.

The average annual rainfall upon the Sudbury River watershed is nearly the same as that in other parts of the state, so that it is not often necessary to take into account any difference of this kind.

The watershed of the Sudbury River contains many hills with steep slopes, some of which are used for pasturage and others are covered with a small growth of wood. The valleys, as a rule, are not steep, and there are extensive areas of swampy land, generally covered with a growth of brush and trees. The hills are, for the most part, of rather impervious clayey material, containing boulders, while the flat land is sandy and in some cases gravelly.

The special characteristics of the Sudbury River watershed have thus been described in detail, so that in applying the results to other watersheds such modifications could be made as would be rendered necessary by the difference in conditions.

In this paper further consideration will be given only to the effect of a varying percentage of water surfaces upon the yield of watersheds, and to the flow during short periods of drought.

With regard to the effect of water surfaces it has been a common practice to leave them out of consideration in estimating the area of a watershed, upon the assumption that the evaporation from water surfaces offsets the rainfall upon them. The Sudbury River records, however, were not made upon this basis, and they are therefore strictly applicable only to watersheds which have the same proportion of water surfaces, unless a correction is made for evaporation.

A table will be presented subsequently which gives the yield per square mile of land surface, when in addition to the land there is a varying percentage of water surfaces. Before presenting this table, however, it may be well to indicate in a general way the relation of the evaporation from water surfaces to the rainfall upon them.

For determining the amount of evaporation, the most valuable information is to be obtained from the paper [1] presented by Desmond FitzGerald, C.E., to the American Society of Civil Engineers, based upon experiments made upon the Boston Water Works, chiefly at Chestnut Hill Reservoir, Boston. In his paper, as the result of several years' experiments, a mean evaporation for each month of the year is given. By comparing this with the mean rainfall for each month, we can obtain the relation between evaporation and rainfall in an ordinary year; and as the evaporation does not vary very much from year to year, we can also obtain approximately the relation between the evaporation and rainfall in a dry year, by comparing the average evaporation with the rainfall in a dry year like 1883.

The results of these comparisons are shown by the table and diagram on the pages following.

It will be seen from the facts presented that the monthly rainfall varies much less during the year than the evaporation; also that in an average year the rainfall is 6.68 inches greater than the evaporation. The average year may be divided into two periods, one extending from May to September, inclusive, in which the evaporation is 8.77 inches greater than the rainfall; and the other extending from October to April, inclusive, in which the rainfall exceeds the evaporation by 15.45 inches.

[1] "Evaporation," by Desmond FitzGerald, C.E., *Transactions of the American Society of Civil Engineers*, vol. XV, 1886, p. 581.

In the year of low rainfall the evaporation was 6.34 inches greater than the rainfall. During the warmer months, from April to September, inclusive, the excess of evaporation was 15.22 inches, and during the other six months the rainfall was 8.88 inches in excess of the evaporation. These figures indicate that a

TABLE 17

TABLE SHOWING RELATION OF EVAPORATION TO RAINFALL

(NOTE. — + indicates excess of rainfall; − indicates deficiency)

Month	Average Year			Year of Low Rainfall		
	Rainfall	Evaporation	Excess or Deficiency of Rainfall	Rainfall	Evaporation	Excess or Deficiency of Rainfall
	Inches	Inches	Inches	Inches	Inches	Inches
January	4.18	0.98	+3.20	2.81	0.98	+1.83
February	4.06	1.01	+3.05	3.86	1.01	+2.85
March	4.58	1.45	+3.13	1.78	1.45	+0.33
April	3.32	2.39	+0.93	1.85	2.39	−0.54
May	3.20	3.82	−0.62	4.18	3.82	+0.36
June	2.99	5.34	−2.25	2.40	5.34	−2.94
July	3.78	6.21	−2.43	2.68	6.21	−3.53
August	4.23	5.97	−1.74	0.74	5.97	−5.23
September	3.23	4.86	−1.63	1.52	4.86	−3.34
October	4.41	3.47	+0.94	5.60	3.47	+2.13
November	4.11	2.24	+1.87	1.81	2.24	−0.43
December	3.71	1.38	+2.33	3.55	1.38	+2.17
	45.80	39.12	+6.68	32.78	39.12	−6.34

pond will not lower by evaporation in a dry summer more than about fifteen inches, even if it receives no water from its watershed.

In order to present in the most convenient form the yield of watersheds per square mile, the following table has been prepared, which gives the quantity of water which may be made available per square mile of watershed (estimating land surfaces only), with varying amounts of storage and a varying percentage of water surfaces. In preparing the table the records of the flow of Sudbury River and of the rainfall upon the Sudbury River

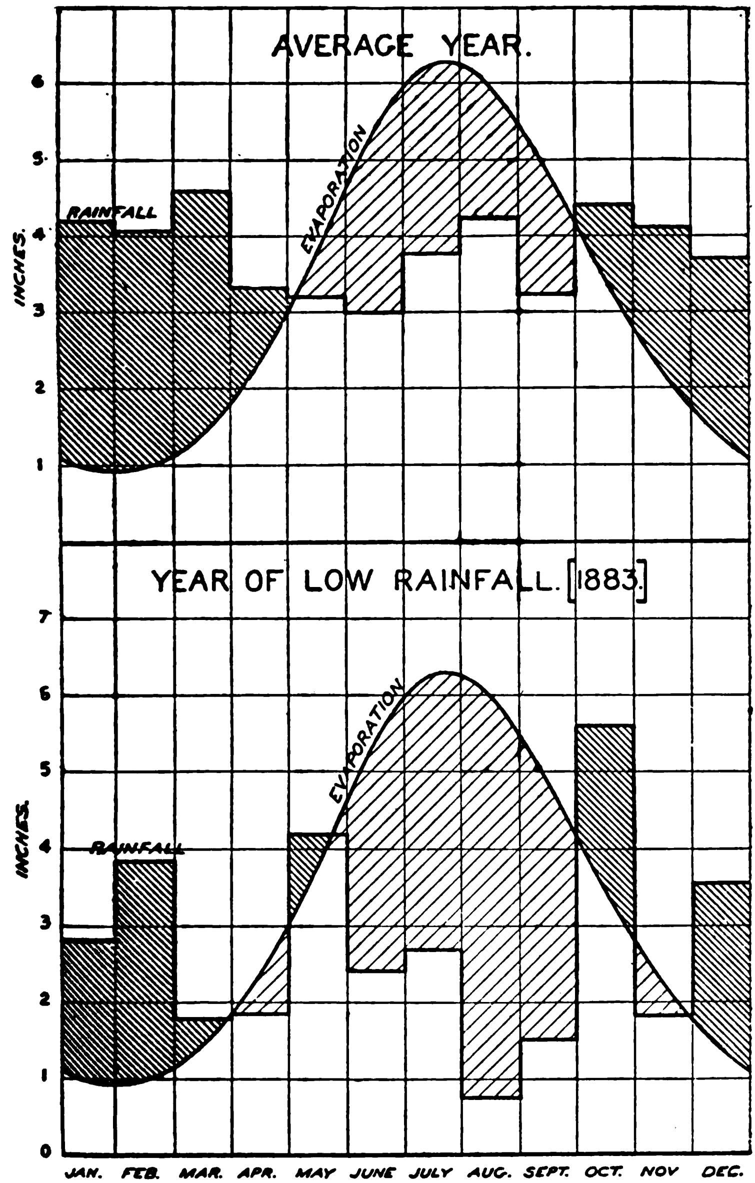


FIG. 3. DIAGRAM SHOWING THE RELATION OF EVAPORATION TO RAINFALL

NOTE.—The curved lines show the average evaporation in inches per month, and the horizontal lines the rainfall, also in inches, per month. The finer hatching indicates the excess of rainfall, and the coarser hatching the excess of evaporation.

watershed from 1875 to 1890, inclusive, have been used; also the records of evaporation from water surfaces from observations made chiefly at Chestnut Hill Reservoir during the years 1876 to 1880 and 1885 to 1887. For other years, when the evaporation was not measured, the average evaporation has been used. The flow per square mile is in all cases the smallest recorded after taking into account the evaporation from water surfaces.

TABLE 18

TABLE SHOWING THE AMOUNT OF STORAGE REQUIRED TO MAKE AVAILABLE DIFFERENT DAILY VOLUMES OF WATER PER SQUARE MILE OF WATERSHED (ESTIMATING LAND SURFACES ONLY), CORRECTED FOR THE EFFECT OF EVAPORATION AND RAINFALL ON VARYING PERCENTAGES OF WATER SURFACES, NOT INCLUDED IN ESTIMATING THE AREA OF THE WATERSHED

Daily Volume in Gals. per Square Mile of Land Surface	Storage required in Gallons per Square Mile of Land Surface to prevent a Deficiency in the Season of Greatest Drought when the Daily Consumption is as indicated in the First Column, with the following Percentages of Water Surfaces				
	0%	3%	6%	10%	25%
100,000	556,000	3,000,000	8,800,000	....	....
150,000	3,400,000	7,100,000	13,400,000	....	....
200,000	9,400,000	11,700,000	18,000,000	....	....
250,000	19,000,000	22,200,000	25,400,000	....	....
300,000	29,800,000	33,000,000	36,100,000	....	....
400,000	52,000,000	54,400,000	57,500,000	....	....
500,000	76,500,000	77,300,000	80,300,000	....	....
600,000	102,000,000	104,600,000	107,100,000	112,800,000	....
700,000	144,400,000	153,000,000	161,600,000	170,700,000	215,900,000
800,000	202,300,000	210,900,000	219,500,000	228,600,000	273,800,000
900,000	346,200,000	349,200,000	352,200,000	353,900,000	381,600,000
1,000,000	514,600,000	516,700,000	519,700,000	523,600,000	532,200,000

The table shows that a daily yield of 1,000,000 gallons per square mile of land surface can be made available when there is a very large amount of storage, such as may be found in some instances where a large pond is fed by a very small watershed. To obtain this quantity, however, would require the reservoir to be below high water mark for eleven years; and during a considerable portion of the time the water would not rise nearly to high water mark, even in the spring. In practice this would be objectionable as it would permit the growth of weeds, grasses and bushes on the exposed shores of the reservoir. Taking everything into account it may be said that the greatest amount which can be made practically available from a square mile of watershed does not exceed 900,000 gallons per day, and the cases are very rare in which more than 600,000 gallons per square mile per day can be made available when it is necessary to store the water in artificial reservoirs.

As a matter of theoretical interest only, it may be said that to make available the average yield of the Sudbury River watershed for the entire sixteen years (1,079,000 gallons per day per square mile) would require a storage capacity of not less than 725,000,000 gallons per square mile. This is about six times the amount of storage which it is now considered feasible to provide on this watershed.

The amount of water which can be made available from a given watershed will not always depend upon the quantity of water which can be stored, because considerations of quality require that the levels of the reservoir should not be made to fluctuate too much, and that the reservoir should not be drawn below high water mark for too long a time.

The application in actual practice of the previous table may be better understood by giving an example. Let us assume that it is desired to know the yield of a pond having an area of 0.15 of a square mile and an available storage capacity of 225,000,000 gallons, which has draining into it 1.5 square miles of land surface. The amount of storage in this case would be equivalent to 150,000,000 gallons per square mile of land surface, and the water surface would equal ten per cent of the land surface. By looking in the column of the table headed ten per cent it will be seen that a storage of 150,000,000 gallons per square mile corresponds to a daily volume of between 600,000 and 700,000 gallons per square mile, or more exactly by proportion to 660,000 gallons, equal to 990,000 gallons daily for the whole watershed. The results obtained by this method will in some cases be practically correct. In other cases it will be necessary to take account of local conditions, prominent among which may be leakage past a dam or filtration through the ground to lower levels; and the application of judgment will often be necessary to determine whether the watershed under consideration will yield the same or a greater or less amount per square mile than that of the Sudbury River.

The only point remaining to be considered with regard to the quantity of surface water relates to the flow from watersheds during short periods of extreme drought. The flow during such periods is chiefly of importance when it is desired to know the minimum flow of streams on which little or no storage can be obtained. On such watersheds the water surfaces are generally insignificant, so that the Sudbury River records are not applicable unless they are corrected for evaporation. It is well known that the natural dry weather flow of streams per square mile depends much upon the extent of the watershed; because it is frequently observed that streams draining but a small area dry up in summer, while those draining large areas continue to flow, though with a greatly reduced volume. There is also a large variation in the dry weather flow from watersheds of the same size due to the amount of water stored in the ground and subsequently coming out in the form of springs. The records of the natural flow of streams in a very dry period are very meagre. The lowest flow of the Sudbury River occurred during the month of September, 1884, and averaged only 44,000 gallons daily per square mile of watershed. Correcting for the excess of the evaporation from water surfaces over the rainfall upon them, we obtain 97,000 [1] gallons per square mile as the amount that the flow would have been if there had been no water surfaces. The next lowest monthly record was in September, 1877, 60,000 gallons per square mile. At this date the reservoirs had not been constructed and the area of water surfaces to be corrected for evaporation was smaller. Making the correction we have as the flow per square mile 82,000 gallons per day.

[1] This quantity is somewhat larger than it should be as no account is taken of the water which came from the ground adjoining the reservoirs as they were being drawn down to supply the city.

XIII

THE GROWTH OF CHILDREN STUDIED BY GALTON'S METHOD OF PERCENTILE GRADES

By H. P. Bowditch, M.D.

[This is but a partial reprint of Dr. Bowditch's admirable paper. Because of their length the tables are omitted, as well as many of the diagrams. It is interesting to observe that the method of statistical analysis here used has been recently taken up by engineers in the study of rainfall and stream-flows, and by sanitarians in the study of bacteriological data. *Twenty-second Annual Report*, 1890, p. 479. — G. C. W.]

In the last report of the Massachusetts State Board of Health the advantages of discussing statistical data by Galton's method [1] of percentile grades were explained and illustrated in a paper entitled "The Physique of Women in Massachusetts." The value of the method in anthropometrical work seemed so obvious that it has been thought desirable to apply it to the large body of observations on the height and weight of Boston school children which formed the basis of an article on "The Growth of Children," published by the Board of Health in 1877.

In this article, at the suggestion of Mr. Charles Roberts, tables were given showing the distribution of the observations; i. e., the number of individuals at each age whose height was recorded at each successive inch or whose weight fell within successive groups of four pounds each. From these tables it was easy to calculate the values at the various percentile grades. For example, it appears that the heights of 848 boys between five and six years old were distributed as shown in the table on the next page.

In this table it will be seen that five per cent, for instance, of the total number of observations is 42.4. Now since the observations corresponding to each successive inch include all the measurements between that inch and the next inch above, it is evident that there are $1+1+7+17 = 26$ individuals less than 38 inches in height and $1+1+7+17+42 = 68$ individuals less than 39

[1] See "Galton, Natural Inheritance," London, McMillan & Co., 1889.

inches in height. Since, therefore, 42.4 lies between 26 and 68 it follows that the height below which five per cent of the observations fall must be between 38 and 39 inches. The exact height can readily be calculated by interpolation. Thus the fraction of an inch to be added to 38 to give the required height is obtained by dividing 16.4 (i. e., 42.4 − 26) by 42 (i. e., the number of observa-

TABLE 19

DISTRIBUTION OF OBSERVATIONS ON HEIGHTS OF BOSTON SCHOOLBOYS. AGE AT LAST BIRTHDAY FIVE YEARS

Inches	Number of Observations	Inches	Number of Observations	Inches	Number of Observations
47	4	41	190	35	1
46	8	40	149	34	.
45	20	39	79	33	.
44	62	38	42	32	.
43	119	37	17	31	.
42	149	36	7	30	1
Total number of observations 848					

tions between 38 and 39 inches). This fraction is 0.39, and, therefore, 38.39 inches is the height below which five per cent and above which ninety-five per cent of the observations fall; i. e., it is the value of the five per cent grade.

In this way tables 1 to 12 have been calculated from tables 4 to 15 inclusive of the original article.[1] These tables show the heights and weights of Boston school children of both sexes and various ages at percentile grades varying from five per cent to ninety-five per cent. Separate tables are, moreover, given for children of American parentage, Irish parentage, and for the whole number of observations irrespective of nationality. The values are given in both the English and the metric system of weights and measures, and in the last column of each table are to be found the average heights and weights of children of each age as given in the original article.

The conclusions which may be drawn from a study of these tables will be best understood after an examination of the curves

[1] These tables are not here reproduced.

which have been constructed from them, and as a preliminary to this study it will be well to consider briefly the general character of curves representing values at various percentile grades.

A geometrical construction of a special case will perhaps best serve to place the matter in a clear light. Let us suppose one thousand grown men standing in line arranged according to height. The heads of these men will form a curved line represented in its general form by the curve ST in Fig. 4. In this diagram the line SO represents the height of the shortest and the line

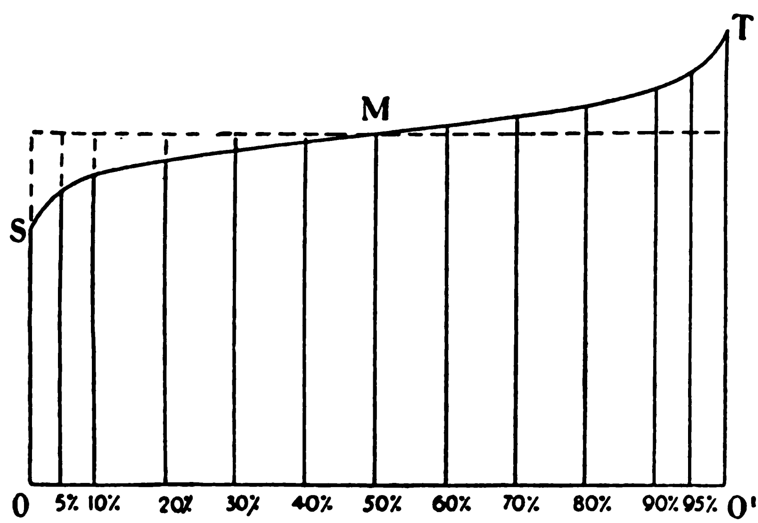


FIG. 4

TO' that of the tallest man. The curve ST, representing the heights of the intermediate men, is approximately a straight line in a large part of its course but bends up sharply at the right and down sharply at the left owing to the presence of a few very tall and a few very short men. Mediocrity is the rule and extremes the exception in height as in everything else.

If now we divide this row of men into two equal parts and ascertain the height of the five hundredth man in the row (or, more accurately speaking, the height half way between that of the five hundredth and that of the five hundred and first man) we shall have a value below which one half and above which the other half of the observations lie. This value is termed by Galton the value of the fifty percentile grade, or the median value, and is designated by the letter M. In the same way the values at other percentile grades may be determined by dividing the row at points corresponding to various percentages of the total number of observations. The percentile grades indicated in Fig. 4 are those adopted by Galton, and are practically sufficient to indicate the character of the curve. With a very large number of observations it would of course be possible to determine values below five per cent and above ninety-five per cent, but in anthropometrical investigations with existing data it does not seem wise to go beyond these limits.

It is evident that the value M will tend to approximate to the average value of all the observations and will be identical with it when the curve ST is symmetrically disposed on both sides of M, i. e., when the values at sixty, seventy, eighty, ninety and ninety-five per cent exceed M by the same amount, respectively, by which the values at forty, thirty, twenty, ten and five per cent fall short of it. If A represents the average value of all the observations, then the value of M — A will be a measure of the direction and extent of the asymmetry of the curve ST, for this value will be zero when the curve is symmetrical, positive when the values at the lower percentile grades fall short of M more than those at the higher grades exceed it, and negative when the reverse is the case.

Let us now apply this test to the data in our possession, confining our attention for the present to tables 1, 4, 7 and 10, which give the total number of observations irrespective of nationality. By subtracting the average from the median values in these four tables the table on the next page (No. 20) has been constructed.

An examination of this table or of the curves constructed from it, as given in Figures 5 and 6, shows that the asymmetry of the curves of percentile grades varies very much, at different ages, both in direction and amount. The variation in the value of M — A in the curves of height is much the same as that in the curves of weight for each sex considered by itself, but there is a great difference between the two sexes. This difference shows itself most distinctly between the ages of eleven and fifteen years. During this time a rise in the curves for the males coincides with a fall in those for the females, while before and after this period the curves, as a rule, rise and fall together. We must conclude, therefore, that the rate of annual increase both in height and weight is different at different percentile grades, or, in other words, that large children grow differently from small ones, and moreover, that between the ages of eleven and fifteen years there is a striking difference in

TABLE 20

VALUES OF M—A

Age at Last Birthday	Heights in Inches		Weights in Pounds	
	Boys	Girls	Boys	Girls
Five	+ 0.10	+ 0.14	− 0.13	− 0.03
Six	+ 0.12	+ 0.05	− 0.15	− 0.17
Seven	+ 0.09	+ 0.11	− 0.17	− 0.16
Eight	+ 0.08	+ 0.07	− 0.35	− 0.59
Nine	+ 0.08	+ 0.17	− 0.28	− 0.45
Ten	+ 0.05	+ 0.12	− 0.12	− 0.95
Eleven	+ 0.07	− 0.01	− 0.44	− 1.22
Twelve	0.00	0.00	− 1.18	− 1.23
Thirteen	− 0.23	+ 0.24	− 1.94	− 0.63
Fourteen	− 0.28	+ 0.26	− 1.88	− 0.68
Fifteen	+ 0.07	+ 0.11	− 1.10	− 0.97
Sixteen	+ 0.35	+ 0.19	+ 0.37	− 0.76
Seventeen	+ 0.05	+ 0.26	− 0.92	− 2.77
Eighteen	+ 0.13	− 0.10	− 0.84	− 2.52

the mode of growth of the two sexes. The significance of this conclusion will be made clearer by an examination of the curves constructed directly from the tables of percentile grades. Curves of this sort are presented in Figures 7, 8, 9 and 10, containing the total number of observations irrespective of nationality. Similar curves have been obtained from the remaining tables in which the observations are grouped according to the nationality of the parents, but as they are less regular, owing to the smaller number of observations from which they are constructed, and lead to no additional conclusions, it has not been thought worth while to present them.

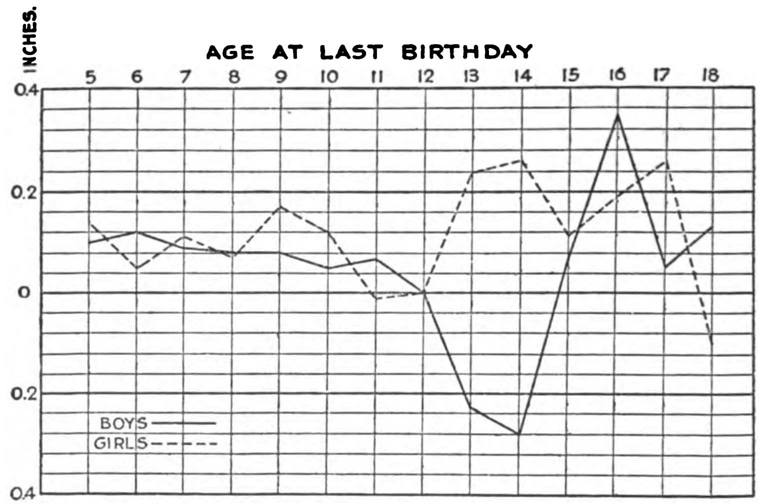


Fig. 5. Heights of Boston School Children
Median Minus Average Values (M-A)

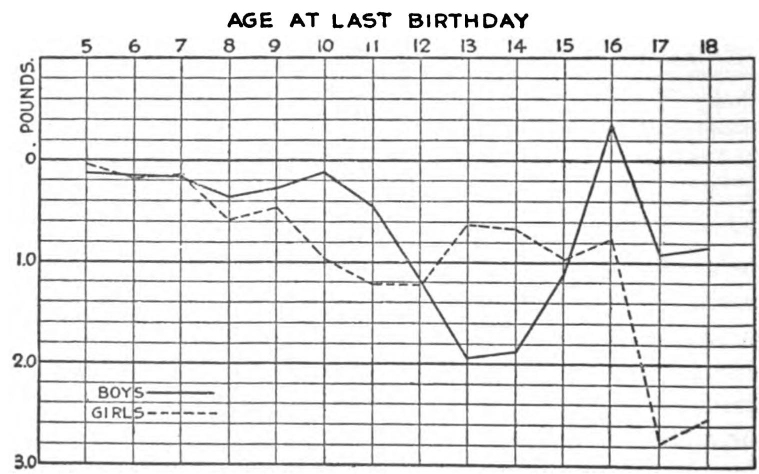


Fig. 6. Weights of Boston School Children
Median Minus Average Values (M-A)

A glance at the curves in Figures 7–10 shows at once the nature of the asymmetry, the existence of which is indicated by the curves in Figures 5 and 6. It will be observed that during the earlier years of school life the curves for the successive years are

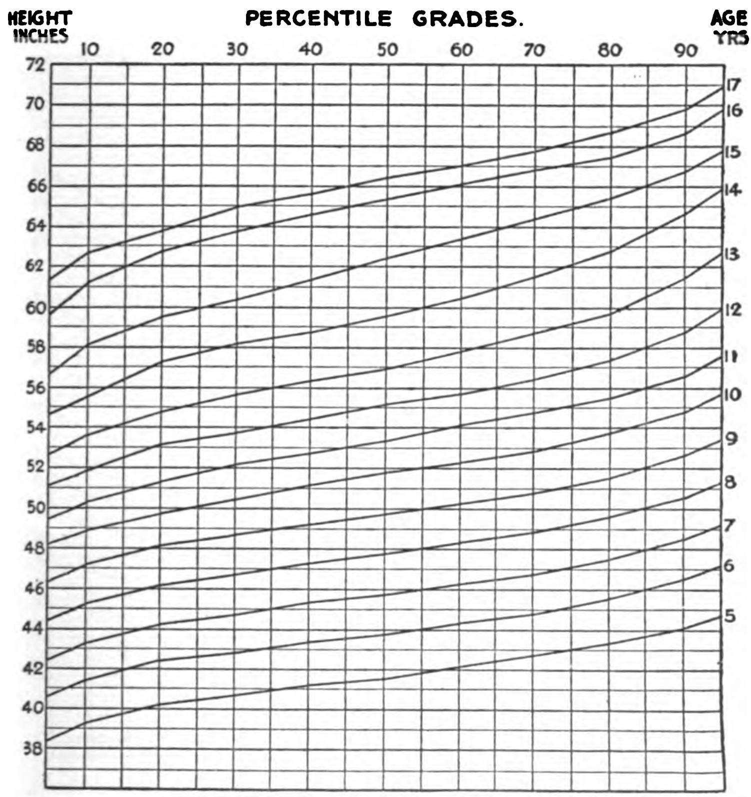


FIG. 7. HEIGHTS OF BOSTON SCHOOLBOYS
Irrespective of Nationality

fairly symmetrical, which is in harmony with the previous observation that in these years the value of M — A does not differ widely from zero. At about ten years of age in girls and eleven or twelve years in boys, the curves become distinctly asymmetrical, owing to the values increasing more rapidly at the higher than at the lower percentile grades. At the age of twelve or thirteen years in girls and fourteen or fifteen years in boys an asymmetry in the opposite direction shows itself, since at this period the values are increasing more rapidly at the lower than at the higher percentile grades. These changes correspond accur-

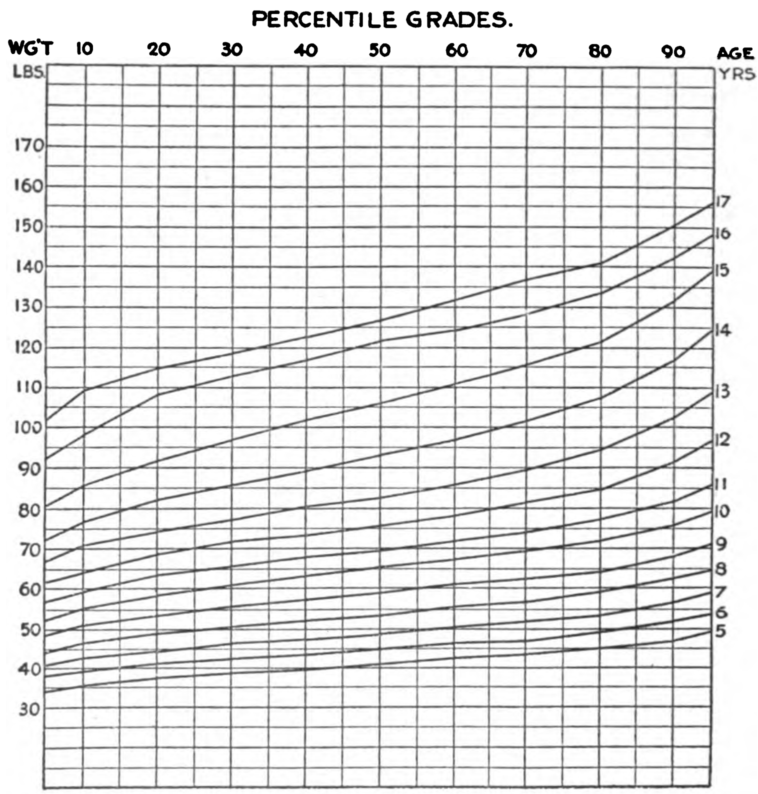


FIG. 8. WEIGHTS OF BOSTON SCHOOLBOYS
Irrespective of Nationality

ately with the fall and rise in the value of M — A, as shown in Figures 5 and 6.

In the original article on the growth of children it was shown that about two years before the age of puberty there is a period during which the growth in both height and weight shows a distinct acceleration. Now, the rate of growth at the various percentile grades is represented in Figures 7–10 by the vertical distances between the curves corresponding to the successive years; and an inspection of these curves shows that the prepubertal period of accelerated growth, already shown to exist by a comparison

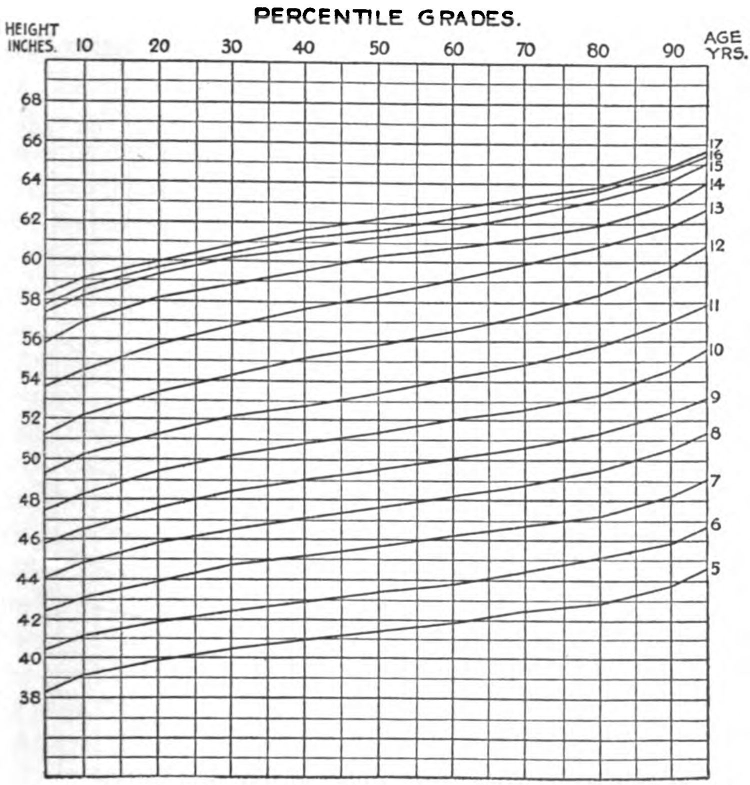


FIG. 9. HEIGHTS OF BOSTON SCHOOLGIRLS
Irrespective of Nationality

of average heights and weights at different ages, occurs all along the line, but that it occurs earlier at the higher than at the lower percentile grades. In other words, we find that the above-mentioned variations in the value of M — A are due to the fact that the period of acceleration, which is such a distinct phenomenon in the growth of children, occurs at an earlier age in large than in small children.

The following are the most obvious conclusions: —

1. The maximum yearly growth in both height and weight is at all percentile grades greater in boys than in girls, and occurs in boys two or three years later than in girls.

2. The age at which this maximum yearly growth in height and weight is reached is, in both sexes, earlier at the higher than

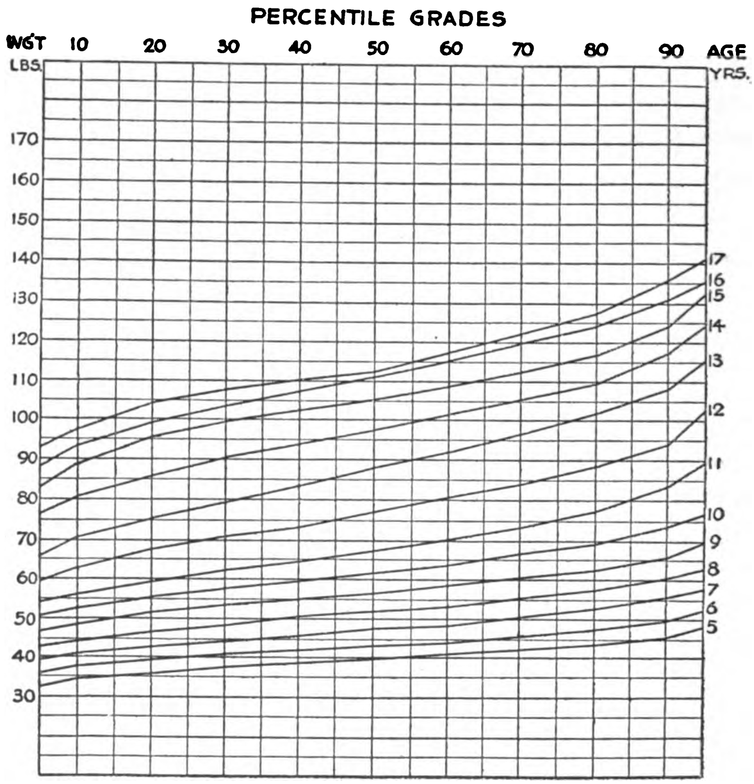


FIG. 10. WEIGHTS OF BOSTON SCHOOLGIRLS
Irrespective of Nationality

at the lower percentile grades, the range being from twelve to fourteen years for girls and from fourteen to sixteen years for boys. In other words, large children make their most rapid growth at an earlier age than small ones.

3. The curves representing the annual growth of boys are characterized on either side of the maximum by a steeper rise and

fall in the lower than in the higher percentile grades, though the maximum itself may be quite as high in the former as in the latter grades. This indicates that the above-mentioned period of accelerated growth in large boys differs from that in small boys rather in duration than in intensity. In girls a difference of this sort does not seem to exist.

4. In boys at eleven years of age there is a period of remarkably slow growth both in height and weight, the curves of annual increase in nearly all the percentile grades reaching at this age a lower point than for several years preceding or subsequent to this age. In girls a similar but less marked period of retarded growth in height is to be noticed at nine years of age, but the rate of growth in weight does not seem to suffer a corresponding diminution.[1]

Among the advantages of this method of discussing anthropometrical results may be mentioned the facility which it affords for comparing the rates of growth of children of different nationalities by determining the percentile rank of the average children of one nationality referred to those of another nationality as a standard. We may take, for instance, the observations of Pagliani[2] on Italian children, and those of Erismann[3] on the employees in Russian factories, and calculate the percentile rank of the children at successive ages when referred to Boston children as a standard. The result of this calculation is given in the table on the following page.

An examination of this table shows that Italian children of both sexes are, in early life, very much smaller than Boston children of

[1] It is interesting, however, to notice that in the curves constructed by Dr. Stevenson (see Lancet, Sept. 22, 1888) from English and American statistics, and representing the annual increase in weight of "boys and girls of the English-speaking races," the period of retarded growth is a marked phenomenon in both sexes, occurring in boys at eleven and in girls at nine years of age.

See also Axel Key, Die. Pubertätsentwickelung. (Verhandlungen des X internationalen medicinschen Congresses, Berlin, 1890. Bd. I, p. 67.) This observer finds that in Sweden the period of least increase in height and weight occurs at ten years for boys and nine years for girls.

[2] "Lo Sviluppo Umano," p. 37.

[3] "Untersuchungen über die körperliche Entwickelung der Fabrikarbeiter in Zentralrussland," Tübingen, 1889. A very thorough investigation based upon measurements of over 100,000 individuals.

the same age, and, though they afterwards increase in relative size, they never reach a higher percentile than 31.4 for boys and 32.4 for girls.

The Russian children show in general, with increasing age, a progressive diminution in percentile rank which is probably to be

TABLE 21

SHOWING THE PERCENTILE RANK OF ITALIAN AND RUSSIAN CHILDREN COMPARED WITH THOSE OF THE BOSTON PUBLIC SCHOOLS

Age at Last Birthday	Percentile Rank			
	Italian (Pagliani)		Russian (Erismann)	
	Boys	Girls	Boys	Girls
Five	below 5	below 5	....	....
Six	5.6	below 5	....	....
Seven	22.1	9.2	75.9	80.7
Eight	26.5	15.8	56.6	63.4
Nine	31.4	29.1	48.9	76.4
Ten	20.0	28.0	40.6	51.9
Eleven	16.4	25.5	42.5	48.8
Twelve	16.1	24.1	36.6	39.0
Thirteen	21.7	23.7	28.7	26.9
Fourteen	21.2	30.0	26.5	22.8
Fifteen	23.7	29.5	29.1	21.4
Sixteen	16.2	32.4	17.7	23.4
Seventeen	13.1	32.2	18.6	22.0
Eighteen	6.6	34.3	15.0	23.6

accounted for by the fact that during the earlier period of life only children who are unusually well developed physically are likely to find their way into manufactories. The children from seven to twelve years of age are therefore to some extent selected cases and do not represent the average development of the working population.

XIV

TYPHOID FEVER IN ITS RELATION TO WATER SUPPLIES

By Hiram F. Mills, A.M., C.E.

[At the time of publication the facts set forth in Mr. Mills' paper were novel. They are still of great interest. The correspondence between Mr. Mills and the city of Lawrence, which preceded the construction of the water filter, is given in the original paper, but not here reprinted. *Twenty-second Annual Report*, 1890, p. 525. — G. C. W.]

Typhoid fever is one of the diseases now generally attributed to one of the bacteria known as the typhoid bacillus.

Bacteria are very minute vegetable growths, and this species is a rod with rounded ends, the diameter being about one thirty-thousandth of an inch and the length about one ten-thousandth of an inch. When very highly magnified, fine hair like appendages (cilia) may be seen extending from near either end.

It may not be unreasonable to think of the invisible kingdom of bacteria as consisting of as many species as the visible vegetable kingdom and all of them doing as beneficent work, in the economy of nature, as the trees and plants which we see around us; but there is a small fraction, perhaps comparable with the small number of poisonous plants, which are disease producing. The number actually known to produce disease is very small, and among those regarded as most carefully determined is the typhoid bacillus.

It is not merely held that this germ is usually associated with typhoid fever, but that typhoid fever does not exist when this germ is not in the system; that it is the actual cause of the disease. It becomes important then to determine how it can get into the system, and under what conditions it can live outside of the human body.

These questions have been and are being studied with care, but there is much yet to be learned. That these germs may be taken into the body with the food and drink appears to be well established. There appears to be no good ground for believing that they live in the air and are carried from place to place by winds; but it is not unreasonable to conclude that they may live in air long enough to be carried with dust on clothing or upon the person, from one sick-room to another, or from the sick-room to the kitchen, or to be blown about a yard where slops from a sick-room have been thrown, or blown into the windows of a sleeping-room with the dust from a privy unfortunately near.

Cases following one another in the same house have been more readily explained by such communication than by the milk or drinking water obtained from the same source as that used by neighbors who were not afflicted.

Milk has been regarded as an excellent food for the typhoid bacillus. When sterilized by heat so that all other bacteria are killed, the typhoid bacilli added to it have been found to increase one thousand-fold in twenty-four hours. Recent experiments by the Board have shown an increase of seventy-fold in sterilized milk; but in milk received from a milk wagon on the street a certain number of the typhoid bacillus added did not increase but rather decreased; and when added to milk drawn directly from the cow, either in the usual way of milking or through a sterilized tube, there was no marked change in the number in eight hours, and little if any increase in twenty-four hours. Many cases of prevailing typhoid fever in cities have been limited to a single milk route and typhoid fever has been found to have been at the farm whence the milk was brought.

In some cases the communication appeared to be through water from a well polluted by soakings from a privy where dejecta from a typhoid patient had been deposited. But the method of communication has not been determined with certainty.

Drinking water has many times been proven to be the medium by which typhoid fever has been communicated. Many marked cases have been recorded in this country and in Europe, but the present object is not to repeat what is already known but to present the results of a study of the influence of the water supplies of the State of Massachusetts upon the prevalence of typhoid fever.

The highest death-rates by typhoid fever in the state are not in the cities, but are in the towns that depend for water upon wells. The five towns highest on the list, for the past eighteen years, have an average death-rate of 12.82 per year for each 10,000 inhabitants; while the five cities having the highest death-rate by typhoid fever, in the past twelve years, average 7.65 per 10,000, and the average for all of the cities of the state, in the same time, has been 4.62.

The town which had the highest death-rate from typhoid fever in the state was Ware. In the fifteen years previous to 1886 the average number of deaths by this disease in 10,000 inhabitants was 16.5. In 1886 this town introduced a supply of water and in the years since, although the water has not yet come to be generally used, the number of deaths has fallen to 6.9, or four-tenths as many as previously.

Improvement is not limited to those communities where the prevailing death-rate was high, as illustrated by the city of Newburyport, which used well water until 1881, when water was brought into the city from springs. In the nine years previous to the introduction of spring water the number of deaths yearly by typhoid fever per 10,000 inhabitants was 4.55. In the seven years since the introduction of pure water the number of deaths per 10,000 has been only 2.07, or less than half as many as previously.

The general decrease in deaths by typhoid fever, resulting from abandoning wells and introducing a public water supply, will be presented later.

Typhoid fever is properly regarded as a preventable disease, and in considering the following facts we must conclude that some of our communities have responsibilities that cannot be ignored in preventing yearly the death of many people scattered through all classes of society.

That this is to a great extent a preventable disease is shown by these general facts: Twenty-five years ago the average number of deaths by typhoid fever in 10,000 inhabitants in the places which are now cities in this state was 7.8; the number now dying yearly from this disease in the same places is 4.6 in 10,000 inhabitants. In fact, the actual number of deaths from this disease twenty-five years ago in these places, when their population was only six-tenths as much as at present, was as great as it is now; and if measures for its prevention had not been taken, and the death-rate had continued as it was twenty-five years ago, we should now have 1,000 deaths yearly, when the actual number in the cities is about 600.

With the usual number of 600 deaths in a year, in all of the cities of the state having a population of one million and one-third, we find that two of the cities having together less than one-tenth of the population have, in the twelve months ending April 1, 1891, had more than one-third as many deaths as all usually have in a year. The city of Lowell, with a population of 78,000, had, in the twelve months mentioned, 150 deaths from this disease, and the city of Lawrence, with 45,000 inhabitants, had 78 deaths. These two cities had 69 more deaths from this disease, in the twelve months, than the city of Boston with four times the population.

If these two cities had had only as many deaths as the average of the city population, the number would have been 36 in Lowell and 21 in Lawrence. There were in Lowell, in one year, 114 more deaths and in Lawrence 57 more deaths by this disease than in the usual average of the same number of inhabitants in the cities of the state.

Deaths in Boston, Lowell and Lawrence

General statements have been made of the relative numbers of deaths by typhoid fever in Boston, Lowell and Lawrence in the twelve months, including the epidemic in the two latter cities. Additional information may be obtained by considering the deaths in these cities from this disease month by month in the past two years.

The actual numbers of deaths from typhoid fever in each of these cities in each month of the past two years are given in the figures below, together with the population in 1890 and the number of deaths in 100,000 inhabitants.

Turning to the diagram of the death-rates in Lawrence, we find that in December, 1889, and January and February, 1890, following a month after the high death-rates of Lowell for that year, the death-rates of Lawrence from typhoid fever were higher than those of Lowell, and eight times as high as in Boston in the same

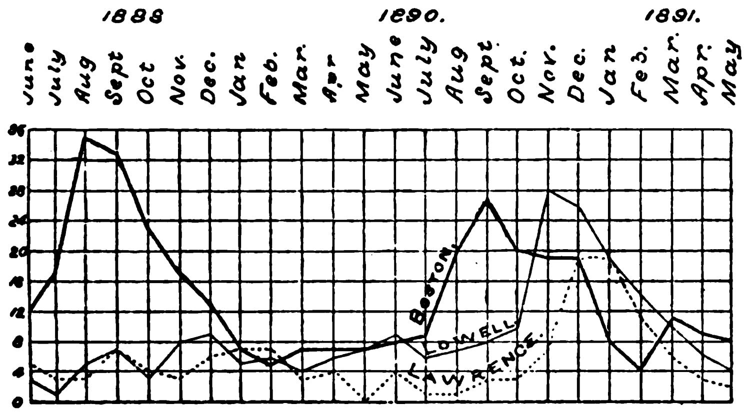


FIG. 11. ACTUAL NUMBER OF DEATHS FROM TYPHOID FEVER IN EACH MONTH IN BOSTON, LOWELL AND LAWRENCE

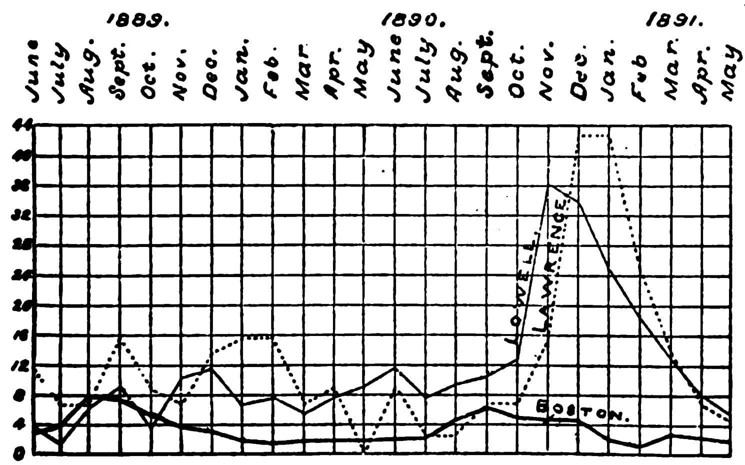


FIG. 12. NUMBER OF DEATHS FROM TYPHOID FEVER IN 100,000 INHABITANTS FOR EACH MONTH IN BOSTON, LOWELL AND LAWRENCE

months. During the next six months, through the spring and summer, the death-rate in Lawrence from typhoid fever averaged about twice that of Boston, and when Boston reached its maximum in the fall, Lawrence had about the same rates; but then followed the great increase in death-rates in Lawrence, being about four times that of Boston in November, ten times that in December, and (owing to the decreasing rates in Boston as usual at that season of the year) amounting to about twenty times that of Boston in January and February.

These high death-rates from typhoid fever in Lawrence occur at a time when there is very little of this disease in other cities except Lowell, and they follow this year, as in the previous year, about a month later than the high death-rates of Lowell.

These conditions all lead to the conclusion that the excess of typhoid fever continually prevailing in Lawrence follows from and is due to the existence of the disease in Lowell, and that the prevailing excess in Lowell is due to the existence of the disease in the towns up the river which discharge sewage into the river.

The question naturally arises, whether typhoid fever germs which grow in the human body at blood heat will survive in water at a temperature a little above freezing long enough to pass from Lowell sewers to the service-pipes of the city of Lawrence. The temperature of the river water in November, 1890, was from 45° to 35° F.; the distance from the sewers in Lowell to the intake of the Lawrence water works is nine miles, and the time for the water to pass from the sewers to the intake was at that time less than eight hours. Entering the reservoir the same day, the water would reach the outlet and enter the service-pipes within ten days, — most of it within a week. It would then be distributed over the city, in the portions near the reservoir, in about one week from leaving the sewers of Lowell, and in more remote parts of the city in about two weeks.

To prove whether typhoid fever germs would survive in the Merrimack River water, when at the low temperature of the month of November, long enough to pass from the Lowell sewers to the service-pipes in Lawrence, a series of experiments was made by the Board by inoculating water from the service-pipes with typhoid fever germs, and keeping the water in a bottle surrounded by ice, at as near freezing as practicable, for a month, and each day taking out one cubic centimeter and determining the number of typhoid germs. The number continually decreased, but some survived twenty-four days.

On the first day there were	6,120	germs
" " fifth day there were	3,100	"
" " tenth day there were	490	"
" " fifteenth day there were	100	"
" " twentieth day there were	17	"
" " twenty-fifth day there were	0	"

This experiment indicates that typhoid fever germs from the sewers of Lowell may live in winter to enter the Lawrence reservoir in large numbers; that the numbers will decrease in the reservoir; but still a considerable fraction will live to enter the service-pipes, and that this fraction will decrease as the water proceeds in the pipes across the city.

This latter reduction is the probable explanation of the fact brought out by plotting the cases for three months in the fall of 1890, at their several locations upon a map of the city, that much the larger number of cases were in portions of the city near the reservoir; but that some germs survived the passage through the pipes was proven by their being found in water drawn from the service-pipes in December, 1890, at the Experiment Station, which is across the city from the reservoir, distant about two and a half miles.

We have found this relation existing between typhoid fever and water supply, viz.: that in general, in the cities of the state, the death-rate by typhoid fever has been greatly reduced by the introduction of a pure public water supply; that in the one city where there has not been such a reduction, a portion of the people use, for drinking, water from canals or from wells subjected to serious pollution by sewage; and that the deaths from this disease are much more frequent among that portion of the community than among others.

The only two remaining cities which have not decreased death-rates by typhoid fever after the introduction of public water supplies receive their supplies from a river polluted by sewage; and the seasons in which this disease prevails in these cities are later than those of other cities, and in the lower city on the river later than in the upper city, at a season when other cities are nearly free from the disease and at the time when it would follow if produced by the sewage from the upper city; further, that when the water of the river which passed the upper city and received its sewage during the greatest prevalence of the disease there had reached the service-pipes of the lower city, and there was the greatest prevalence of the disease in the lower city, typhoid fever germs were found in water from these service-pipes.

XV

A CLASSIFICATION OF THE DRINKING-WATERS OF THE STATE

[This paper, published without signature, contained an account of the normal chlorine map of the state. The publication of this map marked an epoch in the history of water analysis. Part I, *Report on Water Supply and Sewerage*, 1890, p. 677. —G. C. W.]

FROM the standpoint of the public health, the natural classification of waters is into those which have at no time been contaminated by the waste products of human life, and those which have been thus contaminated. Waters of the first class we have called normal; in the latter class, we attempt to express the amount of polluting matter of the nature of sewage which the water has received, by giving its variation from the normal chlorine contents of the region.

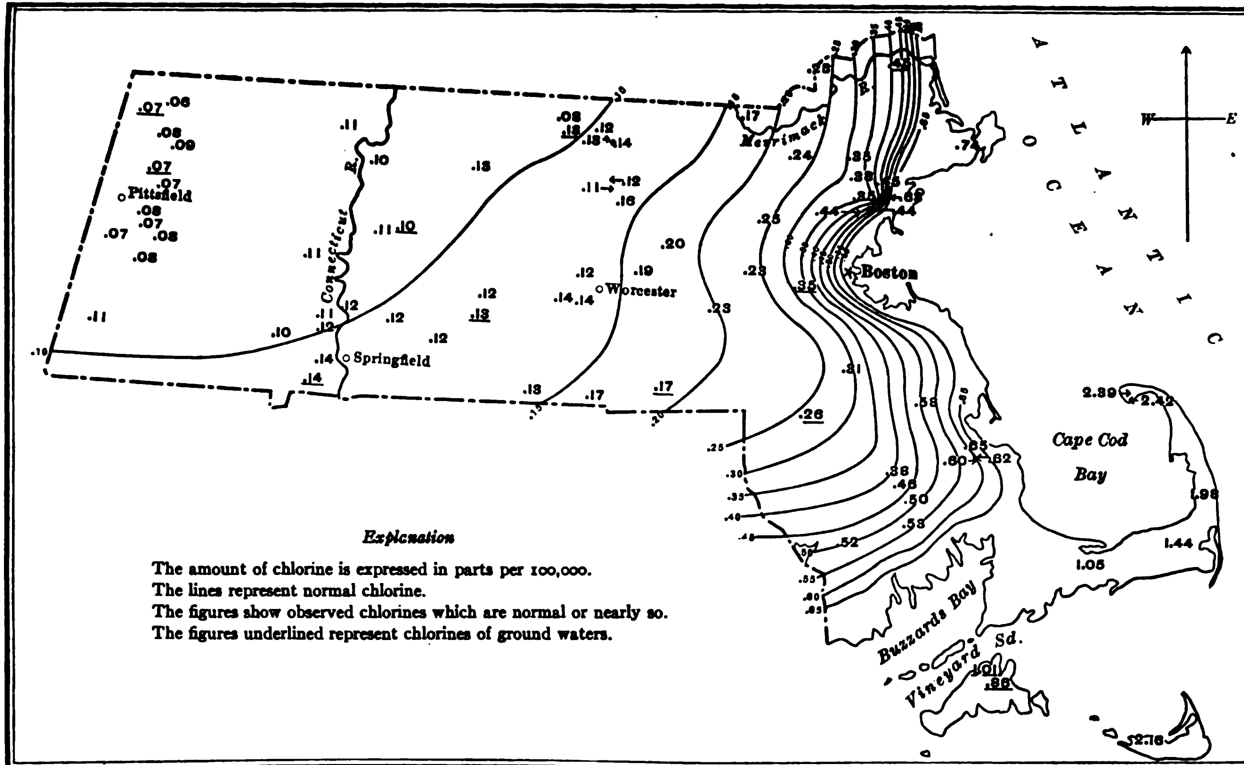
The subject has already been discussed in the chapter on the interpretation of analyses.[1] It was there shown that we have in the chlorine contents of the water the evidence that we need to determine whether or not a body of water has received house drainage, either directly, as when the sewage of a town flows into a stream, or indirectly, as when the drainage from houses or cesspools reaches the water courses after filtration through the ground.

In the accompanying map of normal chlorine of Massachusetts, the points of like normal chlorine have been connected by lines which we will call isochlors. It will be noticed that these isochlors, which represent a difference of 0.05 part of chlorine in 100,000 of water, are, in the eastern part of the state, close together, approximately parallel, and conform in a general way to the coast line. As we recede from the coast westward, the isochlors are wider apart and their parallelism is less marked.

[1] This refers to the Special Report.

In the tabulations of the waters of the state according to their chlorine contents, this map has been used as the basis; that is to say, when the average chlorine contents of a water agree with the isochlors on the map, the water is considered normal; when the amount of chlorine is in excess of the normal, the amount of this excess expresses the extent to which the water is believed to have been polluted. This use of the map of normal chlorine we find justified in most of the cases where we have an accurate knowledge of the drainage area; in other words, we find the excess of chlorine in the water to be in proportion to the population on the drainage area.

There are no data in this country sufficiently complete from which we can determine the amount of chlorine contributed to sewage by each inhabitant per day. Calculations based on the volume of sewage per inhabitant in London, and determinations of the amount of chlorine in the sewage and in the water supply, indicate that the amount of chlorine per person per day is 0.045 pound. The average daily flow of the Sudbury River per square mile of drainage area for the past eleven years is 8,500,000 pounds of water per day. Assuming the data derived from London sewage to be generally applicable, we find that it requires nineteen persons per square mile to increase the chlorine in the water flowing from a drainage area of the size of the Sudbury River 0.01 of a part per 100,000. Another way of arriving at the population required to produce this result is to divide the population per square mile of watersheds in Massachusetts by the corresponding excess of chlorine in the water. In this way we find, from an average of observations of fifteen streams and reservoirs, that it requires twenty-one persons per square mile to increase the chlorine 0.01. Observations of nine other streams, where a portion of the chlorine is probably due to manufacturing wastes, give but thirteen inhabitants per 0.01 increase of chlorine. There are a few streams where the amount of chlorine furnished by manufacturing is still greater, so that each 0.01 of chlorine corresponds to a still smaller population, the minimum number found being 2.8 persons per square mile.



State of Massachusetts showing Normal Chlorine

All the foregoing results are based upon averages for a year or more. In the summer, when the flow is small, the population corresponding to 0.01 excess of chlorine is much smaller, the average of several observations upon streams being seven persons per square mile.

The average results obtained from analyses of ponds should be somewhat larger than those of streams; but the individual results vary so much that it is unnecessary to consider a refinement of this kind. We may say, in a general way, that four families or twenty persons per square mile will add, on an average, 0.01 of a part per 100,000 of chlorine to the water flowing from this area, and that a much smaller population will have the same effect during seasons of low flow.

While we feel confident in the general correctness of the application of the map for the determination of the degree to which the waters have been polluted, it is important that the limitations of its use be clearly understood. Some of these limitations are: —

1. Those waters have been called normal, and have been used in establishing the isochlors, which drain areas believed to be nearly or quite free from population. Until a careful survey of the state be made, with the express object in view of determining the relation of population to the surface and ground waters, we cannot be sure in all cases that we actually have normal water. The normals as now given represent the present state of our knowledge of this relation.

2. Since the source of the chlorine in the normal waters of the state is mainly the salt of the sea water, it is obvious that the direction and force of the wind and the amount and distribution of the rainfall are the important factors governing the amount of chlorine in these waters. The chlorine contents of the waters through which the isochlors are drawn represent, in most cases, the average of monthly determinations from June, 1887, to May, 1889. It may be that another period of like duration, with different meteorological conditions, would give isochlors which would vary in position somewhat from those on the map.

3. It has been already clearly pointed out that the single determinations of the chlorine from which the normal averages are made vary greatly, often fifty or one hundred per cent, and in some cases even more. It is clear, therefore, that a single determination of chlorine may be misleading, when compared with the average normal chlorine.

4. In the eastern part of the state, where the isochlors are near together, it is evident that slight variations from the normal have less significance than in the western part of the state, where the same normal covers a larger area.

5. In any case too much importance must not be attached to slight variations from the normal, as shown on the map, say to the extent of 0.05 part in 100,000. The necessities involved in drawing the isochlors with our present knowledge will often cause a variation, plus or minus, of this amount, in waters believed to be normal. This is particularly the case near the sea, where a general parallelism with the coast has been observed in drawing the isochlors. These irregularities will, it is believed, largely disappear when further surveys and analyses give us more complete knowledge of the waters of the state. Our examinations have hitherto been mainly confined to public water supplies, and the waters of some of the larger rivers. To make the map of normal chlorine complete and accurate, the smaller streams in uninhabited regions should be examined regularly for some years.

In a few cases which will call for detailed mention hereafter, we have a considerable excess of chlorine above the normal, which we are unable to account for by the population on the drainage area. These cases are to be made the subject of future examination. It may be discovered that certain waters contain chlorine of other origin than sewage, or from the sea; as, for instance, from salt contained in certain geological formations, or from factories in which salt or other chlorides are largely used.

6. It must be kept in mind that the excess of chlorine in a water above the normal does not necessarily imply present pollution. The organic matter and ammonia which sewage has brought into a water may have long since disappeared by oxidation or absorp-

tion by plants, but the salt, which is not subject to change, remains. It is thus possible to have a pure water, organically speaking, which shows by its chlorine contents that it was once badly polluted by sewage. This is particularly true of ground waters, since the oxidizing power of porous earth on organic matter is very great.

XVI

THE EFFECT OF STORAGE UPON THE TASTE AND ODOR OF SURFACE WATERS

By FREDERIC P. STEARNS and DR. THOMAS M. DROWN

[Although the study of algae in Massachusetts waters dated back to Dr. Farlow and Professor Nichols, it was this analytical study based upon the carefully collected data which put the subject on its present basis. It shows the advantage of quantitative study as opposed to mere qualitative investigations. Part I, ***Report on Water Supply and Sewerage***, 1890, p. 740. — G. C. W.]

THIS title is not intended to refer to the usual taste and odor of waters, but rather to those which at times make water very disagreeable. These troubles have in nearly all cases been traced to the growth of organisms in the water.

The existence of these troubles can best be determined from the practical experience of those using the water; but they are also indicated by the odors and the amount of suspended organic nitrogen as determined by the chemist, and by the abundance of microscopic growth as determined by the biologist.

Although streams are sometimes subject to certain disadvantages as sources of water supply, such as the pollution due to domestic and manufacturing wastes, the turbidity occasioned by rains, or the peaty character of the water caused by drainage from swamps, it is well known that they are not affected by the peculiar bad tastes and odors to which stored waters are subject. Practically the same conclusion is reached in the report of the biologist, who finds much smaller numbers of organisms in streams than in ponds and reservoirs.

These facts are of limited practical value, because water supplies cannot, in most cases, be obtained from streams without storage; and it is therefore desirable to indicate under what conditions of storage and with what character of water, troubles are least likely to occur; that is to say, are they less likely to occur in natural ponds or in artificial storage reservoirs, in deep basins or in shallow ones, in unpolluted or in polluted waters, in waters of high or of low color, or in those which are stored a long or a short time ? In view of the necessarily imperfect record of the occurrence of bad tastes and odors, and the many causes which affect the results, it would be desirable to have observations at a much larger number of places than this state can furnish; but the observations which have been made throw considerable light upon the subject.

It has already been mentioned that streams are not subject to these bad tastes and odors. The same is true of nearly all of the small reservoirs which contain but a few days' supply. These are frequently built upon mountain streams, and their most important office is to act as settling basins to catch the gravel, sand and débris brought down by the stream. The effect of reservoirs of this kind is wholly beneficial. In a great majority of cases, however, it is necessary to provide storage equal to the amount of water consumed in a month or more, and only such reservoirs as contain this amount of storage will be further considered.

Observations have been made on seventy-one ponds and reservoirs of this class, nearly all of which are sources of water supply. Of these, forty-five, or sixty-three per cent, have at some time given trouble from bad tastes and odors; but in three instances the troubles have occurred in reservoirs which have only recently been filled, and may not recur when the reservoirs are older. In sixteen other cases the trouble has not been serious, or has occurred only at long intervals, leaving twenty-six, or thirty-seven per cent, of the ponds and older reservoirs which have given much trouble. In making a distinction between supplies which have given much and little trouble, those in which the aggregate duration of the bad tastes and odors has not exceeded one month in five years are included in the latter class.

In making a further classification it has been assumed that all natural ponds should be classed as ponds, even though they were made artificial in part by being raised; while all artificial reservoirs are classed as reservoirs, even though they may have existed as mill ponds for a very long time. Ponds and reservoirs are assumed to be polluted when the population upon the drainage area is more than three hundred to the square mile, and the waste products from this population enter the pond or reservoir either directly or by filtration through the ground. In the latter case the sewage may be wholly purified by filtration, yet the effluent will contain nitrates which will promote the growth of organisms, and may thereby cause bad tastes and odors. Where the average depth is less than nine feet, the pond or reservoir is called shallow; and in two instances where there is a great deal of very shallow flowage, ponds having an average depth of ten feet are classed as shallow. Water having a color of 0.30 or more is assumed to have a high color.

Using the above arbitrary divisions, a classification of the ponds and reservoirs, with reference to the occurrence or non-occurrence of troubles, has been made. The three new reservoirs above referred to have been omitted; also Farm Pond and Chestnut Hill Reservoir (both of which have once been seriously affected), for the reason that the former receives most of its water from the storage reservoirs on Sudbury River, and the latter was affected when it received water from Lake Cochituate only. The results are presented in the table on the next page.

The table shows that, out of a total of thirty-eight ponds, eight, or twenty-one per cent, have given much trouble from bad tastes and odors; while of the twenty-eight reservoirs, sixteen, or fifty-seven per cent, are similarly affected.

In comparing the polluted and unpolluted ponds, the effect of pollution is very obvious. All of the polluted ponds are deep; but, notwithstanding this advantage, all are affected to some extent, and half of them give much trouble. Of the twenty-five deep unpolluted ponds, only one has given much trouble, six have given a little trouble, and eighteen no trouble whatever. This indicates that there is little danger of having serious trouble from bad tastes and odors, if a water supply can be taken from a deep pond which is unpolluted. The shallow unpolluted ponds appear to be subject to bad tastes and odors, as three out of a total of five give much trouble, and one a little trouble.

Only two of the reservoirs are polluted, but these give the same indication as the eight polluted ponds, one giving much trouble and the other a little. Of the twenty-six unpolluted reservoirs, one-half are shallow. Of these, eleven give much trouble and two give none. In nearly all of these cases in which trouble has occurred, the reservoirs have been constructed on new sites, and the soil and vegetable matter have not been removed from their bottoms and sides. In one of the cases where there is no trouble

TABLE 22

A CLASSIFICATION OF PONDS AND RESERVOIRS WITH REFERENCE TO TROUBLES FROM BAD TASTES AND ODORS

Condition	Ponds			Reservoirs		
	Much Trouble	Little Trouble	No Trouble	Much Trouble	Little Trouble	No Trouble
POLLUTED						
Shallow and high color	..	..	..	1	..	..
Shallow and low color	..	..	..	..	..	..
Deep and high color	1	..	..	..	1	..
Deep and low color	3	4	..	..	..	..
Total polluted	4	4	..	1	1	..
UNPOLLUTED						
Shallow and high color	..	..	1	10	..	..
Shallow and low color	3	1	..	1	..	2
Deep and high color	..	2	2	1	2	4
Deep and low color	1	4	16	3	2	1
Total unpolluted	4	7	19	15	4	7
Total polluted and unpolluted	8	11	19	16	5	7

the reservoir was used to furnish power for a mill before being used as a source of domestic water supply. The conclusion to be drawn from this comparison is, that a shallow reservoir large enough to hold a supply for a month or more is quite sure to give trouble if the soil and vegetable matter are not removed from it before filling. The experience at the present time is too limited to enable us to predict what proportion of cleaned or old shallow reservoirs are likely to give trouble.

Of the thirteen deep, unpolluted reservoirs, four give much trouble, four a little, and five none. It is noticeable that, of the five which give no trouble, four have had the soil and vegetable matter removed from them, and one was previously a storage reservoir for mill purposes; while, of the eight which have given more or less trouble, none have been thoroughly cleaned, and only one was previously used for mill purposes; and even this has since been raised. Two of the older reservoirs, which are classed as giving little trouble, have not given any trouble in recent years.

Among the four deep reservoirs classed as giving much trouble is the Ludlow Reservoir, at Springfield, which has furnished bad water in summer for sixteen years. The other three reservoirs of this class have not given nearly as much trouble.

In several instances the reservoirs which have given trouble are flowed over swamps and meadows.

Selecting from the table the high and low colored waters, we find that there are twenty-four of the former and forty-two of the latter. Of those with a high color, seventy-five per cent have given trouble; while of those with a low color but fifty-two per cent are affected. This unfavorable showing for the high colored waters appears to be due to other considerations than the color; that is to say, the high colors predominate in shallow reservoirs, while the low colors are found under the more favorable conditions of deep ponds. A study of the table in detail indicates that the effect of color, if any, is very much less than that of pollution and the conditions of storage.

The foregoing classification has been based for the most part upon the information obtained from official reports and other outside sources, and it may be instructive to compare the chemical characteristics of these waters, adhering to the same classification. Such comparisons are presented in the following tables: —

Table 23

Analyses of Ponds and Reservoirs

Polluted Ponds[1]

[Parts per 100,000]

Condition	Location	Color	Ammonia			Nitrogen as		Total Nitrogen	Excess of Chlorine
			Free	Albuminoid		Nitrates	Nitrites		
				Total	Suspended				
Deep, and high color,— much trouble	Woburn, Horn Pond[2] ...	0.34	.0152	.0389	.0058	.0452	.0015	.1257	2.61
Deep, and low color,— much trouble	Boston, Jamaica Pond...	0.03	.0157	.0398	.0299	.0160	.0004	.1072	0.33
	Boston, Mystic Lake[2]...	0.23	.0235	.0264	.0052	.0496	.0015	.1161	1.55
	Natick, Dug Pond	0.15	.0050	.0218	.0039	.0238	.0004	.0658	0.44
	Average of four.......	0.19	.0148	.0317	.0112	.0336	.0009	.1037	1.23
Deep, and low color,— little trouble	Boston, Lake Cochituate.	0.25	.0026	.0207	.0039	.0148	.0003	.0529	.20
	Cambridge, Fresh Pond..	0.11	.0134	.0196	.0035	.0281	.0007	.0735	.94
	Haverhill, Lake Saltonstall	0.05	.0015	.0145	..	.0050	.0003	.0304	.30
	Marlboro, Lake Williams	0.06	.0006	.0196	.0043	.0053	.0001	.0400	.25
	Average.............	0.12	.0045	.0186	.0039	.0133	.0004	.0492	.42
	Average of 8 polluted ponds	0.15	.0097	.0252	.0081	.0235	.0007	.0764	.83

[1] The word polluted as used here has the definition given on page 145.
[2] A large part of the excess of chlorine is due to the drainage from tanneries.

Unpolluted Ponds

Condition	Location	Color	Free	Albuminoid Total	Albuminoid Suspended	Nitrates	Nitrites	Total Nitrogen	Excess of Chlorine
Shallow, and low color, — much trouble	Malden, Spot Pond	0.24	.0007	.0216	.0029	.0044	.0001	.0419	.06
	Nantucket, Wannacomet Pond................	0.07	.0002	.0163	..	.0034	.0002	.0307	.00
	Spencer, Shaw Pond.....	0.03	.0007	.0136	..	.0059	..	.0289	.01
	Average.............	0.11	.0005	.0172	.0029	.0046	.0001	.0338	.02
Shallow, and low color, — little trouble	Haverhill, Lake Pentucket	0.02	.0007	.0164	..	.0040	..	.0317	.09
Shallow, and high color, — no trouble	Randolph, Great Pond...	0.76	.0008	.0253	.0026	.0043	.0001	.0479	.10
Deep, and low color,— much trouble	Holyoke, Ashley and Wright ponds.........	0.06	.0023	.0184	.0043	.0043	.0001	.0385	.02

Table 24

Analyses of Ponds and Reservoirs — *Continued*

Unpolluted Ponds — Concluded

[Parts per 100,000]

Condition	Location	Color	Ammonia			Nitrogen as		Total Nitrogen	Excess of Chlorine
			Free	Albuminoid		Nitrates	Nitrites		
				Total	Suspended				
Deep, and high color, — little trouble	Danvers, Middleton Pond	0.62	.0008	.0207	.0035	.0049	.0001	.0413	.01
	Westboro, Chauncy Pond	0.56	.0005	.0320	.0103	.0025	.0001	.0600	.10
	Average	0.59	.0006	.0263	.0069	.0037	.0001	.0506	.05
Deep, and low color, — little trouble	Concord, Sandy Pond	0.03	.0001	.0129	..	.0041	.0001	.0256	.00
	Hingham, Accord Pond	0.23	.0003	.0144	.0017	.0043	.0001	.0292	.05
	Plymouth, Great and Little South ponds	0.00	.0003	.0130	..	.0013	.0000	.0230	.00
	Wakefield, Crystal Lake	0.14	.0008	.0165	.0017	.0079	.0001	.0365	.14
	Average	0.10	.0004	.0142	.0017	.0044	.0001	.0286	.05
Deep, and high color, — no trouble	Lakeville, Assawompsett Pond	0.38	.0003	.0209	..	.0023	..	.0371	.00
	Weymouth, Great Pond	0.91	.0010	.0224	..	.0037	..	.0415	.07
	Average	0.64	.0006	.0216	..	.0030	..	.0393	.03
Deep, and low color, — no trouble	Abington, Big Sandy Pond	0.15	.0008	.0160	..	.0063	.0001	.0335	.05
	Fall River, Watuppa Lake	0.19	.0005	.0162	.0020	.0055	.0001	.0335	.02
	Gardner, Crystal Lake	0.02	.0013	.0111	..	.0050	.0001	.0245	.11
	Haverhill, Crystal Lake	0.13	.0009	.0166	..	.0030	..	.0310	.00
	Haverhill, Kenoza Lake	0.02	.0006	.0142	.0014	.0045	.0001	.0291	.04
	Hudson, Gates Pond	0.05	.0014	.0155	.0029	.0056	.0001	.0337	.02
	Lake Village, Lake Winnipiseogee	0.01	.0002	.0092	.0014	.0038	.0000	.0198	.02
	Montague, Lake Pleasant	0.01	.0021	.0081	.0013	.0064	.0000	.0220	.02
	New Bedford, Little Quittacas Pond	0.19	.0003	.0160	..	.0035	.0000	.0302	.02
	Norwood, Buckmaster Pond	0.13	.0055	.0220	.0026	.0061	.0002	.0482	.04
	Peabody, Spring Pond	0.00	.0001	.0111	..	.0000	..	.0184	.00
	Peabody, Brown's Pond	0.17	.0001	.0169	..	.0013	..	.0293	.00
	Plymouth, Lout Pond	0.27	.0002	.0156	..	.0029	..	.0288	.00
	Salem, Wenham Lake	0.05	.0018	.0143	.0028	.0047	.0001	.0311	.09
	Sherborn, Waushakum Pond	0.23	.0009	.0195	..	.0060	.0001	.0390	.06
	Webster, Lake Chaubunagungamaug	0.06	.0002	.0129	..	.0043	.0000	.0258	.01
	Average	0.10	.0011	.0147	.0021	.0043	.0001	.0299	.03
	Average of 30 unpolluted ponds	0.19	.0009	.0167	.0030	.0042	.0001	.0331	.04

TABLE 25

ANALYSES OF PONDS AND RESERVOIRS — *Continued*

Polluted Reservoirs

[Parts per 100,000]

Condition	Location	Color	Ammonia			Nitrogen as		Total Nitrogen	Excess of Chlorine
			Free	Albuminoid		Nitrates	Nitrites		
				Total	Suspended				
Shallow, and high color, — much trouble	Arlington, Storage Reservoir	0.73	.0024	.0475	.0165	.0246	.0002	.1118	.36
Deep, and high color, — little trouble	Boston, Reservoir 3 [1]	0.87	.0049	.0285	.0044	.0218	.0003	.0750	.19
	Average of 2 polluted reservoirs	0.80	.0036	.0380	.0104	.0232	.0002	.0934	.27

[1] Has not given trouble during the time covered by these examinations.

Unpolluted Reservoirs

Condition	Location	Color	Free	Albuminoid Total	Albuminoid Suspended	Nitrates	Nitrites	Total Nitrogen	Excess of Chlorine
Shallow, and high color, — much trouble	Athol, Phillipston Reservoir	0.93	.0020	.0221	..	.0107	.0000	.0488	.03
	Brockton, Salisbury Brook Reservoir	0.75	.0028	.0411	.0163	.0058	.0001	.0827	.01
	Easthampton, Williston Pond	0.27	.0021	.0170	.0034	.0140	.0003	.0454	.13
	Hingham, Fulling Mill Pond	0.36	.0028	.0282	.0131	.0068	.0002	.0612	.10
	Leominster, Haynes Reservoir	0.39	.0023	.0409	.0133	.0067	.0001	.0816	..
	New Bedford, Acushnet Reservoir [1]	1.36	.0015	.0248	.0018	.0150	.0001	.0579	.00
	Northborough, Storage Reservoir	0.85	.0013	.0230	..	.0081	.0001	.0472	.02
	Wayland, Storage Reservoir	0.83	.0020	.0298	.0040	.0108	.0001	.0633	..
	Westborough, Sandra Pond [2]	0.45	.0026	.0244	..	.0079	.0001	.0504	.04
	West Springfield, Storage Reservoir	0.31	.0009	.0133	..	.0057	.0001	.0284	.03
	Average	0.65	.0020	.0265	.0086	.0091	.0001	.0567	.04
Shallow, and low color, — much trouble	Chicopee, Dingle Brook Reservoir	0.20	.0010	.0135	.0054	.0138	.0002	.0393	.06

[1] Has not given any trouble during the time covered by these examinations.
[2] Upper Pond, from which no water is now taken directly.

Table 26

Analyses of Ponds and Reservoirs — *Concluded*

Unpolluted Reservoirs — Concluded

[Parts per 100,000]

Condition	Location	Color	Ammonia: Free	Ammonia: Albuminoid: Total	Ammonia: Albuminoid: Suspended	Nitrogen as: Nitrates	Nitrogen as: Nitrites	Total Nitrogen	Excess of Chlorine
Shallow, and low color, — no trouble	Leominster, Morse Reservoir	0.24	.0006	.0093	..	.0032	.0000	.0190	..
	Southbridge, Storage Reservoir	0.25	.0014	.0181	.0045	.0045	.0001	.0374	.00
	Average	0.24	.0010	.0137	.0045	.0038	.0000	.0282	.00
Deep, and high color,— much trouble	Lynn, Birch Pond	0.36	.0019	.0272	.0072	.0065	.0001	.0560	.00
Deep, and low color,— much trouble	Fitchburg, Overlook Reservoir	0.10	.0012	.0151	.0034	.0041	.0001	.0315	.02
	Springfield, Ludlow Reservoir	0.15	.0019	.0381	.0154	.0039	.0002	.0748	.01
	Winchester, Storage Reservoir	0.14	.0033	.0241	.0058	.0104	.0003	.0555	.13
	Average	0.13	.0021	.0258	.0082	.0061	.0002	.0539	.05
Deep, and high color, — little trouble	Gloucester, Dyke's Brook Reservoir	0.52	.0069	.0229	.0037	.0044	.0002	.0496	..
	Lynn, Breed's Pond	0.48	.0018	.0214	.0049	.0042	.0001	.0431	.00
	Average	0.50	.0043	.0221	.0043	.0043	.0001	.0463	.00
Deep, and low color, — little trouble	Greenfield, Glen Brook Reservoir [1]	0.03	.0010	.0046	..	.0090	.0001	.0175	.03
	Worcester, Leicester Reservoir [2]	0.25	.0040	.0162	.0021	.0062	.0001	.0372	.01
	Average	0.14	.0025	.0104	.0021	.0076	.0001	.0273	.02
Deep, and high color, — no trouble	Boston, Reservoir 4	0.73	.0006	.0260	.0042	.0056	.0001	.0509	.03
	Boston, Reservoir 2	1.01	.0008	.0296	.0053	.0089	.0002	.0608	.10
	Cambridge, Stony Brook Reservoir	0.73	.0033	.0286	.0048	.0151	.0002	.0672	.09
	Westfield, Storage Reservoir	0.54	.0003	.0147	..	.0044	.0001	.0290	.00
	Average	0.75	.0012	.0247	.0048	.0085	.0001	.0520	.05
Deep, and low color, — no trouble	Worcester, Holden Reservoir	0.19	.0009	.0155	.0042	.0038	.0001	.0319	..
	Average of 26 unpolluted reservoirs	0.48	.0020	.0227	.0065	.0077	.0001	.0488	.03

[1] The trouble in this reservoir has been attributed to mud and leaves washed in by the mountain stream which feeds it.

[2] Has not given trouble during the time covered by these examinations.

In making comparisons between the different waters given in these tables, it should be borne in mind that the amount of pollution is best indicated by the excess of chlorine.

A comparison of the analyses of the first four polluted ponds which give much trouble, with the next four which give little, shows that the quantity of each of the constituents in the former is in every case larger than in the latter. As this is mainly the effect of pollution, it emphasizes the conclusion before reached, that pollution is one of the prominent factors in producing bad tastes and odors.

It will also be seen upon examination that the suspended albuminoid ammonia, which represents approximately the quantity of algae and other organisms in the water, is most frequently found in waters which are subject to bad tastes and odors. This is shown in a general way by the following condensed table: —

TABLE 27

	Suspended Albuminoid Ammonia		
	Much Trouble	Little Trouble	No Trouble
Polluted ponds	.0112	.0039	...
Polluted reservoirs	.0165	.0044	...
Unpolluted ponds	.0036	.0043	.0021
Unpolluted reservoirs	.0081	.0036	.0046

Having shown the conditions under which bad tastes and odors are most prevalent, it may be asked why this is so. The answer to this question must necessarily be a complicated one, and must, with our present knowledge, involve much uncertainty; but the indications point to the supply of nitrogenous food for animal and vegetable organisms as being one of the most important factors.

The principal sources from which the nitrogenous compounds in water are obtained are the rainfall, swamps and other deposits of decaying vegetable matter, manured fields, and domestic and manufacturing sewage. The nitrogen derived from the rainfall is insufficient in quantity to support any very large growth of organisms. It is, therefore, mainly from other sources that the nitrogen must come to produce the abnormal growths which cause serious trouble. In the case of polluted ponds the supply comes mainly from sewage, and from animal manures which are produced or used in populous districts. It may be well to state here, even at the risk of repetition, that, even if sewage is turned into a cesspool and filters a very long distance before reaching a pond, and in its passage through the ground has all of the organic matter in it destroyed, it will still contain in an inorganic form a large part of the nitrogen, and may have nearly the same effect in promoting growths of organisms in a pond as if the sewage was turned into it directly. The source from which uncleaned reservoirs may obtain a large part of their nitrogen is the vegetable matter at the bottom. A good instance of this is furnished at the Ludlow Reservoir, Springfield. The amount of nitrogen in the reservoir water in summer, when the growth of algae is at its height, is three times as great as in the winter; and, since the amount contained in the water entering the reservoir through its feeders is not large, the only source from which it seems possible to obtain this additional nitrogen is the reservoir bottom. With regard to the depth and size, and absence of very shallow flowage, this reservoir ranks high among those in the state.

As a further indication that depth is less important than the food supply, the case of Pilling's Pond in Lynnfield may be cited. This is a very old storage reservoir, made for mill purposes by flowing a large level meadow to a depth of four feet. The average depth of the pond, including the shallow portions near the edges, is about three feet. At the time of the examination it was kept constantly full. The area of the pond is in the neighborhood of eighty-five acres. Examinations made during the summer of 1889 showed that, notwithstanding the small depth and the consequent high temperature of the water which at times reached 80° F., the water did not contain any abnormal growth of organisms, or become offensive. This comparatively favorable result appears to be due to the fact that the reservoir is so old that the available food has been removed from the mud at the bottom.

To avoid giving the impression that bad tastes and odors are caused only by an abundance of nitrogenous organisms, it is well to cite the case of Naukeag Pond in Ashburnham, which had a very disagreeable odor when it was examined in the spring of 1888 and again in 1889. This pond is deep and unpolluted, and did not contain an unusual amount either of organisms or of nitrogen. Cases of this kind are, however, exceptions to the general rule.

The most important conclusions to be reached from this study of bad tastes and odors are, that from this standpoint a water supply should not be chosen which receives much sewage, either directly or after purification; and that, if water is to be stored in a new artificial storage reservoir, it should have the vegetable matter removed from its bottom and sides.

XVII

THE POLLUTION OF STREAMS

By Frederic P. Stearns

[This paper illustrates the best methods then in vogue for studying the pollution of streams by chemical analysis. The force of the paper lies in the quantitative study of dilution. Part I, *Report on Water Supply and Sewerage*, 1890, p. 785. — G. C. W.]

There are many instances in which sewage is discharged into a stream without producing a degree of pollution which is apparent to the senses, or which is seriously objectionable where the stream is not used for the purposes of domestic water supply. On the other hand, it frequently happens that a stream receives so much sewage that it becomes very foul and offensive to those living near it.

The dividing line between these two conditions must always remain somewhat indefinite, both on account of a difference of opinion as to what degree of pollution is permissible, and because of the great difference in the conditions at different places, such as, for instance, the character of the sewage; the fluctuations in the flow of the stream, occasioned by its use for mill purposes; the existence of mill ponds in which sewage deposits may accumulate; and the presence of population along the banks below the point where the sewage is discharged. At the present time the dividing line is rendered still more indefinite by a lack of information as to the effect of a given quantity of sewage upon a given quantity of water.

The investigation of the rivers in Massachusetts furnishes some information upon this subject, which will be presented in this section.

There are some instances in which the polluting matter from factories is more important in its visible effect upon a stream than domestic sewage; but in a great majority of cases, where the population is provided with sewers discharging into a stream, the domestic sewage is the controlling factor. In attempting to determine a permissible ratio between the amount of sewage and water, we are confronted by another trouble; namely, the variable amount of polluting matter contained in sewage from different communities; but, as this is due to the different amounts of water used in different places rather than to variations in the amount of polluting matter contributed per person, this difficulty will be avoided if we adopt as a basis for calculations the relation of the population to the quantity of water flowing in the stream. The volume flowing in streams is commonly expressed in cubic feet per second; but, in adopting this as a unit, it is necessary, in order to avoid too small quantities, to make the unit of population 1,000.

The quantity of water which will dilute the sewage of 1,000 persons sufficiently to render it unobjectionable for all purposes except drinking can be determined by two methods: first, by actual experience in the discharge of sewage into streams, where the population connected with the sewers and the volume of water flowing in the stream are known; and, second, by determining by chemical analysis the composition of the water of a stream which has been polluted by sewage to the greatest permissible extent, and then determining by calculation what relation of population to volume of water will produce the same composition.

The effect which the sewage of a given population may be expected to produce upon the composition of the water into which it is discharged will be understood best if the second method is first discussed. In order to make the calculations there referred to, it is necessary to know the actual amount of one or more constituents contributed to sewage per inhabitant, which can be determined best from analyses of sewage where the contributing population and the quantity of sewage are known, together with the corresponding analysis of the water supply which by the pollution became sewage. These data are accessible in the report of the Royal Commission on Metropolitan Sewage Discharge, 1884, which contains 181 analyses made by Mr. W. J. Dibden of samples collected so that they would fairly represent the average London sewage, and in the monthly reports of the water supply of the metropolis. Estimating from the population and the dry-weather flow of sewage at this time, the volume equalled thirty-seven United States gallons per person per day; but, in order to allow for a little rain water at the time when some of the samples were collected, the average volume is estimated at forty gallons per person per day, equal to 333 pounds.

The analysis of this sewage and the corresponding average analysis of the water supplied to London at the same time are as follows, the figures given representing parts per 100,000: —

TABLE 28

	Free Ammonia	Albuminoid Ammonia	Dissolved Solids	Chlorine
Sewage	4.5160	.5471	84.7	15.0
Water	.0000	.0078	27.5	1.62
Difference	4.5160	.5393	57.2	13.38

These differences represent the matter added to the water to make it sewage, and from them and the known weight of sewage per person (333 pounds) the absolute amount of each of these constituents contributed per person may be estimated with the following results: —

Free Ammonia	Albuminoid Ammonia	Dissolved Solids	Chlorine
.015 pounds	.0018 pounds	.191 pounds	.045 pounds

The volume of sewage with the corresponding population and analyses are not available in any other place where the sewage is of normal character, except London; but the relative amounts of the different constituents can be determined at other places, as, for instance, at Lawrence and Worcester, Mass. The average analyses of water and sewage at Lawrence are as follows, the figures representing parts per 100,000: —

TABLE 29

	Free Ammonia	Albuminoid Ammonia	Dissolved Solids	Chlorine
Sewage	1.8202	.5302	35.63	5.25
Water	.0014	.0107	3.83	0.21
Difference	1.8188	.5195	31.80	5.04

Analyses of Worcester sewage, made in 1872, and recent analyses of the water supply, are as follows: —

TABLE 30

	Free Ammonia	Albuminoid Ammonia	Dissolved Solids	Chlorine
Sewage	1.8760	.3160	25.35	4.17
Water	.0020	.0158	2.65	0.14
Difference	1.8740	.3002	22.70	4.03

If at each of these three places the amount of free ammonia is assumed as the unit, the ratio of the other constituents to it is as follows: —

TABLE 31

	Free Ammonia	Albuminoid Ammonia	Dissolved Solids	Chlorine
London	1	0.12	12.7	3.0
Lawrence	1	0.29	17.5	2.8
Worcester	1	0.16	12.1	2.2

If the amount of free ammonia contributed per person at each of these places is the same as at London, then, by calculation from these ratios, the amount of each of the other constituents would be: —

TABLE 32

	Pounds			
London	.015	.0018	.191	.045
Lawrence	.015	.0043	.262	.042
Worcester	.015	.0024	.181	.033

Making an average of the above by allowing the observations at London and Lawrence full weight, and those at Worcester half weight, the quantities given below are obtained, which may be adopted, for further calculations, as the standard amounts of each of these constituents contributed daily per inhabitant to change water into sewage: —

Free Ammonia	Albuminoid Ammonia	Dissolved Solids	Chlorine
.015 pounds	.003 pounds	.218 pounds	.042 pounds

Using these figures as a basis, we may determine the parts per 100,000 of each of these constituents added to water to make sewage of different degrees of dilution. In most cases the amount of each originally contained in the water is so small that it may be neglected, in which case the calculated quantity will represent the actual composition of the sewage.

TABLE 33

CALCULATED COMPOSITION OF SEWAGE OF DIFFERENT DEGREES OF DILUTION

[Parts per 100,000]

Volume of Water Per Capita (Gallons)	Ammonia		Dissolved Solids	Chlorine
	Free	Albuminoid		
40	4.50	.90	65.4	12.6
50	3.60	.72	52.3	10.1
60	3.00	.60	45.3	8.4
70	2.57	.52	37.4	7.2
80	2.25	.45	32.7	6.3
90	2.00	.40	29.1	5.6
100	1.80	.36	26.2	5.0
120	1.50	.30	21.8	4.2
150	1.20	.24	17.4	3.4

If the above table is continued so as to include much greater degrees of dilution, then we have presented the conditions which obtain when sewage is discharged into streams. In this case, however, as the dilution becomes greater and the effect of the polluting matters of the sewage less and less marked, it becomes more necessary to take into account the original composition of the water with which the sewage is mingled. In addition to this no allowance is made for the loss of free and albuminoid ammonia, which sometimes takes place when sewage is highly diluted, as will be shown subsequently.

TABLE 34

AMOUNTS OF AMMONIA, DISSOLVED SOLIDS AND CHLORINE ADDED TO STREAMS BY DOMESTIC SEWAGE FOR VARIOUS RATIOS OF POPULATION TO QUANTITY OF WATER FLOWING

[Parts per 100,000]

Volume of Water		Ammonia		Dissolved Solids	Chlorine
Cubic Feet Per Second Per 1,000 Persons	Gallons Per Capita Per Day	Free	Albuminoid		
0.5	323	.5580	.1114	8.10	1.56
1.0	646	.2790	.0557	4.05	.78
1.5	969	.1860	.0371	2.70	.52
2.0	1,292	.1395	.0278	2.02	.39
2.5	1,615	.1116	.0223	1.62	.31
3.0	1,938	.0930	.0186	1.35	.26
4.0	2,584	.0697	.0139	1.01	.19
5.0	3,230	.0558	.0111	0.81	.16
6.0	3,876	.0465	.0093	0.67	.13
7.0	4,522	.0399	.0080	0.58	.11
8.0	5,168	.0349	.0070	0.51	.10
9.0	5,814	.0310	.0062	0.45	.09
10.0	6,463	.0279	.0056	0.40	.08
15.0	9,694	.0186	.0037	0.27	.05
20.0	12,926	.0139	.0028	0.20	.04
30.0	19,389	.0093	.0019	0.13	.03
40.0	25,852	.0070	.0014	0.10	.02
50.0	32,315	.0056	.0011	0.08	.02
100.0	64,630	.0028	.0006	0.04	.01

In order to make practical use of this table in determining the greatest amount of domestic sewage which can be turned into a stream without making it offensive, it is necessary to compare the calculated analyses of the table with observed analyses of polluted streams. In making such comparisons, the free ammonia, which is the characteristic feature of sewage, and which is found only in extremely small quantities in unpolluted streams, is the best index.

The Blackstone River, a short distance below the point where it receives the sewage of Worcester, contained on an average during the two years ending June 1, 1889, 0.2160 parts per 100,000 of free ammonia. The stream at this place is very foul and offensive. At Uxbridge, sixteen miles further down stream, where the sewage is further diluted to a considerable extent by cleaner water from the tributaries, the average free ammonia was 0.1011. The water at this place is so much polluted as to affect its quality for manufacturing purposes, but it is not generally offensive to those living on the banks of the stream. At Millville, in the town of Blackstone, still further down stream, where the dilution is still greater, the average free ammonia is 0.0455, and the river is inoffensive. The odor of the water, however, when a sample is agitated in a bottle, as observed by the chemist, is generally musty and disagreeable, and on a few occasions offensive. The free ammonia at this place was at one time as high as 0.0896.

Stacy's Brook in Swampscott, during the time of its examination, received much sewage from the easterly portion of Lynn, and contained on an average 0.1858 parts per 100,000 of free ammonia. The stream has a foul appearance, and the samples generally had an offensive odor even during those portions of the year when, on account of the high flow, the free ammonia was considerably less than the average above given.

A single sample from Pegan Brook, Natick, collected in June, 1889, and having 0.1200 parts of free ammonia, was characterized by the chemist as having a distinctly musty odor when cold, and a strongly musty and disagreeable odor when hot.

Samples taken in September, 1888, from Coachlace Brook in Clinton, which is a very foul stream, had an average free ammonia of 0.1955, and an offensive odor. The pollution of this stream is partly by sewage and partly by wool-washing refuse. At the same time four samples were taken from the mouth of the south branch of the Nashua River, below Coachlace Brook, which had an average free ammonia of 0.0264. The odor of the samples was faint, and the river did not have a noticeable odor when the samples were collected. In one of the samples the free ammonia was 0.0444.

Two samples collected from the Charles River, below Milford, where it is a very small stream, one taken a week later than the other, in July, 1890, contained respectively 0.1570 and 0.1320 parts of free ammonia. The first had only a faint odor, and the second was decidedly offensive. This case is introduced, in part, for the purpose of showing that the amount of ammonia is by no means an unfailing index of the amount of odor from sewage. It is, however, the best index that we have where the pollution is occasioned by domestic sewage.

Several instances might be enumerated of streams which are polluted by sewage so that the water contains from 0.0100 to 0.0300 parts of free ammonia, without having offensive odors.

It will be seen that the foregoing data are insufficient for reaching a definite conclusion, and a further study of the subject is very much needed. In the meantime, however, it is necessary to solve practical problems, and it is therefore desirable to limit the debatable ground as far as may be justified by the observations. For this purpose two lines have been drawn across the table given above, to include those ratios of population to volume concerning which there may be doubt. These lines include volumes from 2.5 to 7.0 cubic feet per second per 1,000 persons, and free ammonia from 0.0399 to 0.1116.

With smaller volumes of water, the pollution is so great as to be inadmissible. With larger volumes, the pollution is so small as to be clearly admissible from the standpoint of the offensiveness of the water. From other standpoints, however, such as the use of water for certain manufacturing purposes, the amount of dilution should be greater; and in a stream used for domestic water supply it cannot be said, with our present knowledge, that any degree of dilution will make the water entirely safe for use.

All of the foregoing relates to the pollution of the water itself, as if the sewage emptied into a stream of unvarying volume, flowing with sufficient rapidity to prevent deposits. If, instead, the sewage is turned into a stream where it is ponded by a dam, or if there are ponds on the stream below the point of discharge, the solid particles of the sewage may accumulate and decompose, giving off offensive gases. This is more likely to occur if the deposits are covered with foul water in which the dissolved oxygen has been used up, because the decomposition will then be putrefactive rather than a process of oxidation. The fluctuations in the height of a stream, where they cause large areas to be alternately covered with water, and left bare, are also unfavorable for the proper disposal of sewage. In short, there are many things, such as the variations in the volume flowing in a stream occasioned by its use for mill purposes, the amount and character of manufacturing wastes, and the subsequent use of the water for different kinds of manufacturing, which require careful consideration in each case, and often a considerable variation from any general rules which may be laid down.

The other method of determining the ratio of population to flow of streams, referred to in the early part of this section of the report, depends upon observations of the effect of discharging the sewage of a given population into a stream of known size. In this state there are but two streams where a comparison of this kind is practicable; namely, the Blackstone and Merrimack rivers. The former has discharged into it the sewage of the city of Worcester, with an estimated population, in 1888, of 76,500. The total population above the point where samples were collected was at the same time 77,500. The volume of water flowing in the river during working hours was determined, but not the total quantity flowing in the whole twenty-four hours.

In order to obtain the latter quantity, which is needed for these comparisons, it is necessary to make use of the flow per square mile of drainage area, as determined by the actual measurement of the flow of some other stream having a known drainage area. The Sudbury River measurements for the period under consideration are the most applicable to this case.

The average flow of the Blackstone River for the period under consideration, reckoned upon this basis, was 122 cubic feet per second; and, if we assume that the river received the sewage of 70,000 of the population, then the volume per 1,000 persons would be 1.77 cubic feet per second. The amount of pollution at this place, as already stated, is much greater than is permissible. At Uxbridge, which is sixteen miles further down stream, the flow upon the basis above given is 279 cubic feet per second; and, if we assume that the sewage of 3,000 persons enters the river between Worcester and Uxbridge, making a total of 73,000, the volume flowing per 1,000 persons was 3.88 cubic feet per second. The water at Uxbridge was so much polluted that its quality for manufacturing purposes was affected, but it was not generally offensive to those living upon the banks of the stream. The amount of pollution at this place was increased somewhat by the manufacturing refuse turned into the river below Worcester.

The Merrimack River will be considered with reference to the effect of the sewage of Lowell upon it. In this case observations for more than three years are available. The average flow of the river has been 8,720 cubic feet per second, and the average population of Lowell for the same time 74,500; hence, the volume flowing has equalled 117 cubic feet per seond, per 1,000 persons. If, instead of the average flow, we take the low-water flow of 2,200 cubic feet per second, and the population as given by the census of 1890, the volume per 1,000 persons is 28 cubic feet per second. It will be observed that the former of these results represents a greater dilution than any indicated by the table, while the latter shows a dilution four times as great as the highest about which there is any doubt. The discharge of this sewage into the river, added to that which has already entered it from cities and towns above, together with a vast amount of manufacturing sewage, has not affected the water enough to prevent the city of Lawrence, ten miles below, from adopting and maintaining a water supply from this source; although the danger to health which has been found to exist in this water supply has led the city authorities to contemplate the introduction of water from a new source. This is a striking instance of the extent to which a great river can dilute the sewage of a very large population; but the fact that the water is not worse than it is, is undoubtedly due in part to the so-called self-purifying power of streams, which will now be discussed.

Self-Purification of Streams

This subject may be discussed with reference to the subsequent use for drinking of water which has been polluted by sewage, or from the other standpoint of rendering inoffensive a stream which has been made offensive in the same way. In the case of the stream used for drinking, chemical purification is less important than the destruction of disease germs, so that the purification should be considered from a bacterial as well as a chemical standpoint; while in the case of the offensive stream the improvement is well indicated by chemical analysis alone.

The investigation of rivers in Massachusetts has been almost wholly chemical, and the subject will therefore be discussed mainly from this standpoint. In comparing a sample of water taken from a stream at a point where it is much polluted with one taken further down stream, there is often a very marked improvement in the quality of the water at the lower point, owing to the dilution caused by purer tributaries, and by water filtering into the stream from subterranean sources. It is only when the effect of this dilution is eliminated that we can determine the chemical changes which have taken place, as a result of the purifying action of the stream.

The Blackstone River furnishes a good illustration of a change due largely to dilution. The chlorine just below Worcester is 1.19 parts per 100,000, while at Millville it is but 0.46. As the chlorine compounds found in water are very permanent, this cannot be attributed to a reduction in the actual amount of chlorine, but rather to its diffusion in a greater amount of water. This is known to be the case in this instance, as there is added to the water which flows past Worcester, before it reaches Millville, three times its own volume of water containing much less chlorine.

If, instead of comparing analyses directly, we make use of them in connection with the amount of water flowing to determine the number of pounds of each constituent actually carried by the river in a given time, we eliminate the effect of dilution, except that the number of pounds found at the lower station includes not only the amount put in at the upper one, with such modifications as may be due to the purifying action of the stream, but also the number of pounds of each constituent added at intermediate points, both from natural and artificial sources.

In the case of the Blackstone River, the amount of impurity in the water just below Worcester is so great, in comparison with that entering the stream between this place and stations further down the stream, that it is feasible to reach conclusions of some value as to the purifying effect of the stream, without making any allowance for the added impurities. More accurate results can be obtained, however, by making corrections for the impurities added to the river from natural sources. This can be done with a fair degree of accuracy, notwithstanding the fact that no analyses of the tributaries have been made, because the quantity of water brought in by tributary streams is proportionate to their watersheds, and the general character of unpolluted surface waters in this vicinity is known. No correction is necessary in the case of the free ammonia, because the amount naturally found in streams is insignificant when compared with that entering the river from sewage. The correction for chlorine is the largest one, and this is definitely known from the normal chlorine of this region. The corrections for albuminoid ammonia and nitrates are less accurate.

It has not been found practicable to make a correction for the artificial pollution, because the population sewering directly into the stream and the character and extent of the manufacturing wastes are unknown. In consequence of the omission of this correction, any purification which may be found to have taken place between Worcester and a point below occurs notwithstanding the artificial pollution added to the stream at intermediate points.

Two tables are given below: the first shows the average number of pounds per day of free and albuminoid ammonia, nitrates and chlorine passing Worcester, Uxbridge and Millville during the two years ending May 31, 1889; the second table is the same as the first, except that the quantities passing the two lower stations are diminished by the amount of each constituent naturally brought in by tributaries below Worcester.

TABLE 35

TABLE SHOWING THE AMOUNTS OF DIFFERENT CONSTITUENTS IN THE WATER WHICH PASSES THREE POINTS ON THE BLACKSTONE RIVER

[Pounds per day]

Location	Ammonia		Nitrogen as Nitrates	Chlorine	Total Nitrogen
	Free	Albuminoid			
Worcester..........	1728	826	218	8630	.3000
Uxbridge...........	1629	454	491	10406	.2581
Millville...........	1299	734	611	13166	.2891

TABLE 36

SAME AS ABOVE, EXCEPT THAT THE QUANTITIES AT UXBRIDGE AND MILLVILLE ARE REDUCED TO ALLOW FOR THE IMPURITIES NATURALLY BROUGHT IN BY TRIBUTARIES BELOW WORCESTER

[Pounds per day]

Location	Ammonia		Nitrogen as Nitrates	Chlorine	Total Nitrogen
	Free	Albuminoid			
Worcester..........	1728	826	218	8630	.3000
Uxbridge...........	1629	306	426	8738	.2272
Millville...........	1299	382	457	9205	.2156

Before drawing any conclusions from the tables, it may be well to indicate the limitations of accuracy of these investigations. The samples collected just below Worcester were usually obtained on week days in the latter part of the forenoon, and consequently represented the morning flow of sewage diluted with the flow of the river during working hours. Samples were taken at the lower points a day or two later than at Worcester, but the time was not sufficient to permit the water to pass from Worcester to these stations. If a longer time had elapsed, there was great danger that the comparison might be affected by intervening rains, which would increase the dilution at the lower stations. In any method of collection with points so far apart on a stream containing many mill ponds, there is no assurance that any given sample at the lower station represents the day or night flow of sewage at the upper station. In view of these conditions affecting the accuracy of the results, it is obvious that too much stress should not be laid upon small variations in the quantity of any constituent, and it even seemed somewhat doubtful whether the average of observations as given in the table would be trustworthy. To test this point, the results obtained at different periods have been compared. Those given in the table are, as already stated, based upon the analyses of the first two years, and the flow of the river as deduced from the areas of the watersheds above the different points, in connection with the recorded yield per square mile of the watershed of Sudbury River during the same period. The analyses for the third year, June, 1889, to May, 1890, inclusive, were next treated in the same way; and finally the analyses from September, 1887, to December, 1888, were made use of in connection with the average flow of the river, as deduced from actual measurements of the flow during working hours. The results obtained in the three cases corresponded quite nearly, showing a high probability that the general results given in the tables are trustworthy.

Returning to the second of these tables, we find that the albuminoid ammonia (which represents the organic nitrogen both in solution and in suspension) amounts at Worcester to 826 pounds daily. At Uxbridge, sixteen miles below, the quantity is reduced to 306 pounds, showing a loss of rather more than half, which may be attributed to the deposit of suspended particles and the decomposition of a portion of the organic matter in solution. From Uxbridge to Millville the quantity increased from 306 to 382 pounds, which may be due to the growth of organisms which appropriate the free ammonia and nitrates, and to the increase from artificial pollution caused by the population and factories on the large area of watershed which drains into the river below

Uxbridge. It might be thought that the increase from these causes would be insufficient to offset the decomposition of the organic matter of the Worcester sewage, and this would probably be the case were it not that the portion which still remains in the river is comparatively stable in character.

The free ammonia, which is a product of decomposition and a characteristic component of sewage, decreases, from Worcester to Uxbridge, from 1,728 to 1,629 pounds. It is not probable that this represents the whole loss of free ammonia which takes place in this distance, because a considerable amount must have been developed below Worcester by the decomposition of the dissolved and suspended organic matter, and a further amount, as in the case of other constituents, must have entered with the sewage and other polluting matters turned into the stream at different points below Worcester. This view is supported by the increase of nitrogen as nitrates, from 218 pounds at Worcester to 426 pounds at Uxbridge, which is due to the oxidation of the nitrogen of the free ammonia. From Uxbridge to Millville there is a loss of 330 pounds of free ammonia, and an increase of nitrogen as nitrates of but 31 pounds. In this case the loss of ammonia does not appear to be occasioned to any large extent by oxidation. Some of the nitrogen is undoubtedly appropriated by suspended organisms, and some by fixed plants.

The chlorine shows a gradual increase from point to point, which is easily accounted for by the population below Worcester.

If we estimate the total nitrogen at Worcester and Millville, by methods which in this case are necessarily approximate, we find 3,000 pounds at Worcester and 2,156 pounds at Millville, leaving 844 pounds daily unaccounted for. A portion of this is undoubtedly contained in the suspended matter, which settles to the bottom in mill ponds and sluggish places, and either remains there or is swept down the stream by freshets, thereby generally escaping without being represented in an analysis. It is possible that some of the ammonia may escape into the air, and some may be appropriated by fixed plants. It is also not improbable that a portion of the difference may be due to the unavoidable inaccuracies in comparisons of this kind, as previously indicated.

If from this consideration of details we turn once more to the general results, we find that the water in passing from Worcester to Millville loses rather more than one-half of its organic nitrogen, and that the remaining portion is comparatively stable. There is a loss of one-fourth of the free ammonia, caused partly by the oxidation of its components into nitric acid and water; but the striking fact remains, that, after a flow of twenty-three miles, three-fourths of the free ammonia remains unchanged, notwithstanding the long time required for the water to pass this distance, owing to its slow movement through mill ponds, and the aëration which it receives at the dams.

It is known, as will be shown subsequently, that, in some instances where, by reason of the relatively small amount of sewage discharged into a stream, the amount of ammonia contributed to it is also small, this ammonia disappears rapidly and completely. In the Blackstone River the absolute quantity which disappears is large, but the proportionate quantity is small. It may be that the acid liquors turned into the river from the iron works at Worcester prevent a rapid oxidation of the ammonia, and the great amount to be oxidized may also be an important factor.

XVIII

THE FILTRATION OF SEWAGE, A GENERAL VIEW OF RESULTS OF EXPERIMENTS AT THE LAWRENCE EXPERIMENT STATION

By Hiram F. Mills, C.E.

[This is a brief extract from a long report on the filtration of sewage and water. The scientific deductions from the work done at Lawrence during these early years profoundly affected engineering practice. The full report is a classic which should be studied by all students of sanitary engineering. Part II, *Report on Water Supply and Sewerage*, 1890, p. 577. — G. C. W.]

We have now filtered sewage intermittently through clean gravel stones, larger than robins' eggs, through filters made of various grades of gravel and of sand, through a sand whose particles average but 0.004 inch in diameter, — a fine granular dust, — as well as through soils and through peat.

With the gravels and sands, from the coarsest to the finest, we find that purification by nitrification takes place in all, when the quantity of sewage is adapted to their ability, and the surface is not allowed to become clogged by organic matter to the exclusion of air.

With fine soils, containing, in addition to their sand grains, two or three per cent of alumina and oxide of iron and manganese, and six or seven per cent of organic matter, we find that, when only six inches in depth, resting upon fine, sandy material, they retain water so long that the quantity that can be applied is so small, and the interval in which this must settle and dry away to allow air to enter the filter is so long, that the amount of sewage that can be purified is very small. When the quantity applied is adapted to its ability, such a filter may give an excellent effluent, quite free from bacteria.

With greater depth of soil the quantity that can be filtered will evidently become less; and, with the depth of five feet of such a soil, we have found nitrification did not take place; and, although it was probable that no bacteria came through, the organic matter in the effluent was at the end of two years nearly as great as in the sewage. This soil remained continually so nearly saturated that, when only 5,000 gallons per acre were being filtered daily, although free to drain over every square foot of the bottom, sufficient air could not be taken in to produce any nitrification; and the chemical result with this material was, throughout the two years of its trial, nearly the same as would be expected if the filtration had been made continuous, instead of intermittent.

With peat upon the surface of a filtration area, even to the depth of only one foot, its imperviousness to liquid and the quantity that it will retain until it evaporates, renders intermittent filtration impracticable; and a sand area thus covered with peat can be rendered efficient for filtration only by the removal of the peat from the surface.

The truths in regard to filtration of sewage that have been made manifest by the experiments of the State Board of Health in the past two years can be appreciated only by a careful study of the results which have been presented. No statement of general conclusions can convey all that these experiments have made known; but, to one who has carefully considered the results in detail, it may be useful to group the results and bring out some of the general truths with more clearness.

The experiments with gravel stones give us the best illustration of the essential character of intermittent filtration of sewage. In these, without straining the sewage sufficiently to remove even the coarser suspended particles, the slow movement of the liquid in thin films over the surface of the stones, with air in contact, caused to be removed for some months ninety-seven per cent of the organic nitrogenous matter, a large part of which was in solution, as well as ninety-nine per cent of the bacteria, which were of course in suspension, and enabled these organic matters to be oxidized or burned, so that there remained in the effluent but three per cent of the decomposable organic matter of the sewage, the remainder being converted into harmless mineral matter.

The mechanical separation of any part of the sewage by straining through sand is but an incident, which, under some conditions, favorably modifies the result; but the essential conditions are very slow motion of very thin films of liquid over the surface of particles having spaces between them sufficient to allow air to be continually in contact with the films of liquid.

With these conditions it is essential that certain bacteria should be present to aid in the process of nitrification. These, we have found, come in the sewage at all times of the year; and the conditions just mentioned appear to be most favorable for their efficient action, and at the same time most destructive to them and to all kinds of bacteria that are in the sewage.

In grouping the results of our experiments, it will be best to refer to the general diagram of nitrates, of ammonias and of bacteria. There are graphically presented these elements for the sewage and for most of the tanks that have been used.[1]

As nitrification, or the burning up of organic matter, is the essential step in purification of sewage by intermittent filtration, we will first follow by the diagram the rise and fall of the nitrates.

The nitrates of the sewage were nearly zero from beginning to end.

Passing the slight nitrification in January, 1888, in nearly all of the tanks when sewage was first applied, we have through February and March a season of no nitrification. During these months the temperature of the effluents had been about 36° F. When the temperature of the effluent rose to 39° or 40° in the several tanks, a slight increase in the nitrates was observed, which continued slowly rising until about 50° was reached.

This was true of all of the filters represented, except No. 5, which was filled with garden soil, in which no appreciable nitrification occurred during the two years. Filter No. 3, not represented, which was composed of peat, also did not nitrify. Of those represented, the first to nitrify are those presented by heavy lines, No. 1, No. 14, No. 13 and No. 12. These were all of coarse, open sand, like No. 1, which would allow air to enter it most freely; and those began first and burned most rapidly in which the most organic matter had been stored.

[1] For this diagram the reader must consult the original paper.

Filters started at other seasons of the year have shown us that nitrification does not become active until there is an accumulation of organic matter that may be burned.

Following those filters of the most open sand, in nitrification, came the mixed sands of No. 6 and No. 11, which allowed air to penetrate them less freely. These were followed by the finest sand, No. 4, the fine sand of No. 2, and the soil-covered filter No. 7, — the latter being more than a month later than the earliest.

Nitrification was highest in all of these filters in the rapidly growing months of May and June. In the second year the highest nitrates were in general at the same season, but began earlier, in the latter half of April, and continued through May. With the exception of the increased activity of nitrification in the spring months, when in several of the filters more nitrogen came away in the effluent — principally as nitrates — than was being applied in the sewage, the nitrates of the effluent rise and fall, in the several filters which are purifying the sewage, with the rise and fall of the ammonias in the sewage; so that, in the winter months of 1888–89, while the nitrates of the effluent were lower than at other times, we find that the sum of ammonias of the sewage was also lower, and that nitrification at that time was quite as complete as in the previous months.

Before following the varying and exceptional condition of nitrification in some of the filters, we will turn to the diagram of ammonias, and see how they were in general affected by nitrification.

Upon first applying sewage, some of the impurities were held back by the sand by the straining process; and, so far as this occurred, the finer sands held back for a longer time than the coarser. With the coarser sands of No. 1 and No. 6 there was a considerable increase in ammonias soon after the chlorine indicated that liquid from sewage had reached the outlet. With No. 7, No. 2 and No. 4, there was but little increase in the ammonias for some weeks after the original water in the sand had been expelled, and liquid from sewage had permeated all parts of the filter.

All, however, gave an effluent at some time before nitrification began, which contained from twenty to forty per cent as much free and albuminoid ammonia as the sewage. But during this time, in the cold months of a very cold winter, there was an important step in purification going on. This was the conversion of albuminoid ammonia to free ammonia; or, to state the case more definitely, it was the burning up of a part of the organic matter by the combination of oxygen with some of the carbon, producing carbonic acid, and leaving the nitrogen and hydrogen that were combined with this carbon to form ammonia, and thus reducing the amount of combined nitrogen which in our analyses appears as albuminoid ammonia. This is as complete a destruction of organic matter, as far as it goes, as if the free ammonia were again oxidized, forming nitric acid or nitrates; but this process seldom if ever carries the destruction of the organic impurities of sewage to such an extent that the resulting liquid contains so little impurity as when nitrification takes place. We find, further, that this process of reducing the albuminoid ammonia is not so destructive to bacteria as the more complete process of nitrification. It is, however, a process of purification; and the conditions of intermittent filtration are those most favorable to this step in purification.

During the three cold months previous to the beginning of nitrification in April, 1888, we have, under very unfavorable circumstances, the large filters in the field filtering intermittently and purifying without nitrification. The sum of ammonias were — though generally lower — at some time from twenty to forty per cent of the sum of ammonias of the sewage applied; but this does not express the degree of the destruction of organic impurities. We are unable to say, in regard to this short period, how much was destroyed; for a considerable part of that which was in solid form — in suspension — was without doubt held back, and may have been accumulating in the sand. If we compare the albuminoid ammonia of the effluent from the several tanks in the field with the albuminoid ammonia of the sewage, we find that but about five per cent was coming through the filter; but, if we suppose that all that was in suspension in the sewage was mechanically held back by the sand, we still find that the albuminoid ammonia of the effluent was only twenty per cent of the albuminoid ammonia that was in solution in the sewage; that is, in the process of intermittent filtration previous to the beginning of nitrification, there was going on within the filter a chemical change by which a considerable part of the organic impurities were burned up, thus reducing the combined nitrogen that was in solution in the sewage by eighty per cent. This occurred in winter, when frost was in the upper layers of the filters, and the effluents were at the temperature of about 36° F.

When the frost had been melted in the tanks in the field, and the temperature of the effluent in each had reached 39° or 40°, nitrification began in all of the filters composed of sand. The sum of ammonias, however, did not immediately decrease; in fact, it generally increased in the coarser sands for two or three weeks, and in the finest sand for two months. The time when it began to decrease, and the rapidity with which the filter reached a condition of established purification, appears to depend upon the freedom with which air can penetrate the filter, and upon the amount of organic impurity that has been stored in the filter.

Effect on Filtration of Exclusion of Air

The essential difference between intermittent filtration and continuous filtration of sewage is, that in the former air is allowed to enter the filter during the intermissions, and in the latter air is excluded from the filter.

If from any cause the surface becomes impervious to air, by the material becoming so retentive of water that no air can enter between the applications of sewage, the result is similar to that when filtration is continuous; no nitrification takes place, and the effluent gradually grows to contain as much organic matter as the sewage. This was the result with the garden soil of Tank No. 5 throughout the two years. It was the case for a short time with Tank No. 7, covered with garden soil, which, in June, 1888, was receiving 17,000 gallons of sewage per acre per day. This proved to be more than would readily enter; and a green layer of organic matter formed on the surface, that was so retentive of water that no air could enter the filter; and the result is shown upon the diagram in the rapid decrease in the nitrates, until nitrification ceased on July 10, and so continued till August 2, in which time the sum of ammonias increased from 0.10 parts to 0.44 parts. This condition was changed by removing, on July 25, one-half inch in depth of the surface, allowing the air to enter, and causing the nitrates to increase in eleven days from 0.003 parts to 1.100 parts; but purification by nitrification was not well established until the quantity applied was reduced to 14,000 gallons per acre per day. With 9,000 gallons daily per acre it was continued very satisfactorily for eight months.

Effect of Continuous Filtration on Bacteria

The effect upon the number of bacteria in changing from intermittent to continuous filtration was, in No. 12, to increase and then to decrease it. In June, 1888, the number was 166. Through July, with a glass trap on the outlet, the number averaged 891. On July 27, the tank was filled with sewage, and continuous filtration commenced. In a week the number of bacteria in a cubic centimeter of the effluent was 55,900, in three weeks it had gradually decreased to 3,540, and in two weeks more it was only 64. In the next two months, while continuous filtration continued and nitrification ceased, the number averaged less than 100. During this time there was no nitrification to kill them, but they were unable to survive the long passage of three weeks through the sand without oxygen.

Upon drawing sewage out of the tank on November 28, and resuming intermittent filtration, the number of bacteria, when the first liquid from the top — being one week on its passage — reached the outlet, was 10,416, and in two days the number fell off to 34; and in the next three weeks, while the nitrates were increasing from 0.1200 to 1.0200 parts, the number averaged 82.

When nitrification ceased in No. 7, due to the surface becoming impervious to air, the quantity of water that could enter was so small that about two months were required to pass through the sand; and so long a passage without air was undoubtedly the cause of the number of bacteria being very small, although there was no nitrification.

General Effect of Intermittent Filtration of Sewage upon the Bacteria which are Growing in it

The sewage pumped from the sewer at the Experiment Station generally contained about 700,000 bacteria per cubic centimeter. If it was allowed to stand in an open vessel, the number would increase for a few days to three or four times the original number, and then generally decrease to a fraction of the original number.

When sewage was first applied to the sand filters, the number of bacteria found in the effluents, while the sewage was mingling with water that was previously in the sand, rose from the small numbers that had been in the water to appreciable percentages of the number that was in the sewage, and, in the case of Tank No. 11, exceeded that number.

The maximum percentages of the number in the sewage found in the effluents at such times were as follows: No. 1, thirty-one per cent; No. 12, eighty-three per cent; No. 13, forty per cent; No. 14, twenty-six per cent; No. 6, five per cent; No. 11, four hundred and eighty-seven per cent; No. 2, fourteen per cent; No. 4, five per cent; No. 7, five per cent.

The sand of No. 11 had been heated, and the water of both No. 11 and No. 12 had been boiled and put into the sand when hot; and, though the heating of the sand and the boiling of the water probably sterilized each for the time, these processes may have prepared the organic matter in each to be better food for the bacteria afterwards brought in by the sewage, and caused the number to be greater than would have ordinarily existed. Omitting these in the discussion until we have opportunity to give them especial attention, the coarse sands, like No. 1, allowed from twenty-six to forty per cent of the bacteria to pass through; the mixed sand of No. 6 allowed five per cent to pass; the fine sand of No. 2 allowed fourteen per cent; and the still finer sand of No. 4, and the soil-covered sand of No. 7 allowed five per cent to pass through. It is not probable that the five feet in depth of soil in No. 5, or the same depth of peat in No. 3, allowed any to pass through.

These results show us that it is mechanically possible for bacteria to be carried through the several filters of sand in large numbers, and with varying percentages of loss; and that, when the number brought through is far below the percentages above given, we must conclude that some other condition, not merely mechanical, is unfavorable to their passage.

From this summary (not given here) we find from the average results of the filters, — omitting those which have exceptional conditions, — that, under the most favorable conditions, from five to forty per cent of the bacteria applied lived to get through the filters, the smaller number being through fine material and the larger number being through coarse sand, the average amounting to eighteen per cent. This was before the liquid in the tank was all from sewage; and, being a condition that is never found after a filter has been used some months for sewage, it is of interest only in showing that it is mechanically possible for bacteria to pass through these matrials, under favorable conditions, with a loss of from sixty to ninety-five per cent.

The minimum number found on a single day, when the conditions, without nitrification, were exceptionally unfavorable, — given in the third column, and averaging but 0.042 of one per cent, — are significant, but may be passed to consider the more general condition given in the fourth column of the average in the large tanks numbered from 1 to 7, for two months or more, and in the others for a much shorter time, when there was a marked reduction in the organic matter by the burning up of carbonaceous matter, but resulting in only a partial purification with no nitrification. At this time there survived the passage from 0.08 of one per cent to five per cent, averaging 1.05 per cent of the number in the sewage.

We must, from the result, regard the conditions at this time as unfavorable to the passage of bacteria through the sands far beyond that due to mechanical obstruction. Nearly ninety-nine per cent died where there was apparently an abundance of food, and no destruction by the formation of nitric acid or nitrates. Carbonic acid was formed; and probably the oxygen was in some part of the passage all used up in combining with the carbon.

We may suppose that their general destruction at this time, and in the previous time soon after sewage took possession of the tank, was due to the character of the food met with, and to being deprived of oxygen.

Bacteria Decrease with Completeness of Nitrification Independently of the Sum of Ammonias

We have seen that it is mechanically possible for from five to forty per cent, averaging eighteen per cent, of the number of bacteria applied in the sewage to pass through the several filters; but that, after intermittent filtration is established and no nitrification is taking place, — although there is a destruction of organic matter by the burning up of some of the carbonaceous matter, — the number of bacteria that survived the passage was from 0.08 of one per cent to five per cent, averaging 1.05 per cent. In this condition of partial purification ninety-nine per cent of the bacteria are destroyed; but, when nitrification begins, the number surviving the passage suddenly decreases to only 0.08 of one per cent, and a still further decrease to about 0.03 of one per cent when nitrification becomes complete.

During each of these stages there appears to be no lack of food for bacteria; for both free and albuminoid ammonia are abundant, their sum averaging from 0.2 to 0.4 parts per 100,000 of the effluent.

In the stages which follow, a decrease in the sum of ammonias is not accompanied with a further decrease in the number of bacteria. In the seventh column we have a decrease in the sum of ammonias, from 0.270 parts to 0.018 parts, accompanying a decrease in nitrates from 2.42 parts to 0.90 parts, but a much higher average condition of nitrates than in the previous columns; but the number of bacteria is higher, and, when the sum of ammonias is maintained at the very small amount of 0.0140 parts, or about one-half of one per cent of the sum of ammonias of the sewage, the average percentage of the number of bacteria continues about the same; viz., 0.07 and 0.05 of one per cent of the number in the sewage.

We do not here find that the number of bacteria, after nitrification begins, decreases with the decrease in the sum of the ammonias; but it does decrease with the completeness of the nitrification.

Probable Destruction of Bacteria by Oxidation

Although the number of bacteria in the effluent was relatively small, being but one per cent of the number in the sewage, when carbonic acid was formed in the burning up of carbon in organic matter, and the number was decreasing as the process continued, yet it was very much smaller, being from 0.03 to 0.07 of one per cent when nitric acid was formed in the burning up of nitrogen derived from organic matter of the sewage; and the least number was when this oxidation of nitrogen was most complete. It would follow, in a permanently established condition of nitrification, that, when nitrification was most complete, the amount of the ammonias in the effluent would be the least; but in the varying condition of the sewage applied, and the storing and subsequent giving off of ammonias from the sand, we have sometimes found the highest nitrification and the smallest number of bacteria when there was a large supply of the ammonias in the effluent. This would indicate that the most complete destruction of bacteria was not due to a failure of food, so far as that may be supplied by the free or albuminoid ammonia of these effluents, but was rather due to the process of the formation of nitrates, — the burning process. We have thought that their destruction might be due to being deprived of oxygen that was used in the oxidation of other organic matter; but it may be due to their own oxidation, — to their being burned.

The Effluents from the Filters not Adapted to Support Bacteria

We have found that, if food that has been proved to be well adapted to the growth of bacteria be applied to one of these filters, when the sewage ordinarily applied is being very completely nitrified, the number of bacteria will for a time be greatly increased, and continue high until this food has passed out or is becoming nitrified; from which we may conclude that the free and albuminoid ammonias, — although quite high in an effluent, — when they are the residue of a much larger amount that has been burned, indicate substances that are much less able to support bacterial life than fresh organic substances, that would give the same amount of free and albuminoid ammonia in a solution.

Examinations have been made of the number of bacteria in the effluent from Tanks No. 1, No. 2, No. 4 and No. 6, from hour to hour, while filling and after standing two or three days in the measuring basins, to determine whether bacteria would increase in numbers in these effluents, when exposed to the air under circumstances probably more favorable to their growth than if turned into a drinking-water stream.

In some cases there was an increase in numbers on standing, and in others a decrease; but in no case did the growth of bacteria in these effluents indicate that the remaining organic matter was well adapted to support bacteria.

May the Filtered Effluent be Used for Drinking?

We now come to the important question of the character, as regards healthfulness of the effluents obtained by filtering sewage intermittently through five feet in depth of sand, after the sand has filtered sewage for a year or more without being cleaned.

We have found that the sum of ammonias, which have been taken to indicate the amount of nitrogenous organic matter, has been reduced to about one-half of one per cent of those in the sewage, and is less than the sum of ammonias of most of the public drinking-water supplies of the state.

The chlorine and nitrates are higher than in the public drinking waters. They indicate in these effluents, as their excess above the normal does in the drinking waters, that the water which contains them came from sewage; but, in the absence of the ammonias, they indicate that, though the water came from sewage, the organic impurities have been destroyed, and these are merely mineral constituents which remain after that destruction. They are principally common salt and saltpetre, which, in the quantities found in any of the effluents, are regarded as entirely harmless.

Judging by the chemical analyses, there is nothing in the effluents known, or even suspected by chemists, to be harmful.

Although nearly all of the bacteria that were in the sewage did not live to pass through the filters, there have been found in the effluents from filters of coarse sand more bacteria than are found in the public drinking supplies, and some of these evidently come from the sewage; and, until we learn that disease-producing bacteria are not among those that come through, we must assume that they may be among them; and, although reduced in numbers to such an extent that they may do no harm, we yet know that bacteria in general increase with enormous rapidity when under favorable conditions, and we do not yet know enough to allow us to assume that the very small number of one or two in a thousand of the number in the sewage that come through may not increase in the human body or under other conditions to such numbers as to be harmful.

From this cause we are not able to assume that the effluent from the coarse sand filters five feet in depth is suitable for drinking water.

The effluent from the extremely fine sand filter, No. 4, and that from the soil-covered filter, No. 7, and a part of the time from the fine sand, No. 2, we have strong ground for concluding contained no bacteria from the sewage. The numbers that were found in the effluents were smaller than are usually found in public drinking supplies; and we have good reason for concluding that they all grew in the gravel and underdrains beneath the filters. If these conclusions are correct, there is no known reason why these effluents may not be used with safety for drinking.

The effluent from No. 2 has been frequently used for drinking by a number of people, without any noticeable effect; but none of them have been used continuously by a large number sufficiently to prove their safety. In the absence of such positive evidence, we have made the following comparisons.

The city of Lawrence is provided with a public water supply from the river; but there are a dozen or more wells scattered about the city, on the sides of streets, that have been used for many years for watering horses, and are still used for this purpose, or for supplying drinking water to families in the neighborhood, and particularly are used by the public for a cool draught of water in the summer, when it is much more refreshing than the city reservoir water.

The water from ten of these wells has been analyzed and examined for bacteria, and the results obtained from seven of them are arranged below, with the average result obtained by analysis of the filtered sewage from six of our filters, covering from two to eight months, after most of them had been in use a year or more.

TABLE 37

COMPARISON OF THE EFFLUENT FROM SEVERAL OF THE FILTERS FILTERING SEWAGE, WITH WATER FROM WELLS IN COMMON USE

Average Effluent from	Ammonias			Chlorine	Nitrogen as		Bacteria Per Cubic Centimeter
	Free	Albuminoid	Sum		Nitrates	Nitrites	
Tank No. 1, for two months	.0313	.0272	.0585	4.83	1.78	.0008	549
Well water, Atlantic Street	.1410	.0155	.1565	8.08	2.37	.0024	4,370
Tank No. 13, for six months	.0011	.0105	.0116	7.28	1.25	.0004	76
Well water, Hampshire Street	.0078	.0118	.0196	7.51	2.00	.0007	128
Tank No. 6, for three months	.0036	.0104	.0140	4.98	1.66	.0002	678
Well water, Andover Street	.0184	.0046	.0230	2.79	1.50	.0018	46
Tank No. 6, for six months	.0014	.0074	.0088	4.51	1.11	.0001	319
Well water, Mechanic Street	.0016	.0076	.0092	5.29	4.20	.0000	240
Tank No. 4, for two months	.0025	.0108	.0133	3.72	0.75	.0002	20
Well water, Salem Street	.0070	.0086	.0156	7.67	1.40	.0014	447
Tank No. 2, for four months	.0007	.0065	.0072	3.98	0.71	.0000	17
Well water, Lowell Street ...	.0012	.0070	.0082	7.11	2.10	.0000	27
Tank No. 7, for eight months	.0014	.0063	.0077	4.04	1.06	.0000	7
Well water, Haverhill Street	.0022	.0050	.0072	2.44	0.55	.0016	344

Here we find, for each of the filters filtering sewage, a well the water of which is used for drinking by many people, but is in fact sewage not so well purified as the effluent from the filter with which it is associated. This is not presented to show that the effluent from the filters is good for drinking, for we have no reason to so regard those at least in the upper half of the table, and we should without hesitation pronounce the well waters in the upper half of the table as unsafe to drink; but we present this comparison to show that waters in every way as impure and as certainly derived from sewage as the effluents from the several sewage filters are being used daily, and have been used for years by multitudes of people, without their knowing that they were harmed by them.

Every one of these wells should be regarded as unsafe, some of them dangerous in their present condition, and others unsafe because of what they may change to from day to day.

If these wells contained unpolluted water, the chlorine would be about 0.36, while it is from seven to twenty-two times this amount; the nitrates would be about 0.01 or 0.02, while they are from 0.55 to 4.20.

The latter show that a large amount of organic matter, generally more than there is in sewage in a sewer, has been burned out of these waters, and the high chlorines show that this organic matter was of the same character as that in sewage. From the amounts in most of these well waters we must conclude that their previous condition was worse — that is, more polluted — than ordinary sewage in sewers, and that on its way to some of the wells it has by intermittent filtration through the ground been purified to such an extent that they may not in their present condition be harmful; and, where the numbers of bacteria are continually small and the ammonias low, they probably are not harmful; but, where the numbers of bacteria are large and the ammonias are large, although the waters have been previously much worse than at present, and have to a considerable degree been purified, their present condition indicates that the material through which they have filtered has not been able to exclude bacteria nor to burn up all of the food they live on; hence, if disease germs get into their source, some of them will probably get into these wells. Such of the wells as are included in this latter class should be filled with earth, and never used again. Others, if examined from time to time, and always found with low ammonias and small number of bacteria, would probably be harmless; and we should have the same ground for concluding that the effluent from sewage at those fine sand or soil-covered filters through which no bacteria come from the sewage would also be harmless for drinking.

These comparisons have been made, not to advise drinking any of the well waters that have been cited, nor any of the effluents from the sewage filters, but to show that, as people are drinking such waters with impunity, with which the effluents from the filters of fine sand compare favorably in every respect, there can be no doubt that the effluents from sewage filtration through such filters can be turned into a drinking-water stream, where they will be much diluted, without risk of injury to those who drink from it.

XIX

THE CHEMICAL PRECIPITATION OF SEWAGE

By Allen Hazen

[This abstract contains only the introduction and the conclusions of the report. The experimental details consist largely of tables and diagrams. Part II, *Report on Water Supply and Sewerage*, 1890, p. 737. — G. C. W.]

Sewage, as it is found in our city sewers, contains a great variety of substances. Among its principal ingredients are urine and faeces, together with wasted food and wash water. This is diluted with a large amount of water, and in rainy weather, there is in addition a large amount of street washings, which consist of sand from pavements, and organic refuse of various kinds. With the separate system of sewerage, the street washings and rain water would be excluded, so that all the sewage would be like that which is now found in dry weather.

Of this mixed sewage, a portion, the inorganic matter, consisting of sand and various salts, is, from a sanitary point of view, quite harmless. Another portion, the organic matter, furnishes abundant food for bacteria, always present in great numbers. To remove this organic portion is the great problem in purification.

If sewage is allowed to stand for a few hours, a portion of the organic matter will settle out; but the greater part is either too finely divided to separate in a moderate length of time, or is in solution. By adding certain chemicals to the sewage, an inorganic precipitate is formed, which settles rapidly, and carries with it nearly all of the suspended matter, and also a portion of the dissolved matter. This is the chemical precipitation of sewage. Nothing definite is known of the chemistry of the process which makes insoluble a portion of the dissolved organic matter, but it is probably similar to the use of mordants in dyeing for fixing soluble colors.

The substances best adapted and most commonly used for chemical precipitation are lime, and the salts of aluminum and iron.

Lime, containing seventy per cent available calcium oxide, can be bought for $9.00 a ton. Ferrous sulphate or copperas, containing twenty-six per cent of ferrous oxide, costs $10.00 a ton. Aluminum sulphate or crude alum, containing fourteen per cent of alumina, costs $25.00 a ton. A ferric salt can be made by oxidizing copperas with chlorine, or with sulphuric acid and nitrate of soda.

The approximate cost of these oxides in solution is as follows: —

Aluminum oxide	9 cents per pound
Ferric oxide	3 cents per pound
Ferrous oxide	2 cents per pound
Calcium oxide	$\frac{2}{3}$ of a cent per pound

Using these figures, the cost of chemicals has been calculated for the different experiments. One hundred gallons of sewage daily for each inhabitant is assumed in calculating the annual cost.

It seems altogether probable, considering the cheapness of the materials from which they are prepared, that the cost of both crude alum and ferric sulphate, or the corresponding chlorides, might be materially decreased from the prices given, in case there should be a considerable demand for them. Lime and copperas have already a large sale, and could not probably be obtained at lower prices by an increased consumption.

I have endeavored, in the following-described experiments, to determine, first, the best method of using each chemical substance, and to establish, if possible, some relation between the composition of the sewage and the amount of precipitant which will give the best result, or as good a result as a larger quantity; and, second, to compare the effect of equal values of the different precipitants upon the same sewage, after finding, by the first experiments, how to use each with the greatest advantage. The experiments also give an idea of the amount of matter which can be removed by chemical precipitation under favorable circumstances. The observations have been confined to the composition of the sewage and of the effluent, neglecting the sludge altogether.

Conclusions

Using lime as a precipitant, we have found that there is a certain definite amount of lime, depending upon the composition of the sewage, which gives a better result than less, and as good or a better result than more. This amount of lime is that which exactly suffices to form normal carbonates with all the carbonic acid of the sewage. It is possible in a few minutes, by simple titration, to determine approximately the amount of uncombined carbonic acid present in sewage, and how much lime will be required to combine with it. It is also possible to determine in a similar way, after mixing, whether enough or too much lime has been added. The amount of lime required by Lawrence sewage averages about 1,600 pounds per million gallons.

Ordinary house sewage is not sufficiently alkaline to precipitate copperas, and a small amount of lime must be added to obtain good results. The quantity of lime required depends both upon the composition of the sewage and the amount of copperas used, and can be calculated from titration of the sewage. Very imperfect results are obtained with too little lime, and, when too much is used, the excess is wasted, the result being the same as with a smaller quantity.

After mixing the sewage with both copperas and lime, if enough or too much lime has been used the mixture will color phenolphthalein red, while, if too little has been used, no color will be produced. This test can conveniently be used by people having no knowledge of chemistry, and affords an easy and very accurate method of applying enough lime, and of avoiding a useless excess.

Using in each case a suitable amount of lime, the more copperas used the better the result; but, with more than one-half a ton per million gallons, the improvement does not compare with the increased cost.

Some acid sewages contain a considerable amount of iron in solution, and in these cases precipitation by lime is really the rendering available of the copperas already in the sewage, and so is properly classed as an iron treatment rather than a lime treatment. In this case the reaction with phenolphthalein shows the presence of enough lime.

In precipitation by ferric sulphate and crude alum, the addition of lime was found unnecessary, as ordinary sewage contains enough alkali to decompose these salts. Within reasonable limits the more of these precipitants used the better is the result, but with very large quantities the improvement does not compare with the increased cost.

Using equal values of the different precipitants, applied under the most favorable conditions for each, upon the same sewage, the best results were obtained with ferric sulphate. Nearly as good results were obtained with copperas and lime used together, while lime and alum each gave somewhat inferior effluents. The range of these results was, however, comparatively narrow; and it may be that, with sewage of a different character, or with variations in the prices of the chemicals, it would be advantageous to use copperas with lime, or even alum. When lime is used there is always so much lime left in solution that it is doubtful if its use would ever be found satisfactory except in case of acid sewage.

It is quite impossible to obtain effluents by chemical precipitation which will compare in organic purity with those obtained by intermittent filtration through sand.

It is possible to remove from one-half to two-thirds of the organic matter of sewage by precipitation, with a proper amount of an iron or aluminum salt, and it seems probable that, in some cases at least, if the process is carried out with the same care as is required in the purification of sewage by intermittent filtration, a result may be obtained which will effectually prevent a public nuisance.

XX

MICROSCOPICAL ANALYSIS

By William T. Sedgwick

[Historically this is an important paper, as it marked the introduction of a new method of water analysis, — namely the direct application of the microscope to particles strained from the water. Part II, *Report on Water Supply and Sewerage*, 1890, p. 796. — G. C. W.]

Micro-organisms: Microscopical and Bacterial

Introductory

Organisms, the proper subjects of biological study, as they occur in drinking-water or in sewage may be either animal or vegetable, either alive or dead. They are generally microscopic in size, and belong, therefore, almost without exception, to the group of " micro," i. e., " small," organisms. The term micro-organisms is, indeed, often enough employed in a much narrower sense; e. g., as a synonym for the bacteria, or for a miscellaneous collection of bacteria and protozoa. In this report, however, the term micro-organisms will be used only in its strictly etymological or most general and indefinite, significance, comprehending all small organisms; and, for greater precision, it will be considered that micro-organisms include all organisms, whether plants or animals, invisible, or barely visible, to the naked eye.

The micro-organisms might be subdivided into " animal forms " and " plant forms," or otherwise; but the most convenient subdivision for practical purposes is based upon the two entirely different methods by which they are detected, counted and studied.

Of all the micro-organisms those appear to be the most important which are the smallest; namely, the Schizomycetes or bacteria. These are so small that, although they are all " microscopic," i. e., invisible to the naked eye, they cannot be satisfactorily studied by the microscope. Consequently, for them the ordinary methods of microscopical study have to be abandoned, or at least so much supplemented by other methods that they become entirely secondary. The method of first importance in the study of these organisms is the method of "cultures," which consists, essentially, in the observation of the organisms, not as individuals, but as masses or colonies of individuals, growing upon certain nutritive substances. The forms and habits of these "colonies," together with their effects upon such substances as beef-jelly, bouillon, boiled potato, milk, etc., furnish important data which enable the investigator to analyze, enumerate and differentiate the various kinds of bacteria. It is upon this simple method of "cultures" — i. e., the naked-eye observation of the organisms collectively, or in "colonies," when it is impossible, even with the microscope, to study them effectively as individuals — that the new science of bacteriology, created by the genius of Louis Pasteur and of Robert Koch, chiefly rests.

All the micro-organisms excepting the bacteria may be studied more or less effectively, without the use of the method just described, by means of the microscope and such apparatus as is familiar to microscopists. It is therefore reasonable to designate these organisms as "microscopical," and to define the limits of the group as including all micro-organisms excepting the bacteria. This extremely simple arrangement has been found very convenient in the practical work of the Lawrence Experiment Station, for which it was devised, as well as in the examinations of the public water supplies of Massachusetts, both under the auspices of the State Board of Health. It is exhibited in a tabular form as follows: —

MICRO-ORGANISMS Organisms, either plants or animals, invisible or barely visible to the naked eye.	*Microscopical Organisms* Not requiring special "cultures." Easily studied with the microscope. Microscopic in size, or slightly larger. Plants or animals. *Bacterial Organisms.* Requiring special cultures. Difficultly studied with the microscope. Microscopic or sub-microscopic in size. Plants.

Methods of Microscopical Analysis

Although microscopical analyses (so-called) of water or sewage have often enough been undertaken, the methods employed have hitherto been so imperfect that little importance has been attached either to the examinations themselves or to the results.

The methods used have generally involved the direct microscopical examinations of a very small portion of the water itself, e. g., of one drop at a time upon a slide; or, still more often, of a small amount of the sediment deposited by the water upon standing for some hours or even days. Results obtained by either or both of these methods are necessarily only roughly qualitative, and, though often interesting and sometimes important, could never be even approximately exact.

A. — Methods Employed Hitherto

The first systematic microscopical examination of water from the sanitary standpoint appears to have been made by Hassall,[1] upon the river Thames, and the London water supply. A condensed account of his results was published in the *Lancet* for March, 1850. A more complete summary, illustrated by woodcuts, appeared in the same journal in 1851, and is also quoted in a volume by Hassall, entitled, "Food and its Adulterations" (London, 1855). The complete account was also published as an octavo brochure, with colored plates.[2]

It does not appear exactly how Hassall's analyses were made, beyond the bare facts that a "wine-bottle" full of the water was taken, and that, "on allowing the heavier particles contained in a test tube filled with this water to subside, and examining a drop of the sediment," other data were obtained. In what follows it must not be overlooked that, until 1881, microscopical analyses always included the bacterial organisms. Since that time the methods of culture introduced by Koch have tended to draw attention away

[1] Hassall, Arthur Hill. "Memoir on the Organic Analysis or Microscopic Examination of Water Supplied to the Inhabitants of London and the Suburban Districts." The Lancet, 1850, I, 230.

[2] "A Microscopic Examination of the Water Supplied to the Inhabitants of London and the Suburban Districts." London, 1850.

from the microscopical, and to fix it upon the bacterial, organisms. Previous to 1881, however, all microscopical analyses included also, as far as possible, the bacterial analyses.

Hassall begins his earliest paper as follows: "In the chemical analyses of water generally given we find, under the heading, 'Organic Matter,' the word 'traces'; and this, in the majority of instances, is the only information we obtain from the chemist in reference to the most important contamination to which water is liable. . . . In the course of this investigation it will become apparent that these traces are not inconsiderable in amount, that they are complex in organization, endowed with life, and in many cases possessed of action, powers of locomotion," etc.

A year later Hassall wrote: "We have dwelt thus long and fully on the organic impurities of water, because of their extreme and primary importance; for it is on these that the deleterious properties of impure water for the most part depend. Until very recently chemists did not in general attach sufficient importance to these organic contaminations; and in most of their analyses we find the different kinds of organic matter, vegetable and animal, living and dead, all lumped together, and included under the word 'traces.' Indeed, chemistry is but ill adapted to investigate the nature of these organic matters; it gives but a very rough estimate only of their gross amount, and does not discriminate, as we have said, the animal from the vegetable, the dead from the living; and tells us nothing about the families, genera and species to which the numerous living productions contained in impure waters severally belong, or of their habits and modes of life, etc. This inquiry belongs rather to the naturalist, the physiologist and the microscopist; and to ourselves belongs the credit of having first applied the resources of these, extensively, and in a practical as well as scientific manner, to an examination of the actual condition of water in general, and particularly the state of that now in use in the metropolis." (*Lancet*, 1851. "Food and its Adulterations," p. 55. London, 1855.)

In 1865 Radlkofer[1] published an account of a microscopical

[1] Radlkofer, Ludwig. "Mikroscopische Untersuchung der Organischen Substanzen im Brunnenwasser." Zeitschrift für Biologie, I (1865), 26.

investigation of the organic substances found in certain well waters of the city of Munich. No statements are given as to the method employed; but it would appear that Radlkofer examined the water and the mud of the wells simply by the direct observation of small portions, microscopically, upon a slide.

During the cholera epidemics of 1852 and 1866 the wells of Breslau, in Silesia, were regarded with suspicion. Water from some of the worse wells was officially submitted for microscopical examination to Dr. F. Cohn,[1] who has described his method and discussed his results in what is perhaps the most important and suggestive paper hitherto published upon the microscopical, as distinguished from the bacterial, analysis of water. The method employed consisted, however, simply in the direct microscopical examination of a few drops of the water, and of the sediment obtained from the water after it had stood for some hours, or even days.

Cohn writes as follows: " While the number and the accuracy of the chemical analyzes of water is steadily increasing year by year, the number of microscopical investigations of drinking water is still extraordinarily small. . . . At the same time, there is no doubt that microscopical examinations of drinking waters, properly conducted, will support and supplement chemical examinations, at the most essential points, besides throwing light upon certain questions which the reagents of the chemist are powerless to answer. . . . The plants living in water remove from it, sometimes, during their growth, the minutest traces of calcium carbonate which may be detected as crystals between their filaments. . . . The presence of traces of iron in water, and sometimes of sulphuretted hydrogen, is directly discoverable in certain microscopic algae. But, above all, microscopical analysis gives direct and positive evidence of the kinds and conditions of the nitrogenous substances present, information — both qualitative and quantitative — which chemical analysis but incompletely supplies." Reference will be made to other portions of

[1] Cohn, F. " Ueber den Brunnenfaden (Crenothrix polyspora) mit Bemerkungen über die Mikroscopische Analyse des Brunnenwassers." Beiträge zur Biologie der Pflanzen. I (I), 108. Breslau, 1870.

this paper hereafter, especially in the interpretation of results. As a key to the literature of the subject previous to 1870, and as a memoir of the first importance, it should be in the hands of every sanitary biologist.

In 1879 Hirt,[1] of Breslau, published an article upon the principles and the method of the microscopical analysis of water, in which the method recommended consists in (1) the direct observation of numerous samples of the water taken, a drop at a time, while the sample is fresh: twenty to thirty drops being thus successively mounted and scrutinized; and (2) of an examination of the sediment (if any) deposited by the sample on standing for two to six days; as well as (3) a study of the surface pellicle (if any) which sometimes forms upon the sample after standing. Thirty to forty preparations of the sediment and pellicle are recommended to be made from each sample, and these must be studied till the investigator has clearly made out their character and significance. "Although I must frankly admit that this method of the microscopical investigation of water is still imperfect; that it cannot escape among numerous objections, especially this, — that the amount of water or sediment actually examined is always very small in comparison with the quantity to be tested, — still, on the other hand, I can testify that serious errors do not occur, provided one follows the method closely; and, further, that, so long as no better method exists, biologists will do well to employ this one with confidence." Professor Hirt expressly says that this was the method employed in Cohn's laboratory at that time (1879), and it appears also to have been employed by Hirt and others in a systematic study of the river Oder and the water supply of Breslau, between 1877 and 1881, the results of which have been published in an important paper by Hulwa.[2] The interesting tables which accompany this paper give the microscopical results side by side with the chemical, and probably indicate the highest point reached by such work hitherto, and

[1] Hirt, Professor Dr. L. "Ueber den Principien und die Methode der Mikroscopischen Untersuchung des Wassers." Zeitschrift für Biologie, XV (1879), 91.

[2] Hulwa, Dr. Franz. "Beiträge zur Schwemmkanalization und Wasser-Versorgung der Stadt Breslau." Centralblatt für allegemeine Gesundheitspflege, Ergänzungshefte, I, 89. Bonn, 1885.

previous to the introduction of the more exact methods of bacteriology, in 1881.

Macdonald's "Guide to the Microscopical Examination of Drinking Water"[1] was published (in the first edition) in 1875. The method recommended in the edition of 1883 consists in the collection of the sediment, as follows (p. 4): A tall glass vessel is "filled with the water to be examined, and a circular disk of glass, resting on a horizontal loop at the end of a long aluminum wire, lowered to the bottom, when the whole arrangement, tightly covered, must be set aside for twenty-four or forty-eight hours, as the case may be. At the end of the specified time, the water should be siphoned off with a piece of india-rubber tubing, so as to leave only a thin stratum of the liquid over the glass disk. This should now be carefully raised and laid upon blotting paper, to dry its under surface and remove the surplus moisture, when it may be at once transferred to the microscope, with a large piece of covering glass so placed upon it as to exclude all air-bubbles. An ordinary watch glass may in some cases be substituted for the disk alluded to, with advantage. . . . Another good plan, which is perhaps the better of the two, is to siphon off the water until only a sufficient quantity remains to permit the sediment to be shaken up with it and poured into a tall conical glass, from which, after standing again for a short time, portions may be taken up by means of a pipette, and placed on slides for examination."

To the foregoing outline of the literature of the methods of the Microscopical Analysis of Waters, it only remains to add that the latest, and, without doubt, the best, summary of water analysis hitherto published ("Untersuchung des Wassers," Tiemann und Gartner, 1889), has no better method to propose.

Meanwhile, the development of special methods for the study of the bacteria, and, above all, the introduction by Koch of the method of "solid cultures," have simplified the problem of the microscopical examination of water, by relieving it of its heaviest burden. In the more absorbing pursuit of bacteriology this is not yet generally recognized; but the fact is, that, by the removal of

[1] Macdonald, J. D. "A Guide to the Microscopical Examination of Drinking Water," etc. London, 1883.

the necessity for detecting bacteria by the microscope, it has become a comparatively simple matter to enumerate and examine the remaining micro-organisms.

B. — New Methods: With a Special Account of the Method of Microscopical Analysis Employed at The Lawrence Experiment Station, and in the Monthly Analyses of the Drinking Waters of the State

In the establishment of the Lawrence Experiment Station, the attempt was made to control all the conditions. The engineering problems were well in hand, the chemical problems were thoroughly conceived, the bacterial organisms in water or sewage could be counted and examined; but, at the outset, the microscopical organisms could not be compared, because there was no known method for their quantitative study.

The paradoxical condition actually existed that the extremely minute bacteria (if alive) could be easily estimated as to their numbers, though with difficulty as to their kinds; while the infinitely larger metazoa and algae could indeed be arranged as to their kinds, but not determined as to their numbers. The microscopical organisms in sewage or water were easily classified as "Yeast," "Synedra," "Paramoecium," etc.; but, for quantities, expressions such as "abundant," "scarce," "very abundant," "very scarce," had to be employed. It was obvious, however, that, if a similar systematic and thorough study was to be made of these as of the bacteria, the ammonia, the amounts of liquid applied and recovered, etc., some quantitative method must be devised.

At the request of the chairman of the Committee (Mr. Mills), Mr. G. H. Parker, then biologist to the Board, undertook the examination of the filtered and unfiltered water. The object of these examinations was to determine whether any of the larger organisms, algae, etc., which were known to occur in the unfiltered water, made their way through the filters, and escaped in the filtered water. In order to ascertain whether this were true or not, the following method was employed: Cotton cloth, similar to that by which the organisms in the unfiltered water were detected, was firmly tied over the open ends of the escape-pipes from the filters, and the filtered water allowed to strain through this cloth. When possible, five gallons of water was strained; in many instances, owing to the slowness with which the water traversed the filter, this amount could not be conveniently strained, and the examination was then necessarily made upon smaller amounts. The cloth, after having been removed from the pipe, was inverted (turned inside out) over the lower end of a glass tube, to which it was held firmly, while the worker applied the cloth to an ordinary slide, and blew smartly through the tube from above, down upon the slide. The organisms originally detained upon the inside of the cloth are now upon the outside (after the inversion of it), and are therefore comparatively easily removed from the cloth by a stream (of air) in the reverse direction to that which lodged them upon the cloth. A drop of moisture usually adheres, or may be added, to the cloth, and aids in the detachment. Once upon the slide in a drop of water, the organisms are distributed as evenly as possible, are covered by a piece of thin glass, and examined with the microscope. The number of gallons thus strained being known, and the number of organisms observed being counted, or computed, it became possible to make a rough approximation to the number of organisms actually present.

A modification and improvement of this method, which was devised by Mr. Parker, and was known to the investigators of the Board as the "cloth method," was employed for some months in the microscopical examinations of the drinking waters, ice, etc., of the state, and will be found fully described in Volume I, of the present Report, pp. 581–582. It was superseded by the method now to be described, and known as the "sand method," on June 1, 1889.

In the autumn of 1888, Mr. Alexander L. Kean, at that time a special student in my laboratory, was invited to make, for the Boston Water Works, a series of tests of the efficiency of certain sand filters, in respect to the removal of microscopical organisms; and, being familiar with the methods of the bacteriological examination of air by means of filters of sugar and of sand, he determined to employ a modification of these methods in his work upon water. The necessary concentration of the organisms in the water is effected here, as in the case of air, by filtration through sand, supported, in this case, upon a brass gauze stop in the stem of a funnel. After withdrawing the stop, the sand is washed down into a watch glass by one cubic centimeter of distilled water, delivered from a pipette. Upon stirring the contents of the watch glass, the sand settles to the bottom, and the organisms for the most part remain in the supernatant fluid. A thousandth part of a cubic centimeter of this, with its contained organisms, is then transferred to a slide having upon its surface a concavity containing, when covered, one cubic millimeter. The bottom of the concavity is ruled in squares, which facilitate the counting or computation of the total number of organisms present. It is afterwards only necessary to multiply by one thousand the result obtained from the actual count of the organisms upon the slide, to obtain the number present in the entire cubic centimeter, i. e., removed by filtration from the sample to be examined. An account of this method was published in *Science*, of February 15, 1889.[1] To Mr. Kean, therefore, belongs the credit of having first devised and employed for practical purposes a quantitative method for the microscopical examination of water. If, for example, 100 cubic centimeters were filtered, and yielded 23 organisms in the cubic millimeter, then $\frac{23 \times 1000}{100} = 230$ is the number per cubic centimeter in the original sample.

The most serious defect of this method is that the amount actually examined is too small, compelling the use of a large factor of multiplication, and so limiting the amount actually scrutinized that important organisms may easily be overlooked. Since it is necessary to multiply by 1,000 an error of one in the counting becomes an error of 1,000 in the result; or of 10 per cubic centimeter, if 100 cubic centimeters were originally taken. Moreover, if only one be found in the counting, it must be interpreted to indicate 1,000 in the cubic centimeter in the watch glass, or at least 10 per cubic centimeter if 100 cubic centimeters were originally taken. It is impossible to get a number between 0 and

[1] Kean, A. L. "A New Method for the Microscopical Examination of Water."

10 per cubic centimeter, unless more than 100 cubic centimeters be filtered. It would be necessary to filter as much as a liter, in order to get 1 per cubic centimeter.

Suspecting that this method yielded too high results, I placed the watch glass directly under the microscope, and soon became satisfied that it did not contain quite as large numbers as were indicated by Kean's method. Moreover, it was apparent that, if all the sand and its contents could be directly observed with the microscope, it would be an immense advantage. Accordingly, I constructed a chamber or cell suitable for receiving the sand and the organisms held back, and permitting them to be evenly and thinly distributed over the surface. In reality, this was simply enlarging the cell employed in the previous method, for here, also, the bottom of the cell was ruled in squares; yet the advantage was very great, since the new cell or plate was large enough to permit the examination of all the organisms removed by filtration.

The cell, or counting plate, actually fixed upon after numerous trials, is 50 millimeters in length and 20 millimeters in width, and contains, therefore, an area of 1,000 square millimeters. It is bounded by a brass border, one or more millimeters high and four or five millimeters wide. This rectangular brass border is firmly cemented to an ordinary glass slide of the English form, upon which originally were ruled with a dividing engine 1,000 squares, each one millimeter in area.[1] If the filtration be done as before, and 100 c.c. of water be taken all the sand and the organisms detained by it are washed down into the counting plate or cell, with enough of distilled water directed from a wash-bottle to ensure the covering of the entire bottom. From one to two cubic, centimeters are usually employed for this purpose. The sand and the organisms are now evenly distributed over the bottom by a needle or a piece of wire, care being taken by a rapid survey to make sure of the evenness of distribution and are then examined directly with a rather low power, e. g., the BB objective and 2 or 4 ocular of Zeiss. It is now theoretically possible to count the

[1] For the patient and skillful elaboration of these details, and for the actual construction of a number of accurately ruled plates, I am indebted to Miss C. A. Woodman, formerly a student in my laboratory.

contents of every square millimeter upon the plate; in practice, however, this is neither possible nor necessary. From the start it was found that 20 squares, taken from representative portions of the cell, were as many as could conveniently be counted, though the fact that the entire surface can be rapidly scrutinized is a conspicuous advantage, as affording a check upon the results obtained from the 20 squares. The total number of organisms found in the 20 representative squares must, obviously, be multiplied by 50 to get the number upon the entire surface of the plate. This method, therefore, ordinarily requires the use of 50 as a factor of multiplication, instead of 1,000 as in the previous method. The quantity of water thus really examined is $\frac{1}{50}$ of the quantity originally taken instead of $\frac{1}{1000}$. Thus if 100 cubic centimeters be filtered $\frac{100}{50} = 2$ cubic centimeters are actually scrutinized as against $\frac{100}{1000} = \frac{1}{10}$ cubic centimeter by the previous method. If only a single organism were found, the result would be $1 \times 50 = 50$ in 100 cubic centimeters, i. e., 0.5 organisms per cubic centimeter. Obviously, the method gives no certain means of detecting quantities between 0 and 0.5 organisms per cubic centimeter, unless more than 100 cubic centimeters be concentrated. The possible error may be appreciated in another way. Supposing that there were but one organism in the entire 100 cubic centimeters taken, and that this were found among the 20 squares, the result would be 50 organisms, where but one really existed. If it were not found in the 20 squares or by the rapid scrutiny of the entire surface the result would be zero, and this result would, clearly, be much more likely to be obtained than the other.

After the method had been thoroughly tested in a series of experiments conducted under my supervision by Miss C. A. Woodman, it was introduced into the work of the Board on June 1, 1889, and has since that time been in use at the Lawrence Experiment Station, as well as in the regular microscopical examinations of drinking waters from all parts of the state.

On June 11, 1889, the new method was fully described at the annual meeting of the New England Water Works Association in

Fall River, and a brief account of it was afterwards published.[1] It was adopted during the summer of 1889 by the experts of the State Board of Health of Connecticut, and has been used by them in a long series of investigations of the water supplies of that state. At about the same time, Mr. George W. Rafter, C.E., began a novel and elaborate series of microscopical investigations, under the direction of Desmond FitzGerald, Esq., C.E., Superintendent of the Western Division of the Boston Water Works. The method just described was demonstrated to them in my laboratory and they were furnished with a counting plate. Mr. Rafter soon after introduced valuable improvements in the details of the method, an account of which has since been published.[2]

The first important improvement introduced by Mr. Rafter consisted in the substitution of a ruled square in the eye-piece for the ruling upon the plate. This is obviously a great gain since it removes the necessity of the expensive plates, specially ruled by a dividing engine. The plan adopted by Rafter is to place within the eye-piece a disk of glass, precisely similar to that used for ordinary ocular micrometers, excepting that, in the place of the usual scale it has upon it a ruled square. This is chosen of such a size that it covers one square millimeter upon the ordinary slide. I have found it as well or better to employ in place of the glass disk a blackened metal disk, with a square hole cut out of its centre, since it is not only cheaper and more durable, but allows only the area that is to be counted to be seen.

The only disadvantage of the eye-piece square is that it must be carefully standardized, i. e., made to coincide in outline with a square millimeter actually upon the slide. With different powers this involves some loss of time. It is, then, simply necessary to have for this work, besides the filter and the microscope, (1) a metal eye-piece diaphragm perforated by a square hole of such size that, with the objectives used, it shall easily cover one square millimeter upon the slide; (2) a stage micrometer, ruled in millimeters, or, better, in millimeter squares; (3) slides of the ordi-

[1] W. T. Sedgwick. "Recent Progress in Biological Water Analysis." Journal of the New England Water Works Association. September, 1889.

[2] George W. Rafter, C.E. "The Biological Examination of Potable Water." Proceedings, Rochester Academy of Sciences. 1890. Rochester, N. Y.

nary pattern to each of which is cemented a rectangular brass border, inclosing an area 50 × 20 millimeters.

The second improvement suggested by Mr. Rafter is equally important, since it seeks to do away with the presence of the sand during the counting. I have made very numerous experiments in this direction, trying to find some substance which should serve as a filter and afterwards dissolve. No such substance, however, has been found. Professor S. W. Williston, microscopist to the state Board of Health of Connecticut, informs me that he has introduced precipitated silica in the place of sand, finding that it filters rapidly, yet thoroughly, and distributes itself well upon the counting plate. By working in a different direction, Mr. Rafter has been more successful. He advises the use of larger funnels and comparatively coarse sand, and recommends that 300 to 500 cubic centimeters of the water to be examined be filtered. The sand and organisms are then washed down into a test tube with 3 to 5 cubic centimeters of distilled water. The tube is shaken thoroughly, and the sand allowed, for an instant, to settle. The water is then quickly decanted, and carries with it most of the organisms. One cubic centimeter of this water is then transferred to the counting plate, covered with a piece of thin glass, and examined in the usual way. The use of a brass border one millimeter high provides a chamber holding exactly one cubic centimeter. It will be observed that the principle here involved is the same as that in Kean's method of agitation in a watch glass, and the examination of a portion of the supernatant liquid in a special cell. The advantage of this mode of procedure is obvious. The sand, which constitutes an obstacle in counting, is avoided; the low brass border allows the use of higher powers; and the fatigue of counting 20 squares is diminished. The greatest disadvantage is the surrender of the possibility of inspecting the entire result of filtration. The quantity actually observed remains the same as before, but it is a sample of the material held back by the sand, instead of the entire mass. Some experiments still in progress lead me to believe, however that this disadvantage is less real than appears from a theoretical consideration alone; and it appears to me that these several modifications introduced by Mr.

Rafter are improvements of the greatest value. Mr. Rafter has also devised a simple mechanical stage by which the counting plate is moved one millimeter at a time from side to side or at right angles to this direction. This is undoubtedly a convenience, and it aids in the unbiassed selections of squares to be counted — a point of much importance; but it appears to me of less importance than the improvements already described.

The sand used should be sharp quartz sand, completely clean. " Berkshire " sand is perhaps the best for the purpose. I have been accustomed to use much finer sand than Mr. Rafter; namely, for ordinary drinking waters such as would pass through a sieve having 80 meshes to the linear inch, but not through one having 100. Such sand may be described as " 80 to 100 sand." For the effluents at the Lawrence Experiment Station a still finer sand has been frequently used; viz., finer than 140; i. e., sand which will pass through a sieve having meshes making (nominally) 140 to the linear inch. In order to separate the sand by quickly decanting, as described above, a rather coarse sand must be used; but, on the other hand, more of it can readily be employed. The worker must be left to determine in any particular case the degree of fineness advisable; but a high degree of accuracy is, apparently, never consistent with very rapid work.

The sand is conveniently supported, either by a rolled plug made of fine brass gauze, or better, by a platform of No. 140 brass gauze, made by pushing a strip of the gauze up from below into the funnel stem, by means of a tight-fitting cylindrical punch, such as a glass rod or a piece of coarse wire. The funnel stem must be of even bore, and not flaring.

The greatest care must be taken to secure an average sample of the water to be examined. It must be remembered that diatoms, algae, infusoria and the like, are suspended bodies of different specific gravity, and that they are whirled about by currents, tend to collect in eddies, and in other ways behave far differently from substances in solution. The same considerations should warn us against the expectation of high quantitative accuracy, either in these methods or in those of bacteriology. There is every reason to believe, however, that quantitative results may be obtained by this method of microscopical examination, quite as accurate and trustworthy for the microscopical organisms, as by the methods of bacteriology for the bacteria.

It is obvious that the method permits the direct observation and examination of water, sewage, etc., since it is only necessary to place upon the counting plate or cell, one cubic centimeter of the liquid to be examined. This method is, in fact, employed with sewage, since in it the organisms are abundant; but for water or effluents it is of no use, since the quantity actually inspected is too small to be a fair sample, viz., $\frac{1}{50}$ of one cubic centimeter. With certain modifications the method is also available for the microscopical examination of sands.

Mr. Rafter has done me the honor to state that this new method for the microscopical examination of water should bear my name (*op. cit.*); but, inasmuch as his own improvements now form a most important and indispensable part of it, I venture to suggest that his name be joined to mine in referring to the method. A careful investigation of the Sedgwick-Rafter method, with numerous tests by G. N. Calkins, microscopist to the Board, is already nearly completed, and will appear in the *Twenty-second Annual Report of the Board.*

XXI

INVESTIGATIONS UPON NITRIFICATION AND THE NITRIFYING ORGANISM

By EDWIN O. JORDAN and ELLEN H. RICHARDS

[The importance of nitrification in the purification of sewage was conclusively shown by the Lawrence experiments. This paper by Dr. Jordan and Mrs. Richards describes an attempt to establish the biological basis of nitrification. Part II, *Report on Water Supply and Sewerage*, 1890, p. 865. — G. C. W.]

THE nitrogen of organic substances is, for the most part, liberated during decay in the form of ammonia or ammoniacal compounds; and these substances yield, by oxidation, nitrous acid and finally nitric acid, which, in turn, in the form of nitrates feeds the living plant, and thus begins again the cycle of transformation.

The oxidation of the nitrogen of ammonia, and its ultimate conversion into nitric acid, is called nitrification. This change is especially active in soils near the surface, where nitrates are formed abundantly from percolating waters which contain much nitrogenous matter.

This phase of nitrification, the formation of nitrates in porous soil, has been attentively studied. But less attention has been given to the process of nitrification as it goes on in surface waters, such as streams and ponds; and it is to this side of the question, namely, nitrification as it occurs in natural waters, that our study has been chiefly directed.

Some eighty samples of water, selected from the two hundred and forty coming each month to the laboratory of the State Board of Health, were examined at intervals of from two to seven days for ammonia, nitrites and nitrates. These samples were received from all parts of the state, and included all classes of surface water, rivers, ponds, and reservoirs. They were examined repeatedly during the months of June, July, and August, 1888.

The results may be briefly stated as follows. The organic matter in suspension decays in about seven days, as is shown by the increase in "free ammonia." In about fourteen days this "free ammonia" has disappeared, and nitrite has taken its place, reaching a maximum in about twenty-one days. Later the nitrite too disappears, and in twenty-eight days or more all the nitrogen has been converted into the form of nitrate. When the suspended matter is removed by filtration through paper or by precipitation with alumina, no change occurs unless free ammonia were present at the outset.

These changes were so universal and so independent of the character of the water and of its condition of aëration, that it seemed important to avail ourselves of the unusual opportunity offered by the close proximity of the chemical and biological laboratories of the State Board of Health, to carry on a series of chemical and bacteriological investigations on solutions of known composition. Accordingly we began a series of experiments covering a period of nearly two years, in which the daily and weekly changes caused by the growth of bacteria were watched from both the chemical and the bacteriological standpoint, in order to determine the sequence and rate of such changes. Other points came up in the course of the work, as will appear from the following pages.

There are thus several views which are held regarding the action of individual species of bacteria on nitrogenous solutions:

1. That there is a group of bacteria capable of oxidizing ammonia to nitric acid, and another and separate group able to reduce nitrates to nitrites in the presence of organic matter. Both kinds are widely and abundantly distributed. Attendant circumstances determine whether the reducing or the oxidizing group will gain the upper hand. (Heroeus.)

2. That all kinds of bacteria, under favorable circumstances, are capable of producing nitric acid, and that the same organisms in the presence of organic matter are capable of reducing nitrates. (Celli and Zucco. Leone.)

3. (*a*) That different species of bacteria vary greatly in their ability to reduce nitrates; and (*b*) that there is no reliable evidence that any individual species is able to oxidize ammonia either to nitric or nitrous acid. (Warington. Frankland.)

Such is a brief sketch of the divergent opinions upon nitrification which were held at the time we[1] began our work in the autumn of 1888. It seemed to us important to approach the subject from all sides, and we have worked accordingly not only with pure cultivation of bacteria, but also with various sands, soils, and waters containing mixtures of several kinds. We have considered it of fundamental importance to determine the distribution of the nitrifying organism, and, if possible, to ascertain the relative frequency with which it occurs over a wide area. The question, for instance, naturally arose, is the nitrifying organism present in the Boston city water as delivered from the tap in the laboratories of the Massachusetts Institute of Technology, since this is the water used in making up our solutions? To this question we are able to give a decided affirmative. Ammoniacal solutions carefully made with tap water always nitrify. Moreover, ammoniacal solutions which have been sterilized and then inoculated with a cubic centimeter of fresh tap water always nitrify. Repeated experiments show that the nitrifying organism is invariably present in this water. When, however, ammoniacal solutions were inoculated from the separate colonies appearing on a gelatin plate culture of this water, in every instance there has been obtained only a negative result. To this matter of inoculation with pure cultures of bacteria we shall recur presently.

In many of our early experiments upon nitrification we used a mixture of one cubic centimeter of fresh urine with two liters of tap water. This mixture was found to yield, when freshly made, about 0.5000 free ammonia, 0.2000 albuminoid ammonia, 0.0002 nitrites and 0.0250 nitrates, in 100,000. This nitrogenous solution was allowed to stand at the temperature of the room (21°–23° C.), and was tested from time to time for nitrites and nitrates. The method used for the determination of nitrites has been Griess's naphthalamine method. This method is sufficiently delicate to detect the presence of one part of nitrogen as nitrite in one thousand millions. The method for determining nitrates is a

[1] The series of experiments detailed in this paper were planned and carried out jointly by the authors, the bacteriological portion of the work being done by Mr. Jordan, and the chemical portion by Mrs. Richards.

modified form of the phenolsulphonic method of Grandval and Lejoux.

The following tables contain the results of a few experiments out of the many hundreds which we have made with solutions of nitrogenous substances: —

TABLE 38

ILLUSTRATIONS OF NITRIFICATION IN NATURAL WATERS

A. Ground Water

[Parts per 100,000]

From Westborough, 1st Sample — *From Westborough, 2d Sample*

	Nitrogen as					Nitrogen as			
	Albuminoid Ammonia	Free Ammonia	Nitrites	Nitrates		Albuminoid Ammonia	Free Ammonia	Nitrites	Nitrates
1888					1888				
June 26.......	.0047	.0347	.0000	.0020	July 18	.0035	.0412	.0000	.0020
After 8 days..	..	..	.0000	..	After 8 days .	..	..	.0001	..
" 16 " ..	..	..	.0320	..	" 16 " .	..	..	.0067	..
" 20 " ..	..	..	.0360	..	" 20 " .	..	..	.0400	..
" 27 " ..	..	..	.0000	.0280	" 27 " .	..	..	.0000	..
" 31 " ..	..	..	.0000	.0300	" 31 " .	..	..	.0000	.0320

B. Surface Waters

[Parts per 100,000]

Ludlow Reservoir, Springfield — *Birch Pond, Lynn*

	Nitrogen as					Nitrogen as				
	Albuminoid Ammonia in Solution	Albuminoid Ammonia in Suspension	Free Ammonia	Nitrites	Nitrates	Albuminoid Ammonia in Suspension	Albuminoid Ammonia in Solution	Free Ammonia	Nitrites	Nitrates
1888										
When collected ...	.0059	.0176	.0110	.0000	.0020	.0038	.0178	.0006	.0000	.0000
After 9 days.....	..	..	.0222	..	..	..	..	.0083	.0036	..
" 21 "	..	..	.0145	.0060	..	..	..	..	.0087	..
" 27 "	..	..	..	.0000	.0280	..	..	..	.0005	..
" 47 "	..	..	..	..	..	..	..	..	..	.0250

Not only is the nitrifying organism present in Boston tap water, as the above experiments clearly demonstrate, but it appears to be equally common in water from all parts of the State of Massachusetts. So far as our experience has gone, any natural water, containing the ordinary amount of free or albuminoid ammonia, contains also the nitrifying organism, as is shown by our long series of tests. In these natural waters the nitrifying organism seems to be under wholly normal conditions, and to be abundantly able to effect the oxidation of the small quantities of nitrogen usually present in these waters. Waters that contain high "albuminoid ammonia," in cases where this "ammonia" comes from the nitrogen in infusoria, algae, etc., go through the same changes as those which contain "free ammonia," but more slowly. The organisms in time die, the bacteria set free the nitrogen of their bodies, forming free ammonia, and then in turn nitrites and nitrates.

It might, perhaps, be reasonably expected that, since the nitrifying organism is undoubtedly present in all these waters, an examination of gelatin plate cultures of these waters would reveal some particular kind or kinds of colonies common to all, and in that way aid in sifting out the nitrifying organisms. Our experience has shown, however, that such a hope is unfounded. So far as the inspection of gelatin plate cultures enables us to judge, no one kind of colony is common to all these waters. This fact, on the surface, seemed to favor the view that the power of nitrification was not the property of any particular organism, but was very likely possessed in common by a number of kindred species.

The other line of bacteriological work — the inoculation of nitrogenous solutions with pure cultures of isolated bacteria — has been followed up from the outset, and was begun with full confidence in ultimate success. It is unnecessary to give a detailed account of our experiments in this direction. It is sufficient to say that the nitrogenous solutions have, from beginning to end, failed to nitrify. Nitrogenous solutions of various sorts have been used, pepsin solutions, peptone solutions, ammonium chloride solutions, Frankland's solution,[1] etc., all with the same

[1] Zeitschr. für Hygiene, Bd. VI, 1889, p. 376.

unfailingly negative result. A large number of species of bacteria have been used for inoculation, not only well-known species like B. prodigiosus, B. megaterium, Proteus, etc., but many species freshly isolated from water, sewage, the sand of nitrifying filter tanks, and similar favorable situations for the nitrifying organism. The experiments have been always prolonged for several months, and in some cases for more than a year. Conditions of temperature, amount of surface exposed to the air, etc., have been varied in many directions. Nitrogenous solutions containing a single species of bacterium have been poured upon sterilized sand, and allowed to settle in such a way as to imitate closely the conditions obtaining in filter tanks. In all, more than one hundred and fifty experiments have been made, covering a period of two years. In every case, without a single exception, there was not the slightest evidence of nitrification by any single species.

There still remained a plausible explanation of this striking succession of negative results. It might be that, although any one species working alone was not able to effect nitrification, a number of different species working together might be able to produce the desired result. This was certainly not an unreasonable supposition, judging from analogous fermentative processes; co-operation and combination might perhaps effect more than individual and independent action. Several experiments were accordingly made with the view of determining this point. Here again the results were invariably negative. Ammoniacal solutions, inoculated with mixtures of several species under pure cultivation, always failed to nitrify. In one experiment, for example, a nitrogenous solution, found by experience to nitrify rapidly and completely when seeded with garden soil, was inoculated with a mixture of six different species of bacteria. These six species were all isolated from soils and waters known to contain the nitrifying organism. An examination of the solution from time to time, by the method of gelatin plate culture, showed a vigorous growth on the part of all the species, but there was at no time the slightest evidence of nitrification, although the experiment continued for upwards of five months.

Hardly were our experiments well under way, before our interest was stimulated by the publication of communications by Percy F. Frankland and Grace Frankland, and by Robert Warington.[1]

The Franklands, having reached a conclusion similar to our own regarding the behavior of the nitrifying organism in gelatin, had also attempted to isolate the nitrifying organism by the dilution method, and had succeeded in this attempt. They state, in their abstract of the paper read before the Royal Society, that, " after a very large number of experiments had been made in this direction, the authors at length succeeded in obtaining an attenuation consisting of about 1–1,000,000th of the original nitrifying solution employed, which not only nitrified, but, on inoculation into gelatin-peptone, refused to grow, and was seen under the microscope to consist of numerous characteristic bacilli, hardly longer than broad, which may be described as bacillo-cocci."

Warington's communication entirely confirms that of the Franklands, in so far as it relates to their earlier and negative results. He had not, however, at the time of writing, succeeded in isolating the nitrifying organism.

A paper by Winogradsky followed soon after. He appears to have discovered independently a nitrifying organism, and attributes his success largely to his microscopic examinations of the nitrifying solutions, and to his use of solutions devoid of organic matter. The following is the composition of the liquid finally adopted by him:—

Ammonium sulphate	1 grm.
Potassium phosphate	1 grm.
Water from the lake (at Zurich, *très pure*)	1,000 grms.

Each portion of 100 cubic centimeters received in addition 0.5 to 1 grm. of basic magnesium carbonate, suspended in distilled water. Winogradsky found that this layer of magnesium carbonate at the bottom of each flask afforded an excellent gathering place for flocks of the nitrifying organism. The " nitric ferment " does not, as the Franklands had already shown, grow well upon ordinary gelatin plate cultures; and this is probably the cause of the failure

[1] The Chemical News, Vol. LXI, p. 135, March 21, 1890.

of all previous experimenters to isolate the special ferment. For Winogradsky's detailed description of the nitric ferment, and for a statement of his peculiar views concerning its function, " de regulariser la circulation du carbone sur notre planète," we must refer to his original papers.[1]

Before receiving Winogradsky's paper, in the spring of 1890, we had been using in our work, at the suggestion of Mr. Allen Hazen, an ammoniacal solution of the following composition: —

Ammonium chloride (resublimed)	1.9070 grms.
Sodium carbonate	3.7842 grms.
Sodium phosphate	.2000 grm.
Potassium sulphate	.2000 grm.

These salts were dissolved in such a quantity of redistilled water that the solution contained 100 parts of nitrogen per 100,000, and two equivalents of alkali. Ten cubic centimeters of this solution were mixed with one liter of redistilled water, and then inoculated as desired. The flasks used have been made chemically clean by boiling with potassium permanganate, and the water used has been twice distilled. The other rigid precautions absolutely necessary in all work of this character have always been taken. The solutions thus prepared have contained from 0.0001 to 0.0010 parts per 100,000 of albuminoid ammonia.

Proceeding with this solution by the method of dilution, we at length succeeded in isolating a nitrifying organism. A flask was first inoculated with a few grains of sand from Tank No. 13, at the Lawrence Experiment Station, and when nitrification was at its height in this solution, a small portion was transferred from this to a second flask, and so on. After a large number of unsuccessful attempts, two solutions were finally obtained which nitrified well, but gave no growth upon ordinary gelatin plate cultures, although the plates were allowed to stand for seven days. Microscopic examination of these solutions showed them to be inhabited by a particular form of bacillus, and apparently by that alone. These bacilli are short, of a slightly oval shape, and vary from 1.1 μ to 1.7 μ in length; they are about 0.8 μ to 0.9 μ broad. They are grouped very characteristically in irregular clumps, and are held

[1] Annales de l'Institut Pasteur. Tome IV, 1890, No. 4, p. 213; No. 5, p. 257.

together by a jelly-like material. Each aggregation is indeed a typical zoögloea. The aggregations of bacteria were found chiefly on the bottom of the flasks, as was also the case with the organism described by Winogradsky. These masses of zoögloea, obtained as a pure culture from a nitrifying solution, resemble significantly the zoögloea discharged in considerable quantities from the filter tanks at Lawrence. The bacilli stain with some difficulty with the usual aniline dyes. We have not observed independent movement. Owing to the lack of the usual means of diagnosis, it is difficult to determine in a short time whether this species is the same as the one described by the Franklands and by Winogradsky. On one important point there appears to be a difference between our results and those reached by the above-mentioned investigators. The organism discovered by them oxidizes ammonia to nitrite, but carries it no farther. Our own flasks give complete oxidation to nitrate. Whether this be due to a difference of conditions, a difference in the virility of the organisms, or a specific difference in the bacteria, we are not at present prepared to say. The short time at our disposal has made it impossible to settle this and many other questions to our own satisfaction. We are not even prepared to say that there may not have been a mixture of two or more species in our flasks, all agreeing closely in morphological characters, and in giving no growth on gelatin, but differing in important physiological respects. Further investigation is necessary to settle this and other important points regarding the relations of this organism to the process of nitrification.

Whether or not we accept the views of Winogradsky, it is certainly worthy of remark, as he observes, that an organism should exist, which, without chlorophyll and in the apparent absence of organic nitrogen and of organic carbon, should be able to multiply and thrive upon wholly inorganic compounds. It may well be doubted, we think, whether this is really the case. It seems more reasonable to suppose that exceedingly minute quantities of organic nitrogen and carbon are actually present, and escape detection by our present methods of chemical analysis, although in reality sufficient to nourish generations of bacteria.

Our own experience, as well as that of previous investigators, seems to be a warning against a too confiding use of the gelatin plate culture in bacteriological work, since in this instance such confidence has left us for a long time in ignorance of a common and widespread as well as highly important organism.

XXII

THE INTERPRETATION OF WATER ANALYSES

By Thomas M. Drown, M.D.

[In Part I, of the *Report on Water Supply and Sewerage*, 1890, p. 517, Dr. Drown published a report, now rightfully regarded as a classic, on water analyses and their interpretation. The article here reprinted is practically a summary of the former work. *Twenty-fourth Annual Report*, 1892, p. 319. — G. C. W.]

The value of a sanitary analysis of water rests on its interpretation. It has little in common with an analysis made for the purpose of determining specific substances. The result of an analysis of a mineral water, for instance, in which the amounts of various mineral substances are given, is a statement of fact which needs no interpretation. But in the case of a sanitary analysis the results must be considered in connection with a great number of conditions, such as locality and surroundings of the water, the season of the year, depth of lake or pond at which the sample is taken, and a great many more. To take one illustration only: an amount of chlorine in a water in one locality, which would be without significance, would in another be an evidence of considerable pollution with sewage. It is the object of the present article to give very briefly the conditions governing this interpretation, and the reader is referred to an article on the same subject in the volume on the "Examination of Water Supplies," 1890, in which the subject is treated at greater length.

The object of a sanitary analysis of water is to determine the amount of mineral and organic matter dissolved and suspended in the water, and also, as far as it is possible, to determine the character and condition of the organic matter. The microscope is a valuable aid in this connection, as it enables us to recognize forms of vegetable and animal life, and also at times the products of their disintegration and decomposition. The appearance of the water is also carefully noted, the amount and character of its permanent turbidity and sediment, and also its odor, both cold and hot.

Organic matter, both animal and vegetable, is composed mainly of carbon, hydrogen, nitrogen and oxygen, united in various proportions. Animal matter contains generally much more nitrogen than vegetable matter, and decomposes more rapidly. By decomposition is meant the gradual oxidation of the carbon, hydrogen and nitrogen of the organic matter, whereby these elements are converted into carbonic acid, water, and nitric acid (nitrates). In this process of oxidation the carbon first combines with the oxygen, and ammonia (a combination of nitrogen and hydrogen) is formed. This ammonia is next oxidized, the hydrogen to water and the nitrogen first to nitrous acid (nitrites) and ultimately to nitric acid (nitrates). Carbonic acid, water and nitric acid are the final results of the complete oxidation or mineralization of the organic matter, while ammonia and nitrites are intermediate products, and represent decomposition in progress. These chemical changes are the result of the activity of micro-organisms, and do not take place in their absence.

Owing to the fact that many of the compounds of nitrogen can be determined with great accuracy and facility, it is usual to determine organic matter in water, and the extent of the change which it has undergone by decomposition, by means of the amount and condition of the nitrogen. Thus we determine the amount of the nitrogen existing in the organic matter which has not yet begun to decompose (organic nitrogen — albuminoid ammonia), the amount existing as ammonia, the amount in the form of nitrites, and the amount in the form of nitrates.

Other methods of determining organic matter in water are by means of the " oxygen consumed," when the water is treated with potassium permanganate, and by the " loss on ignition," when the solid residue of the evaporation is heated to dull redness. The " fixed residue " after ignition represents the amount of mineral matter in the water. The determination of chlorine expresses the amount of common salt in a water, and is a measure of the degree of pollution by sewage or house drainage, as will be subsequently described.[1]

[1] For the methods of analysis, the reader is referred to the special reports of the Board on the " Examination of Water Supplies," and the " Purification of Sewage," 1890.

The differences in surface and ground waters are so great and radical, the former containing always more or less vegetable and animal life, and the latter being (normally) free from life, it is necessary to consider the significance of the different determinations in these two classes of water separately.

Albuminoid Ammonia

Albuminoid ammonia represents the nitrogen in organic matter which has not yet begun to decompose by oxidation. As ordinarily determined by the methods of the State Board of Health, it is about one-half of the total nitrogen in the unaltered organic matter. It affords in itself no indication whether the source of the nitrogen is animal or vegetable matter. In surface waters which are unpolluted by sewage we find a very wide range in the amounts of albuminoid ammonia. Brown swampy waters always contain a large amount in solution, and waters with abundant vegetable growth have in addition a considerable amount in suspension. Following are a few instances, the average amount during many years, of albuminoid ammonia in unpolluted ponds and reservoirs: —

Table 39

[Parts per 100,000]

	Color	Free Ammonia	Albuminoid Ammonia	
			Total	Suspended
Lenox, Storage Reservoir.	....	.0001	.0028	....
New Bedford Storage Reservoir	1.36	.0015	.0248	.0018
Springfield, Ludlow Reservoir	0.15	.0019	.0381	.0154
Leominster, Haynes Reservoir (average)	0.39	.0023	.0409	.0133
Leominster, Haynes Reservoir, August, 1887	0.60	.0006	.1052	....
Lynn, Walden Pond	1.21	.0058	.0615	.0212

An average analysis of Lawrence sewage shows 0.5302 part albuminoid ammonia, and 1.8202 parts of free ammonia per 100,000. It would therefore take more than twenty per cent of sewage added to a pure body of water to raise the amount of albuminoid ammonia to the amount found in one instance in Haynes Reservoir. Instances might be multiplied to show that high albuminoid ammonia is in itself no evidence of sewage pollution. In most surface waters the source of the albuminoid ammonia is to be sought in organic matter derived from vegetable growths in the water, from vegetable débris in the bottoms of ponds and reservoirs, and also from swamps. In the latter case the water has a brown color. New Bedford water, cited above, is a good instance of a water highly colored with vegetable matter. Neither is high albuminoid ammonia, when accompanied with high free ammonia, necessarily indicative of sewage pollution.

The rapid decomposition of animal and vegetable matter, when in excessive amount, gives rise also to high free ammonia. Thus one analysis of water from Glen Lewis Pond, in Lynn, November, 1891, has 0.1060 part of free ammonia with 0.0606 part of albuminoid ammonia. Considerable sewage pollution of a body of water is, nevertheless, accompanied by high free and albuminoid ammonia. Thus the average analysis of the highly polluted Blackstone River below Worcester for 1891 shows 0.3340 free ammonia and 0.1563 albuminoid ammonia. The point which it is desired to emphasize is that coincident high free and albuminoid ammonia do not necessarily indicate sewage pollution.

In good ground waters albuminoid ammonia is frequently entirely absent, and rarely exceeds 0.0025 part per 100,000. When it is much more than this, the excess may be due to an admixture of surface water, or to imperfect filtration. Thus the average albuminoid ammonia of the well at Ware was for two years 0.0011; for the wells at Eaton's Meadows, Malden, for 1891, 0.0007. Instances of imperfect filtration are seen in Wayland and Whitman, where filter-galleries alongside of ponds show respectively 0.0186 and 0.0188 albuminoid ammonia. In contrast with these cases of imperfect filtration may be mentioned the water in filter-gallery on the borders of the highly polluted Horn Pond in Woburn, in which the albuminoid ammonia is ordinarily only 0.0028 parts in 100,000.

When a ground water containing considerable nitrogen in the form of nitrates is exposed to light in open reservoirs, the conditions are particularly favorable for a rapid growth of algae, which appear in the analysis as albuminoid ammonia. By reason of this exposure to the light, the ground water has become a surface water, and must be classified accordingly.

Free Ammonia

Free ammonia is always a decomposition product of organic matter. In itself it is harmless mineral matter; its significance in water analysis rests on the fact that it may be accompanied by organic matter in the process of decomposition, or that it may indicate the presence of sewage, of which free ammonia is one of the characteristic ingredients.

In good clean ponds, unpolluted by sewage, the free ammonia is very rarely high, for as fast as it is formed by the decomposition of the vegetable and animal organisms in the water it is immediately appropriated by growing water plants.

For instance, the average of monthly determinations for two years of free ammonia in Watuppa Lake, Fall River (a light-colored water), was 0.0005 part per 100,000; in Reservoir 4 of the Boston Water Works (in a moderately dark-colored water), 0.0006 part; and in Acushnet Reservoir, New Bedford (a very dark-colored water), 0.0015 part per 100,000. In bodies of water which receive much sewage the free ammonia may be in much greater quantity than the plants can appropriate. Thus the average of free ammonia in Horn Pond, Woburn (which receives a large amount of wastes from tanneries), for two years was 0.0152 part per 100,000, and in Mystic Lake the amount was 0.0235 part.

The amount of free ammonia in the warmer months, when the vegetation is most active, is lower than in the colder months. Thus in Mystic Lake in August, 1888, the free ammonia was entirely absent, while in January of the same year it was 0.0573 part per 100,000. Even in clean, unpolluted ponds the free ammonia is generally higher in winter, although it seldom reaches any considerable amount. The highest winter free ammonia noticed in Reservoir 4 of the Boston Water Works, at a depth of one foot, was in January, 1891, when it was 0.0028 part. In reservoirs which have been flooded, without the removal of the soil and stumps of trees, the decomposition of the vegetable matter may be so rapid in summer that the free ammonia formed is greatly in excess of that which the plant growth can absorb. Glen Lewis Pond, Lynn, is a reservoir of this character. The average free ammonia for 1890 was 0.0412 part per 100,000; and in September of that year it was 0.1390 part.

The depth of the water has also an influence on the amount of free ammonia. The lower layers of deep ponds are stagnant in summer, and when the bottom contains much decomposable organic matter the oxygen is quickly exhausted, and putrefaction sets in with the formation of much free ammonia. In clean ponds and reservoirs this tendency is not strongly marked. For instance, the bottom stagnant layer of water of Reservoir 4 (a basin carefully cleaned before filling), at a depth of forty feet, rarely reaches 0.0050 part in free ammonia, while the bottom layer in Jamaica Pond, Boston (fifty feet from the surface), has been known to contain nearly 0.5000 part per 100,000. This condition of affairs is apt to occur also when the supply of oxygen is shut off from a water which contains much decomposable organic matter, as, for instance, when a stream or pond is for a long time covered with ice.

The significance of free ammonia in ground waters is of entirely different character from that in surface waters, owing to the fact that no free growth can take place in the absence of light. The oxidation of the nitrogen of ammonia to nitric acid goes on so rapidly in the pores of the ground near the surface where air is abundant, that it is unusual to find any unoxidized nitrogen in natural ground waters. That is to say, the nitrogen in these waters is usually entirely oxidized, and appears in the form of nitrates. The presence of free ammonia in a ground water is an indication of imperfect purification of a water which has contained organic matter. As instances may be taken the water of wells at Eaton's Meadows, above cited, which shows by its high nitrates that the water originally contained a large amount of nitrogen in the form of organic matter or ammonia, and the water of the well in Stoughton, which is likewise high in nitrates. In the first instance free ammonia is almost always absent, averaging 0.0002 part for a year, while in the latter it is almost always present, averaging 0.0013 part for a year. Many house wells in close proximity to cesspools contain very high free ammonia, as the result of incomplete oxidation of the ammonia in the passage of the foul water through the ground.

But while we generally refer the presence of free ammonia to imperfect oxidation of organic matter of house drainage or sewage, there are cases in which the ammonia has its origin in vegetable organic matter in the ground itself. Thus the water of the filter-gallery on the shores of the storage reservoir of the Wayland Water Works always contains considerable free ammonia, while the water in the reservoir contains very little. There are several cases of like character in the state, and they are all associated with iron oxide and the fungus *Crenothrix*. The existence of organic matter and sesquioxide of iron in the soil together, in the absence of oxygen, are the favorable conditions for the oxidation of the organic matter by the oxide of iron (with the formation of ammonia), the development of *Crenothrix*, and the solution of the iron in the form of protoxide, which separates out in the form of iron rust when the water is exposed to the air. Many wells sunk in swampy regions and in ferruginous river silt show the same phenomena.

Continuous pumping of new wells in these situations is frequently followed by a gradual increase of free ammonia and iron in solution, as the result of drawing water from these ferruginous organic deposits. The odor of these waters is often disagreeable from dissolved sulphuretted and carburetted hydrogen.

The water from deep artesian wells not infrequently contains considerable free ammonia. Its origin is not always known, but the topographical and geological conditions preclude the possibility of this free ammonia having any connection with sewage pollution. This ammonia in some cases is associated with coal deposits, which always contain nitrogen. Other geological formations also contain organic matters, and may give rise to ammonia. There is no free oxygen in deep waters, and consequently no possibility of the ammonia becoming oxidized to nitrates.

Rainwater always contains considerable ammonia which it washes out of the atmosphere. A sample collected at Lawrence, October, 1888, had 0.0414 part, and a sample of snow collected at Jamaica Plain, Boston, December, 1887, 0.0258 part, per 100,000. The atmosphere of cities contains much more ammonia or other impurities than in the open country, and the rain or snow first falling is always the most impure.

Rainwater stored in cisterns generally retains its free ammonia.

Nitrites

Nitrous acid (forming nitrites when combined with bases such as potash, soda or lime) is an intermediate product of oxidation of the nitrogen of ammonia. In unpolluted surface waters it is generally absent, or present only in very minute amount, rarely exceeding a yearly average of 0.0002 part per 100,000. In waters which receive sewage, or highly nitrogenous manufacturing refuse, however, the amount of nitrogen in the form of nitrites is considerably higher. The average for Horn Pond was, for 1891, 0.0009 part, for Abbajona River 0.0021 part, for Mystic Lake 0.0012 part, for the Blackstone River below Worcester 0.0032 part, and for the Neponset River at Hyde Park, during 1887–89, 0.0082 part, per 100,000. High nitrites in a surface water, say above 0.0005 part, together with high free ammonia, is an evidence of considerable sewage pollution.

In good ground waters nitrites are always absent. When nitrogen is present in this form in a ground water it is an evidence that the oxidizing capacity of the earth through which the water percolates is insufficient to oxidize completely the nitrogen it contains. As in the case of surface waters, coincident high nitrites and ammonia in a ground water point to pollution by sewage or house drainage, which has not been completely purified by filtration.

Nitrates

Nitric acid is the completely oxidized form of nitrogen. In waters it is combined with alkalies or with lime, forming nitrates. Potassium nitrate is ordinary saltpetre. One might expect that this mineralized condition of nitrogen would accumulate in waters. But, like ammonia, it is a plant food, and in surface waters it is quickly taken up by growing plants. Hence, in good unpolluted ponds and reservoirs the nitrates are always low and often absent. They are lower in the warmer months, when the vegetation is most active. Middleton Pond, an unpolluted body of water, had an average contents of nitrogen as nitrates during 1891 of 0.0053 part per 100,000, the highest amount being 0.0200 part in March; in September and October nitrates were entirely absent in this water. In Horn Pond, which is highly polluted, the average contents of nitrates were in 1891 0.0502 part, the highest, 0.1000 part, occurring in January, and the lowest, 0.0050 part, in August. Stacy's Brook, in Swampscott, a very highly polluted stream, had an average of 0.1149 nitrates for two years, the highest being 0.4000 part.

In unpolluted ground waters the nitrates are also very low. The source of nitrates in these waters is decomposing surface vegetation. Vegetable matter, such as leaves, grasses, mosses and peat, are not highly nitrogenous, and, moreover, decompose very slowly. The ammonia and nitrates are largely taken up by the roots of plants, and but little nitrogen in the form of nitrates penetrates into the ground water. A good illustration is found in the water of the well of the Mansfield Water Works, in which the average of four determinations for a year gave only 0.0083 part of nitrogen as nitrates, the lowest being 0.0050 part and the highest 0.0120 part, per 100,000. In striking contrast to this is the water of wells situated in populous regions, in which the drainage from houses and cesspools is oxidized in its passage through the ground, and the nitrates accumulate in the ground water. The amount of nitrogen as nitrates in the water of the wells at Eaton's Meadows is about 0.5000 part, and is remarkably constant. The nitrates in the well at Stoughton are still higher, namely, 0.8280 part, and the spring waters of Everett contain from 0.4000 to 1.1500 parts per 100,000. Nitrates when present in these large amounts represent considerable previous pollution of the water by sewage (or its equivalent in house drainage); but as far as the nitrates themselves are concerned they indicate complete oxidation of organic matter to harmless mineral matter. When high nitrates are associated with free ammonia or with nitrites, it is an evidence that the oxidation of organic matter is incomplete.

The effect of exposing water high in nitrates to light in open reservoirs has already been referred to. The rapid growth of algae which takes place under these conditions is generally accompanied by disagreeable tastes and odors.

CHLORINE

It has been found within the State of Massachusetts that the amount of chlorine (indicating the amount of common salt) in waters of streams and ponds in uninhabited drainage areas is tolerably constant in each locality. This amount decreases from the seaboard westward, and there is sufficient evidence to prove that the chlorine in the unpolluted waters of Massachusetts has its source in the sea, and is carried inland by easterly winds. By placing on the map of the state the amount of chlorine normally present in its unpolluted waters, and then connecting the points of equal amounts, lines of like chlorine contents are obtained which are called isochlors. In the volume of "Examination of Water Supplies," 1890, and in the *Twenty-second Annual Report of the Board*, this map is given. From it will be seen that the waters near the coast contain normally about 0.65 part of chlorine per 100,000, and in the western part of the state the amount sinks to less than 0.10 part.

The application of this map as a test of pollution is very simple. Having determined the amount of chlorine in a water, this is compared with the amount which the normal or unpolluted waters of the region contain. Any considerable excess above this normal is an evidence and measure of the amount of pollution, which directly or indirectly, the water has received.

In the case of the nitrogen compounds in water, it has been noted that they may undergo many transformations, but with common salt there is no change in its amount or character, either in surface or ground waters. A highly polluted water may be completely purified by filtration through the ground, but the chlorine remains to tell the tale of its origin. High nitrates in ground waters are always accompanied by an amount of chlorine which is much above the normal. A fuller discussion of the subject of normal chlorine may be found in the volume on the "Examination of Water Supplies," pages 542–545, 679–682.

Oxygen Consumed

When a solution of potassium permanganate is added to a water containing organic matter, a certain amount will be decolorized, showing that the permanganate has parted with some of its oxygen in oxidizing the carbon of the organic matter. There are various methods of conducting this process; the one used in the work of the State Board of Health is that known as Kubel's, in which the water is boiled with the permanganate for a definite time, about five minutes. The amount of oxygen that the permanganate gives up under these conditions is recorded as the "oxygen consumed" by the organic matter in the water. It is only the carbon of the organic matter that is thus oxidized, and only an indeterminate amount of this carbon. Different organic compounds behave very differently when thus treated, and the determination has therefore no precise value. It is mainly in comparing waters of the same character, or in comparing sewage or other polluted liquids with the effluents derived from their purification, that it has its principal value. The determination is also of value as applied to well waters. A good ground water seldom has a higher "oxygen consumed" than 0.0100 part per 100,000. When it is considerably more than this, it indicates carbonaceous impurity in the water.

Hardness

The hardness of a water, as expressed in a water analysis, is the amount of soap-curdling substance equivalent to a like amount of carbonate of lime. Thus a hardness of two means that the water has a hardness which would be produced by two parts of carbonate of lime in 100,000 of water. High hardness in a water is ordinarily caused by lime and magnesia which the water has dissolved from rocks, or by the infiltration of sea water which also contains lime and magnesia. In localities where the hardness could not be derived from these sources it has its origin probably in sewage contamination. Unpolluted waters in Massachusetts, except in the extreme western portion, have a hardness of five-tenths to two parts.

IRON

It was mentioned above in connection with free ammonia that many ground waters contain iron in sufficient amount to produce a rusty precipitate when the water is exposed to the air and the iron oxidized. This amount of iron unfits a water for domestic use. Surface waters rarely contain much iron in solution. The brown swampy waters contain usually the most. When these waters are bleached by exposure to the sun, the iron is precipitated; but under ordinary circumstances this does not take place. When a ground water contains 0.0500 part of metallic iron per 100,000 in solution, it will generally precipitate on standing. The determination is of special importance in the case of new ground water supplies, for a constant increase, on continued pumping, even though the amount may be very small at first, points to a time when the amount of iron will become excessive.

Some ground waters contain also considerable manganese, which is dissolved from the ground under the same conditions that cause the solution of iron.

COLOR

The color of surface waters is mainly due to organic coloring matter which the water has dissolved from leaves, grasses, mosses, peat, etc., particularly where the water flows sluggishly through swamps. The standard of measurement has been described in the Methods of Analysis, in the volume on the "Examination of Water Supplies." The average color of Boston water is about 0.35, of New Bedford water 1.36, of Wenham Lake 0.05, of the Plymouth ponds 0.0. Ground water is ordinarily colorless. A notable exception is the dark brown water from wells in Provincetown, which penetrate a peaty layer under the sand. Ground water containing iron in solution acquires a reddish-brown color when the iron begins to oxidize. The water under these conditions assumes a milky appearance. Ultimately, however, this very fine suspended iron oxide separates out, and the water becomes again colorless.

Odor

The cause of the odor in waters had a full discussion in the volume on "Examination of Water Supplies." Some further facts have been obtained since that volume appeared, but our information on the subject is far from being as full as we could wish. A notable addition to the subject will be found in the *Twenty-third Annual Report of the Board*, in Mr. Calkins' article on *Uroglena*, an infusorian which communicates a decided oily odor to waters, and is much more abundant in ponds than has been generally supposed. There is now no difficulty in recognizing its characteristic odor, especially when water containing it is heated.

The fishy odor so often complained of in surface waters is generally due to infusoria. The diatom, *Asterionella*, is also easily recognized by its characteristic aromatic odor, when present in considerable amount.[1]

Turbidity and Sediment

The permanent turbidity and sediment of a water are observed in the large clear white glass bottles in which the water is collected, after standing over night. The character of the turbidity, whether floating algae or clayey matter, or the milkiness which occurs in water containing much iron or sewage, is noted, and also its amount. The amount and character of the sediment on the bottom of the bottle is also recorded, — whether earthy, flocculent, fibrous, etc.

Residue on Evaporation

When water is evaporated to dryness, a solid residue remains, which consists of the matters, mineral or organic, which were dissolved in the water, and also the suspended matters, if the water had not previously been filtered. In good ground waters this residue is white. In surface waters the residue may be more or less brown from dissolved organic matter. If this brown residue is heated to dull redness under carefully controlled conditions

[1] An article in a subsequent portion of this volume by Mr. Calkins treats at length of the connection between the odors of waters and the organisms they contain.

(see Methods of Analysis, in "Examination of Water Supplies," 1890), the organic matter is burned off, and this "loss on ignition" represents the amount of organic matter in the water. It is only an approximate determination at the best, but not without value with soft surface waters. This "loss on ignition" is not obtained with ground waters, as the result would be meaningless as a determination of organic matter.

The residue after burning off the organic matter in surface waters is the fixed residue, or total contents of mineral matter in the water. In ground waters the residue on evaporation, without ignition, is recorded as the total mineral matter.

XXIII

SOME PHYSICAL PROPERTIES OF SANDS AND GRAVELS, WITH SPECIAL REFERENCE TO THEIR USE IN FILTRATION

By Allen Hazen

[It was Mr. Hazen's work at Lawrence which established the methods of sand analysis and sand rating now almost universally used. To him is due the use of the terms "Effective Size" and "Uniformity Coefficient." ***Twenty-fourth Annual Report*****, 1892, p. 539. — G. C. W.]**

The experiments at the Lawrence Experiment Station under the direction of Hiram F. Mills, C.E., have necessitated many investigations in regard to the physical properties of filtering materials. The following is a brief account of some of the methods of analysis devised in the course of these investigations, together with the more important results obtained.

Method of Analysis

A knowledge of the sizes of the sand grains forms the basis of many of the computations. This information is obtained by means of mechanical analyses. The sand sample is separated into portions having grains of definite sizes, and from the weight of the several portions the relative quantities of grains of any size can be computed.

Collection of Samples

In shipping and handling, samples of sands are best kept in their natural moist condition, as there is then no tendency to separation into portions of unequal-sized grains. Under no circumstances should different materials be mixed in the same sample. If the material under examination is not homogeneous, samples of each grade should be taken in separate bottles, with proper notes in regard to location, quantity, etc. Eight-ounce wide-necked bottles are most convenient for sand samples, but with gravels a larger quantity is often required. Duplicate samples for comparison after obtaining the results of analyses are often useful.

Separation into Portions having Grains of Definite Sizes

Three methods are employed for particles of different sizes, — hand picking for the stones, sieves for the sands and water elutriation for the extremely fine particles. Ignition, or determination of albuminoid ammonia, might be added for determining the quantity of organic matter, which, as a matter of convenience, is assumed to consist of particles less than 0.01 millimeter in diameter.

The method of hand picking is ordinarily applied only to particles which remain on a sieve two meshes to an inch. The stones of this size are spread out so that all are in sight, and a definite number of the largest are selected and weighed. The diameter is calculated from the average weight by the method to be described, while the percentage is reckoned from the total weight. Another set of the largest remaining stones is then picked out and weighed as before, and so on until the sample is exhausted. With a little practice the eye enables one to pick out the largest stones quite accurately.

With smaller particles this process becomes too laborious, on account of the large number of particles, and sieves are therefore used instead. The sand for sifting must be entirely free from moisture, and is ordinarily dried in an oven at a temperature somewhat above the boiling point. The quantity taken for analysis should rarely exceed 100–200 grams. The sieves are made from carefully selected brass-wire gauze, having, as nearly as possible, square and even-sized meshes. The frames are of metal, fitting into each other so that several sieves can be used at once without loss of material. It is a great convenience to have a mechanical shaker, which will take a series of sieves and give them a uniform and sufficient shaking in a short time; but without this good results can be obtained by hand shaking. A series which has proved very satisfactory has sieves with approximately 2, 4, 6, 10, 20, 40, 70, 100, 140, and 200 meshes to an inch; but the exact numbers are of no consequence, as the actual sizes of the particles are relied upon, and not the number of meshes to an inch.

It can be easily shown by experiment that when a mixed sand is shaken upon a sieve the smaller particles pass first, and as the shaking is continued larger and larger particles pass, until the limit is reached when almost nothing will pass. The last and largest particles passing are collected and measured, and they represent the separation of that sieve. The size of separation of a sieve bears a tolerably definite relation to the size of the mesh, but the relation is not to be depended upon, owing to the irregularities in the meshes and also to the fact that the finer sieves are woven on a different pattern from the coarser ones, and the particles passing the finer sieves are somewhat larger in proportion to the mesh than is the case with the coarser sieves. For these reasons the sizes of the sand grains are determined by actual measurements, regardless of the size of the mesh of the sieve.

It has not been found practicable to extend the sieve separations to particles below 0.10 millimeter in diameter (corresponding to a sieve with about 200 meshes to an inch), and for such particles elutriation is used. The portion passing the finest sieve contains the greater part of the organic matter of the sample, with the exception of roots and other large undecomposed matters, and it is usually best to remove this organic matter by ignition at the lowest possible heat before proceeding to the water separations. The loss in weight is regarded as organic matter, and calculated as below 0.01 millimeter in diameter. In case the mineral matter is decomposed by the necessary heat, the ignition must be omitted, and an approximate equivalent can be obtained by multiplying the albuminoid ammonia of the sample by 50.[1] In this case it is necessary to deduct an equivalent amount from the other fine portions, as otherwise the analyses when expressed in percentages would add up to more than one hundred.

Five grams of the ignited fine particles are put in a beaker 90 millimeters high, and holding about 230 cubic centimeters. The beaker is then nearly filled with distilled water at a temperature of 20° C., and thoroughly mixed by blowing into it air through a

[1] The method of making this determination was given in the American Chemical Journal, vol. 12, p. 427.

glass tube. A larger quantity of sand than 5 grams will not settle uniformly in the quantity of water given, but less can be used if desired. The rapidity of settlement depends upon the temperature of the water, so that it is quite important that no material variation in temperature should occur. The mixed sand and water is allowed to stand for fifteen seconds, when most of the supernatant liquid, carrying with it the greater part of the particles less than 0.08 millimeter, is rapidly decanted into a suitable vessel, and the remaining sand is again mixed with an equal amount of fresh water, which is again poured off after fifteen seconds, carrying with it most of the remaining fine particles. This process is once more repeated, after which the remaining sand is allowed to drain, and is then dried and weighed, and calculated as above 0.08 millimeter in diameter. The finer decanted sand will have sufficiently settled in a few minutes, and the coarser parts at the bottom are washed back into the beaker and treated with water exactly as before, except that one minute interval is now allowed for settling. The sand remaining is calculated as above 0.04 millimeter, and the portion below 0.04 is estimated by difference, as its direct determination is very tedious, and no more accurate than the estimation by difference when sufficient care is used.

Determination of the Sizes of the Sand Grains

The sizes of the sand grains can be determined in either of two ways, — from the weight of the particles or from micrometer measurements. For convenience the size of each particle is considered to be the diameter of a sphere of equal volume. When the weight and specific gravity of a particle are known, the diameter can be readily calculated. The volume of a sphere is $\frac{1}{6}\pi d^3$, and is also equal to the weight divided by the specific gravity. With the Lawrence materials the specific gravity is uniformly 2.65 within very narrow limits, and we have $\frac{w}{2.65} = \frac{1}{6}\pi d^3$. Solving for d we obtain the formula $d = 0.9\sqrt[3]{w}$ when d is the diameter of a particle in millimeters and w its weight in milligrams. As the average weight of particles, when not too small, can be determined with precision, this method is very accurate, and altogether the most satisfactory for particles above 0.10 millimeter; that is, for all sieve separations. For the finer particles the method is inapplicable, on account of the vast number of particles to be counted in the smallest portion which can be accurately weighed, and in these cases the sizes are determined by micrometer measurements. As the sand grains are not spherical or even regular in shape, considerable care is required to ascertain the true mean diameter. The most accurate method is to measure the long diameter and the middle diameter at right angles to it, as seen by a microscope. The short diameter is obtained by a micrometer screw, focusing first upon the glass upon which the particle rests and then upon the highest point to be found. The mean diameter is then the cube root of the product of the three observed diameters. The middle diameter is usually about equal to the mean diameter, and can generally be used for it, avoiding the troublesome measurement of the short diameters.

The sizes of the separations of the sieves are always determined from the very last sand which passes through in the course of an analysis, and the results so obtained are quite accurate. With the elutriations average samples are inspected, and estimates made of the range in size of particles in each portion. Some stray particles both above and below the normal sizes are usually present, and even with the greatest care the result is only an approximation to the truth; still, a series of results made in strictly the same way should be thoroughly satisfactory, notwithstanding possible moderate errors in the absolute sizes.

Calculation of Results

When a material has been separated into portions, each of which is accurately weighed and the range in the sizes of grains in each portion determined, the weight of the particles finer than each size of separation can be calculated, and with enough properly selected separations the results can be plotted in the form of a diagram, and measurements of the curve taken for intermediate points with a fair degree of accuracy. This curve of results may be drawn upon a uniform scale using the actual figures of sizes and of per cents by weight, or the logarithms of the figures may be used in one or both directions. The method of plotting is not of vital importance, and the method for any set of materials which gives the most easily and accurately drawn curves is to be preferred. In the diagram published last year the logarithmic scale was used in one direction, but in many instances the logarithmic scale can be used to advantage in both directions. With this method it has been found that the curve is often almost a straight line through the lower and most important section, and very accurate results are obtained even with a smaller number of separations.

Examples of Calculation of Results

Following are examples of representative analyses, showing the method of calculation used with the different methods of separation employed with various materials.

TABLE 40

ANALYSIS OF A GRAVEL BY HAND PICKING, 11,870 GRAMS TAKEN FOR ANALYSIS

Number of Stones in Portion (Largest Selected Stones)	Total Weight of Portion — Grams	Average Weight of Stones — Milligrams	Estimated Weight of Smallest Stones — Milligrams	Corresponding Size — Millimeters	Total Weight of Stones Smaller than this Size	Per Cent of Total Weight Smaller than this Size
	....	....	....	....	11,870	*100.*
10	3,320	332,000	250,000	*56.*	8,550	*72.*
10	1,930	193,000	165,000	*49.*	6,620	*56.*
10	1,380	138,000	124,000	*45.*	5,240	*44.*
20	2,200	110,000	93,000	*41.*	3,040	*26.*
20	1,520	76,000	64,000	*36.*	1,520	*13.*
20	1,000	50,000	36,000	*30.*	520	*4.4*
20	460	23,000	10,000	*20.*	60	*.5*
10	40	4,000	2,000	*11.*	20	*.2*
Dust	20	....	....	....	....	....

The weight of the smallest stones in a portion given in the fourth column is estimated in general as about half-way between the average weight of all the stones in that portion and the average weight of the stones in the next finer portion.

The final results are shown by the figures in italicized type in the last and third from the last columns. By plotting these figures (Fig. 13) we find that 10 per cent of the stones are less than 35 millimeters in diameter, and 60 per cent are less than 51

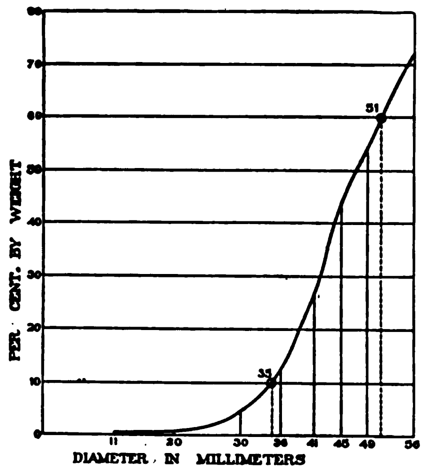


Fig. 13.

millimeters. The "uniformity coefficient," as described below, is the ratios of these numbers, or 1.46, while the " effective size " is 35 millimeters.

Analysis of a Sand by Means of Sieves

A portion of the sample was dried in a porcelain dish in an air bath. Weight dry, 110.9 grams. It was put into a series of sieves in a mechanical shaker, and given one hundred turns (equal to about seven hundred single shakes). The sieves were then taken apart, and the portion passing the finest sieve weighed. After noting the weight, the sand remaining on the finest sieve but passing all the coarser sieves was added to the first, and again weighed, this process being repeated until all the sample was upon the scale, weighing 110.7 grams, showing a loss by handling of only 0.2 gram. The figures were as follows: —

TABLE 41

Sieve Marked	Size of Separation of this Sieve	Quantity of Sand Passing	Per Cent of Total Weight	Sieve Marked	Size of Separation of this Sieve	Quantity of Sand Passing	Per Cent of Total Weight
	Millimeters	Grams			Millimeters	Grams	
190	*.105*	.5	*.5*	40	*.46*	56.7	*51.2*
140	*.135*	1.3	*1.2*	20	*.93*	89.1	*80.5*
100	*.182*	4.1	*3.7*	10	*2.04*	104.6	*94.3*
60	*.320*	23.2	*21.0*	6	*3.90*	110.7	*100.0*

Plotting the figures in italicized type we find from the curve (Fig. 14) that 10 and 60 per cent respectively are finer than

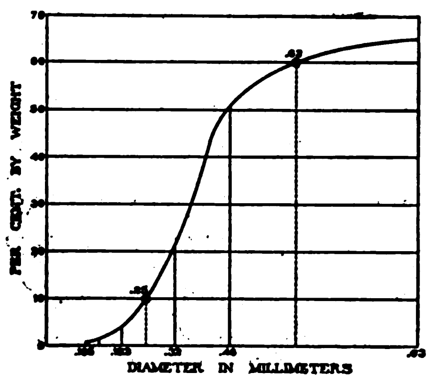


FIG. 14.

0.25 and 0.62 millimeter, and we have for effective size, as described above, 0.25, and for uniformity coefficient 2.5.

ANALYSIS OF A FINE MATERIAL WITH ELUTRIATION

The entire sample, 74 grams, was taken for analysis. The sieves used were not the same as those in the previous analysis, and instead of mixing the various portions on the scale they were separately weighed. The siftings were as follows: —

Remaining on Sieve	10, above	2.2	millimeters	......	1.5 grams
" "	20, "	.98	"	......	7.0 "
" "	40, "	.46	"	......	22.0 "
" "	70, "	.24	"	......	20.2 "
" "	140, "	.13	"	......	9.2 "
Passing sieve	140, below	.13	"	......	14.1 "

The 14.1 grams passing the 140 sieve were thoroughly mixed, and one-third, 4.7 grams, taken for analysis. After ignition, just below a red heat in a radiator, the weight was diminished by 0.47 gram. The portion above 0.08 millimeter and between 0.04 and 0.08 millimeter, separated as described above, weighed respectively 1.27 and 1.71 grams, and the portion below 0.04 milli-

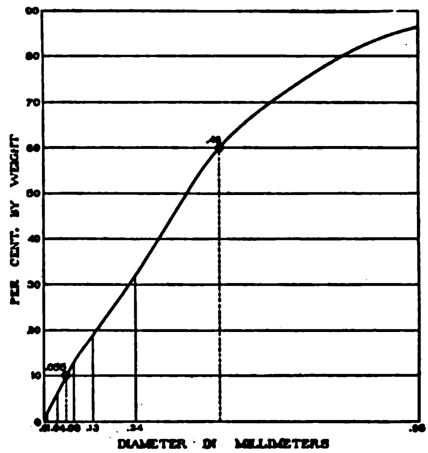


FIG. 15.

meter was estimated by difference (4.7 − (0.47 + 1.27 + 1.71)) to be 1.25 grams. Multiplying these quantities by 3, we obtain the corresponding quantities for the entire sample, and the calculation of quantities finer than the various sizes can be made. (See table below.)

By plotting the italicized figures, we find (Fig. 15) that 10 and 60 per cent are respectively finer than 0.055 and 0.46 millimeter, and we have effective size 0.055 millimeter and uniformity coefficient 8.

The Effective Size

As a provisional basis which best agrees with the known facts, the size of grain where the curve cuts the 10 per cent line is considered to be the "effective size" of the material. This size is such that 10 per cent of the material is of smaller grains, and 90 per cent is of larger grains than the size given. The results

TABLE 42

Size of Grain	Weight (Grams)	Size of Largest Particles (Millimeters)	Weight of all the Finer Particles (Grams)	Per Cent by Weight of all Finer Particles
Above 2.20	1.50	....	74.00	*100*
.98–2.20	7.00	*2.20*	72.50	*98*
.46– .98	22.00	*.98*	65.50	*89*
.24– .46	20.20	*.46*	43.50	*60*
.13– .24	9.20	*.24*	23.30	*32*
.08– .13	3.81	*.13*	14.10	*19*
.04– .08	5.13	*.08*	10.29	*14*
.01– .04	3.75	*.04*	5.16	*7*
Loss on ignition (assumed to be less than 0.01 millimeter)	1.41	*.01*	1.41	*1.9*

obtained at Lawrence indicate that the finer 10 per cent have as much influence upon the action of a material in filtration as the coarser 90 per cent. This is explained by the fact that in a mixed material, containing particles of various sizes, the water is forced to go around the larger particles and through the finer portions which occupy the intervening spaces, and so it is this finest portion which mainly determines the frictional resistance, the capillary attraction, and, in fact, the action of the sand in almost every way.

Another important point in regard to a material is its degree of uniformity; whether the particles are mainly of the same size, or whether there is a great range in their diameters. This is conveniently shown by the "uniformity coefficient," a term used to designate the ratio of the size of grain which has 60 per cent of the sample finer than itself to the size which has 10 per cent finer than itself. These sizes are taken directly from the curve of results.

It is not probable that the above data regarding a sand include all the important points to be known, or that further study will not modify or change the method of calculation; but, in the absence of better methods, their use allows extremely valuable approximate calculations, which would otherwise be almost impossible.

Determination of Open Space and Water by Volume

As it is often necessary to make determinations of open space and water in sands, a few notes in regard to the most suitable methods will be given.

The specific gravity of the solid particles is obtained by putting a weighed quantity of the thoroughly dry material into a narrow-necked graduated flask of distilled water, taking great care that no air bubbles are inclosed, and weighing the displaced water. Very accurate results may be obtained in this way. The specific gravity of the material as a whole is obtained by weighing a known volume packed as it is actually used, or as nearly so as possible. As the material is usually moist, it should either be dried before weighing or else a moisture determination made and a correction applied. The open space is invariably obtained by dividing the specific gravity of the material as a whole when dry by the specific gravity of the solid particles, and deducting the quotient from 1. The results obtained by measuring the quantity of water which can be put into a given volume when introduced from below are invariably too low, because the water is drawn ahead by capillarity, and air bubbles are inclosed and remain, often causing serious errors. A rough estimate of the open space can be made from the uniformity coefficient. Sharp-grained materials having uniformity coefficients below 2 have nearly 45 per cent open space as ordinarily packed; and sands having coefficients below 3, as they occur in the banks or artificially settled in water, will usually have 40 per cent open space. With more mixed materials the closeness of packing increases, until, with a uniformity coefficient of 6 to 8, only 30 per cent open space is obtained, and with extremely high coefficients almost no open space is left. With round-grained water-worn sands the open space has been observed to be from 2 to 5 per cent less than for corresponding sharp-grained sands.

The quantity of water contained in sand is obtained by drying a weighed portion in the usual way. The volume of the water is reckoned by the formula $V = sp.\ gr.\ \frac{M}{100-M}$ when $sp.\ gr.$ is the specific gravity of the material as a whole when dry and *M* is the per cent of moisture by weight. The difference between this figure and the open space is, in general, the air space.

Capillarity

To determine the capillarity of a sand it is so placed that it is drained at a defined level, great care being taken to secure a compact packing free from stratification. Water is put freely upon it, and after a definite time, usually twenty-four or forty-eight hours, sand samples are taken at various levels, and water determinations made as described above. The results plotted give a curve of "water capacity."[1]

The height to which water will be held to such an extent as to prevent the circulation of air can be roughly estimated by the formula $h = \frac{1.5}{d}$ when h is the height in millimeters and d the effective size of sand grain. The data from which the constant given above as 1.5 was calculated are very inadequate, and consequently the formula may require modification with more extended observations.

The height to which water is held by capillarity is independent of temperature.

Determination of Frictional Resistance

To determine the frictional resistance of a material, a cylinder of galvanized iron of convenient size is filled with the material packed under conditions as far as possible like those under which it is to be used. For water filtration the material is put loosely in position and settled to a compact condition by introducing water from below. Stratification must be carefully avoided. Water is then passed through at definite rates, keeping the material covered with an excess of water, and regulating the rate of flow by the faucet at the bottom. The accompanying diagram (Fig. 16) represents a section of the apparatus (not drawn to scale). The loss of head between two points at a definite distance apart and both well within the material under examination is observed

[1] The results of a number of such experiments were given in the annual report for 1891, p. 432.

in glass tubes attached to pet cocks covered with fine wire gauze to keep back the material. By proceeding in this way we eliminate the loss of head in the surface layer of sand, which is always much greater than for corresponding material below the surface, and is better studied by itself. The friction when the experiment

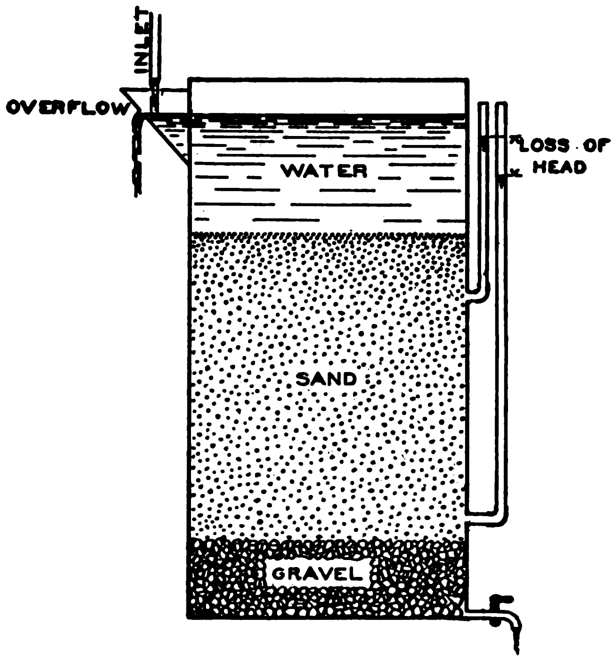


Fig. 16.

is first started is always high, because many air bubbles are retained in the sand; but if water not entirely saturated with air is applied continuously for some days the air bubbles are absorbed and constant normal results are obtained.

Friction of Water in Sands and Gravels

The frictional resistance of sand to water within certain limits of size of grain and rate of flow varies directly as the rate and as the depth of sand. This is given by Piefke [1] as Darcy's law. I have found that the friction also varies with the temperature,

[1] "Zeitschrift für Hygiene," vol. VII, p. 115.

being twice as great at the freezing point as at summer heat both for coarse and fine sands, and also that with different sands the resistance varies inversely as the square of the effective size of the sand grain. It probably varies also somewhat with the uniformity coefficient, but no satisfactory data are at hand upon that point.

Putting the available data in the shape of a formula, we have

$$V = c\, d^2 \frac{h}{l} (0.70 + 0.03t),$$

where

(V) is the velocity of the water in meters daily in a solid column of the same area as that of the sand,

(c) is a constant factor which present experiments indicate to be approximately 1,000,

(d) is the effective size of sand grain,

(h) is the loss of head,

(l) is the thickness of sand through which water passes,

(t) is the temperature on the centigrade scale ($\frac{t \text{ Fahr.} + 10}{60}$ may be substituted for the last term, if desired).

The data at hand only justify the application of this formula to sands having a uniformity coefficient below 5, and effective size of grain 0.10 to 3.00 millimeters.

The quantity of water which will filter through a sand when its pores are completely filled with water and in the entire absence of clogging, with an active head equal to the depth of sand, and at a temperature of 10° C., forms an extremely convenient basis for calculation, and for convenience is called the "maximum rate," as it is approximately equal to the greatest quantity of water which can be made to pass the sand under ordinary working conditions. Thus a sand with effective size, 0.20 millimeter, has a maximum rate of 40 meters per day; with effective size 0.30 millimeter, the maximum rate is 90 meters per day, etc.

TABLE 43

TABLE SHOWING RATE AT WHICH WATER WILL PASS THROUGH DIFFERENT SANDS, WITH VARIOUS HEADS, AT A TEMPERATURE OF 10° C.

$\frac{h}{l}$	Effective Size in Millimeters, 10 Per Cent Finer than —						
	0.10	*0.20*	*0.30*	*0.40*	*0.50*	*1.00*	*3.00*
	Meters per day	Meters per day	Meters per day	Meters per day	Meters per day	Meters per day	Meters per day
.001	.01	.04	.09	.16	.25	1.	9.
.005	.05	.20	.45	.80	1.25	5.	45.
.010	.10	.40	.90	1.60	2.50	10.	90.
.050	.50	2.	4.50	8.	12.50	50.	....
.100	1.	4.	9.	16.	25.	100.	....
.500	5.	20.	45.	80.	125.	....	....
1.000	10.	40.	90.	160.	....	....	....
2.000	20.	80.	180.	320.	....	....	....

The effect of variation in the temperature is shown by the following table: —

TABLE 44

RELATIVE QUANTITIES OF WATER PASSING AT DIFFERENT TEMPERATURES

Degrees, Centigrade	0°	5°	10°	15°	20°	25°	30°
Degrees, Fahrenheit	32°	41°	50°	59°	68°	77°	86°
Quantity	.70	.85	1.00	1.15	1.30	1.45	1.60

For gravels with effective sizes above 3 millimeters the friction varies in such a way as to make the application of a general formula very difficult. As the size increases beyond this point, the velocity with a given head does not increase as rapidly as the square of the effective size; and with coarse gravels the velocity varies as the square root of the head instead of directly with the head as in sands. The influence of temperature also becomes less marked with the coarse gravels.

The available data for materials above 3 millimeters, which are far less complete than could be desired, have been obtained entirely from screened gravels with uniformity coefficients from 1.4 to 2.0, and at a temperature of 10° C., or a little above. The results obtained were plotted, making a diagram from which the table given below has been prepared. The figures given in the table must be taken as provisional, and for use only until more extended results are obtained.

TABLE 45

TABLE SHOWING RATE AT WHICH WATER WILL PASS THROUGH DIFFERENT GRAVELS WITH VARIOUS HEADS

$\frac{h}{l}$	Effective Size in Millimeters, 10 Per Cent Finer Than —									
	3	5	8	10	15	20	25	30	35	40
	Meters per day	Meters per day	Meters per day	Meters per day	Meters per day	Meters per day	Meters per day	Meters per day	Meters per day	Meters per day
.0005 .	3.5	10	20	30	50	80	110	150	200	250
.001 .	7	21	41	58	100	148	205	275	370	450
.002 .	14	40	78	110	190	275	370	480	590	710
.004 .	27	77	150	208	350	480	610	740	870	1,000
.006 .	41	112	207	275	450	626	780	930	1,090	1,240
.008 .	54	142	252	340	530	720	900	1,090	1,270	1,450
.010 .	67	173	300	385	610	830	1,030	1,220	1,410	....
.015 .	98	238	378	480	760	1,030	1,260	1,480	....	....
.020 .	127	300	467	580	890	1,180	1,470	....	....	....
.030 .	185	400	615	750	1,110	1,450	....	....	....	....
.050 .	280	560	885	1,060	1,490	....	....	....	....	....
.100 .	495	930	1,310	1,550	....	....	....	....	....	....

In making calculations in regard to underdrains for either sewage or water filters, or in regard to the movements of ground waters, there should be no perceptible clogging of porous materials free from stratification by a clear ground water, and the formulas given can be used with only a moderate factor of safety to cover possible errors of sampling, analysis, and errors in the formulas themselves. In estimating the actual capacity of a filter, so many other conditions come in — the presence of air bubbles and especially the increased friction in the upper layers — that it is impossible to calculate the practicable rate of flow by formulas, and we can only safely rely upon actual results from known materials.

The analyses of the materials used at Lawrence have been given in previous reports of the Board in connection with the results obtained from them. The following table contains the result of analyses of some other materials, which may be of general interest: —

TABLE 46

MECHANICAL ANALYSES OF SANDS

	Effective Size 10 Per Cent Finer Than —	Uniformity Coefficient
	Millimeters	
Filter Tank No. 1, Lawrence, Mass.	.48	2.4
Filter Tank No. 9, Lawrence, Mass.	.18	2.0
Filter Tank No. 2, Lawrence, Mass.	.08	2.0
Sewage filters, Gardner, Mass.	.10–.24	6–14
Sewage filters, Marlborough, Mass.	.12	3.4
Sewage filters, South Framingham, Mass.	.35–.42	4–5
Water filter, Lawrence, Mass.	.25–.30	2.5–4.5
Water filter, Birmingham, Eng.	.27	1.8
Water filter, Southwalk & Vauxhall Co., London, Eng.	.29	2.0
Water filter, Poughkeepsie, N. Y.	.25–.35	1.8–1.9

The data already collected clearly show that a well-selected material is essential to successful filtration; and, with the method of examination and calculation now proposed, we can decide with confidence many otherwise indefinite points, and thus avoid unnecessary expense and unsatisfactory results from the use of unsuitable or poorly arranged materials.

XXIV

REPORT OF THE JOINT BOARD UPON THE IMPROVEMENT OF CHARLES RIVER

[This report was made by a joint board consisting of the Metropolitan Park Commission and the State Board of Health. Following this report the construction of the Charles River Basin was begun. *Special Report*, 1894, p. vii. — G. C. W.]

THE undersigned, members of the joint board, consisting of the Board of Metropolitan Park Commissioners and the State Board of Health, to whom was referred, by chapter 475 of the Acts of 1893, the investigation of the sanitary condition, and the preparation of plans for the improvement of the beds, shores and waters of the Charles River, between Charles River bridge and the Waltham line on Charles River, and for the removal of any nuisance therefrom, respectfully submit the following report: —

The two boards named in the act met for organization August 10, 1893. H. P. Walcott was elected chairman of the joint board and H. S. Carruth, secretary. At a later date F. P. Stearns, C.E., was appointed engineer to the board, and Messrs. Olmsted, Olmsted and Eliot were asked to consider the subject of the improvement of the river, to submit a report thereon and to prepare a plan of the improvements recommended. Mr. Eliot had been a member of the Charles River Improvement Commission appointed under authority of chapter 390 of the Acts of 1891, had acquired complete familiarity with the actual condition of the river, and had made, in a public document, valuable suggestions for its improvement. Dr. Robert W. Greenleaf of Boston was asked to make a sanitary survey of the district designated in the act.

The members of the board have personally examined the river and its banks at many times and under various conditions. They have carefully considered the reports made to them by the experts employed, and have reached the following conclusions.

The position of the Charles River, in its relation to the metropolitan district, has necessarily a very great influence upon the health and comfort of the people living in its vicinity. So long as the stream was comparatively unpolluted its banks were occupied at eligible sites by dwellings of the better sort. The increase of pollution and the consequent nuisance occasioned by it have driven from the banks those who could afford to establish new homes in more attractive regions, and the places of these have been taken by a population less sensitive because they cannot afford to avoid offensive surroundings, or by manufactories that seek the stream for commercial advantage or to be at a distance from neighbors likely to complain of offensive processes incident to the business carried on. Even in those portions of the river where the vast quantities of salt water brought in by the tide so far diminish the degree of pollution that offensive odors are not observed except at low tide and in consequence of local causes, and where some of the finest residences of the Back Bay district of the city of Boston are to be found, — even here the river has ceased to be a welcome neighbor except so far as the views to the distant hills to the north and west are enhanced by the water in the not too near foreground, a foreground consisting of a poorly kept alleyway behind a line of unsightly sheds and stables situated at the rear of the lots on the north side of Beacon Street, a rude stone wall, upon which grow tufts of seaweed and unsightly grasses, holding as sponges do the floating putrescible materials that come in contact with them, and at the base of the wall, at low tide, a muddy expanse of many acres, marred by rubbish of every description.

So many of the great cities of the world have made use of the banks of rivers and basins as sites for their finest public and private buildings and ornamental grounds that we cannot escape from the conviction that the disinclination to so use the Charles River within the limits under consideration rests either upon nuisances already in existence or the apprehension of danger to health. The river runs through the very centre of the metropolis and upon its shores should naturally be placed its most attractive structures, its monuments and its finest dwellings. It does not seem appropriate that this territory, so favored by position, lying at the very heart of our great city and upon the borders of a stream not necessarily offensive, should be condemned to its present ignoble and noxious uses. If any streams or any lowlands are to be so used in the vicinity of Boston it would be well that they should be as far as possible from the centre. An enumeration of the people who are actually resident upon the territory which lies within a distance of two miles upon either bank of the river, throughout the district now under consideration, shows a population of not less than 500,000. Here in the future will probably be found, as now, the bulk of the metropolitan population.

The banks of the river and the exposed flats have become from year to year more offensive until, on certain portions of the river, the people living near the stream have been exposed to the disagreeable and probably injurious emanations therefrom. So far reaching had this nuisance become that during the summer of 1892 a very large portion of the territory of Old Cambridge was subject to its influence, and a petition was addressed to the State Board of Health signed by hundreds of householders, and by nearly all the practicing physicians of that portion of the city, praying that some relief might be given from a condition of things believed to be positively injurious to health, and known to be so offensive that windows had to be closed during the period of low tide in the river.

The medical profession believes that the gases arising from decomposing organic materials are injurious to health; it has not been proved, however, that these gases do produce some one distinct disease, but rather that the continued breathing of them lowers the vital resistance and predisposes the person exposed to them to diseases of various kinds and all degrees of severity. But even if the physicians are in error in believing such emanations to be a danger to health, it is quite certain that the owners of lands or houses on the borders of such foul smelling streams suffer a pecuniary loss in the diminished value of their property, a loss from which they should be protected if it be practicable to do so.

In recent years it has been thought that the steady progress of malaria in the valley of the Charles has had a very close connection with the increasing pollution of the stream; the careful examination into this subject by Dr. Greenleaf does not show, however, that the cases of malarial fever have been in such near connection with the river as to make it probable that the contaminations of its waters have had any direct influence upon the spread of the disease. Dr. Greenleaf, in the course of a house-to-house survey of the district adjoining the river, did, indeed, discover cases of malarial fever, but a satisfactory explanation of their occurrence was almost invariably found, either in local conditions not dependent upon the state of the river, or else by exposure of the affected individuals in localities known to have become malarial in recent years. His observations lead to the same conclusions in this inquiry that other competent authorities have drawn in all parts of the world, that the most important condition to be sought for defence against the malarial infection is a thorough drainage of the soil, together with a maintenance of the water contained therein at an unchanged level.

Two plans occur to us for the relief of the conditions thus briefly sketched, assuming in both cases that the Metropolitan Sewerage System, now nearly completed, will remove the more serious forms of pollution: —

(1) To dredge all flats now exposed, and to continue the embankment constructed in the substantial and attractive form used by the city of Boston at the Charlesbank, ultimately carrying this construction through the whole length of the estuary and upon both banks.

(2) To maintain the water in the river through a greater or less length in its course at a permanent high level by the construction of a dam.

The objections to the first plan are these: While the river would rise and fall against a vertical wall, thus exposing the smallest possible surface at the banks, even this surface would soon become defaced by growths more or less offensive, as has already happened to the recently constructed walls in the Charles River Basin. The embankment would be many miles in length, would entail very extensive fillings of lowlands in order to render such lands available for any public use or profitable private occupation, and the general effect would not be pleasing to the eye, except when the water is at or near high tide, and lastly, the difficulties of the construction of walls on account of poor foundation and their great expense would preclude for the present at least the building of them.

Having a due regard to the imperative need of some measure of relief in this valley, it does not seem safe to longer delay the adoption of a sufficient remedy, and we, therefore, recommend the second plan, the erection of a dam high enough to keep even extreme tides out of the basin and the maintenance of the water at a permanent level, in accordance with the plan of our engineer, F. P. Stearns, C.E., herewith presented.

The place selected for the dam is about 600 feet above Craigie's bridge, where the river is not more than 1,100 feet wide. The details of this structure have been so thoroughly considered that we confidently believe that it will answer the purposes for which it is designed, the maintenance of a nearly permanent level at all times, and no greater interference with commerce than would be produced by the operation of a drawbridge, — indeed, not so much, should the drawbridge happen to lie on the line of a railroad. Provision has been made for a lock in the dam capable of receiving the largest vessels used upon the river; and it is obvious that commerce directed to the upper portions of the stream would gain much from the power to ascend the river independently of the rise and fall of the tide. Vessels which might have occasion to be moored at the wharves on the river above the dam would find in this new condition of things the great advantage of floating at all times. How great this gain would be can be understood when it is stated that the river bed is practically exposed at the United States Arsenal at Watertown at low tide.

Estimates have been made for a dam to be 100 feet in width, and there would thus be provided a foundation for another roadway into the city of Boston from East Cambridge and the country beyond of permanent character, a means of approach to the city likely to be much needed when the time comes for the reconstruction of Craigie's bridge.

The landscape architect would also be able to connect this structure with the public lands on both banks of the river by such additional fillings and rounding of the corners as would materially increase the area of these grounds and add new features of attraction.

We cannot convince ourselves that the harbor will be noticeably injured by the loss of the large quantities of water discharged by the outgoing tide. The opinions of the experts, who have from time to time examined the harbor, have in recent years been considerably modified, possibly in view of the unimpaired value of the harbor, notwithstanding the great decrease in the water areas of the Charles River and other basins. If the river below the site of the dam is only to serve the purpose of conveying the waters of the Charles and Miller's rivers to the sea, such diminution of its area as has already taken place will be of little consequence, for a smaller channel than the present would be sufficient to carry all that the Charles River alone could ever empty into it.

The more certain formation of ice on the basin created by the dam ought not, in the absence of any considerable amount of winter commerce on the Charles, to be anything but favorable to the use of this stretch of several miles of river for skating, one of the best of winter exercises and sports. The probable more ready freezing of the channel of Boston Harbor below the dam would be an inconvenience if the constant movement of tugs and ferry boats were not quite certain to break up the ice almost as soon as formed.

The fear is often expressed that such basins as this may become, by reason of an insufficient current and the accumulation of organic matter in them, sources of nuisance and a menace to the public health. The statistics contained in the engineer's report show that there will be a very considerable movement of this sheet of water, and with the improvement in the quality likely to follow the operation of the new metropolitan sewer but little danger of such contamination of the water or such accumulation of filth on the bottom of the basin as could produce offensive smells or conditions dangerous to health. But should the unexpected, nevertheless, happen, the openings in the dam would easily allow of the admission of such quantities of salt water as would keep the basin in a perfectly satisfactory condition by establishing in it a very considerable circulation at each tide. We are fortunately, however, not without examples of basins quite similar to this, situated also in the midst of large populations, and in the most conspicuous example, the world-renowned Alster Basin, the water park of the city of Hamburg, there is no means of introducing any water beyond that flowing in the comparatively insignificant Alster. This basin is very shallow and has a muddy bottom, but is surrounded by some of the best private houses of this flourishing and wealthy port, and the water surface of the basin and its shores constitute the most frequented places of resort in the city. During the terrible cholera epidemic of 1892, when Hamburg suffered, as few European cities ever have suffered, from this pestilence, the wards in which lie the Alster Basins showed the lowest death-rates in the city. We do not intend to say that cholera spreads only where there is filth, but it is true that the conditions among which it finds its widest extension are those of unsanitary surroundings.

There is no question probably in the mind of any sanitary observer that a river of moderately pure water flowing at a constant level between clean banks is much to be preferred to a similar stream which is subject to a rise and fall of many feet twice in the twenty-four hours. Streams of the latter description constantly deposit upon the banks the material floating on the surface, material that occasions little offence while surrounded and saturated with water, but rapidly decays when exposed to the sun and air upon the shores of the river.

Whatever care may be taken of the Charles River in the time to come, if it remain an estuary, there is no doubt in our minds that the banks, sloping as now to the stream, will be more or less a nuisance; dwellings will, so far as possible, not be erected in its neighborhood, or, if they are built here, will be of the sort which are compelled to seek undesirable, consequently cheap, land. A population will be established here which will resist most obstinately and naturally the destruction of their homes, and one more, and perhaps the greatest, opportunity to permanently improve the incomparable situation of Boston and its suburbs will have passed away.

In order to protect the low-lying portions of the territory within the valley of this portion of the Charles River, it has seemed advisable to us to make the permanent level in this basin somewhat lower than that of ordinary high tides. The level which seems most advantageous is that of two feet and six inches below such tides. It is well known that exceptionally high tides have done much injury throughout the estuary of the river, both by flooding and by interference with sewers, and we may reasonably expect that still more will be occasioned on account of the increased occupation of these lowlands whenever we again have such tides as that which occurred at the time of the destruction of the Minot's Ledge lighthouse in 1851, or, indeed, tides of much lower height. The forlorn marshes that now border upon the river would become, without the expenditure on them of a dollar, fertile meadows, scarcely needing treatment to become attractive places for recreation; and capable, with treatment, of becoming scenes of great beauty, as the designs of the landscape architects so clearly show. Some solicitude has, in recent years, been manifested in regard to the preservation of the piles upon which are placed the foundations of so many valuable buildings in the Back Bay district of Boston. The maintenance of a basin at a constant level considerably above that at which, by city ordinance, these piles are cut off will probably increase the security of such substructures. We believe that the amount of organic or putrescible material at present deposited on the banks and bed of the river need not present any serious obstacle to the carrying out of this plan. The completion of the whole design will be a matter of years, the addition of the most serious kind of pollution, sewage, will cease, probably, in the course of a year, the narrowing of the stream in the present basin is rapidly going on, with consequent diminution of deposit, and whatever remains after this will be profitably removed to the banks of the stream for such fillings as may be necessary to prepare the river for its new functions.

Whatever plan is adopted for the future treatment of the river, it seems to us essential that all the lands indicated on the plan presented by the landscape architects should be at once acquired. The mere fact that it was public property would alone, we think, improve the value of all the adjoining lands to such an extent as to make the purchase a wise business transaction.

Mayor Mathews, in an inaugural address delivered in the year 1891, before the city council of Boston, used the following words: —

> We have in this basin the opportunity for making the finest water park in any city in the country; an opportunity which should be grasped before it is too late.
>
> The eventual solution of this whole problem should, I think, be an imitation of the plan adopted by the city of Hamburg, under similar circumstances. We should dam up the stream at the narrowest point between Charlestown and Boston, and lay out a series of parks and boulevards along the basin thus created.

We have incorporated in this report copies of photographs showing various aspects of the Alster Basin in Hamburg. They tell their story so effectively that minute description is hardly needed. Hamburg lies on the east bank of the Elbe, at a distance of seventy miles from the German Ocean, and is the most important commercial city of the German Empire. The population of the city and suburbs exceeds 600,000. The climate is harsh and fully as much exposed to cold and disagreeable winds as Boston is. The thermometer does not indicate so low degrees of temperature, but the difference between the two cities in this regard is not very great. In former times the Alster was a small stream flowing through the centre of the city and entering the Elbe at right angles to the latter's course. At the entrance of the Alster into the Elbe an estuary was formed which sheltered the small vessels engaged in the commerce of those days.

With the growth of the city larger and more convenient docks were formed on the Elbe; and the formation of the Alster Basin was begun at a point about a mile distant from the entrance of the Alster into the Elbe; dams across the stream were constructed with suitable contrivances for the passage of mastless vessels.

Constant improvements have been going on in this water park, some the results of the needs of a growing city and some from efforts to increase the attractions of the basin and its borders. There are two basins, an upper and a lower, separated by a bridge. About this basin are ranged some of the finest of the private houses, the principal hotels, and such shops as are usually found in the better quarters of a city.

It will be noticed that the lower water park is treated in a formal way with walls, straight lines of street, and rows of trees; in the upper basin walls are replaced by beaches; the shore lines no longer run parallel to the streets, and the trees and shrubbery are grouped in effective masses. At points more distant from the city and on the upper reaches of the river, very little attempt has been made to improve the naturally pleasing variation of banks but slightly elevated above the stream and verdant meadows interspersed with trees, shrubbery and gardens.

We desire to call attention to the evidences of appreciation of all these charms shown by the life everywhere manifest, — the little steamer makes its rounds from one point to another on the water park; rowboats are plenty, and when some much-frequented place of resort on the stream is reached, the popular enjoyment of it all should convince this community that much labor and expense could be profitably invested in procuring for the metropolitan district the opportunity for the same innocent enjoyments. We have a framework for such scenes far superior to that possessed by Hamburg, and the expense of preparation is not excessive.

That all this outdoor life is not peculiar to the German nation is well shown by the illustration of boating on the Thames. Nothing of all this has hitherto been possible in the estuary of the Charles, although some suggestion of the possibilities in this direction may be obtained from the rapidly growing use of the comparatively inaccessible fresh-water basin further up the stream extending from Waltham to Riverside. The repulsive appearance of the shores of the estuary at the lower stages of tide, the foul odors along its banks and flats, and the difficulties experienced in passing under the low bridges at high tide, have combined to make boating and the use of the stream by small steamboats unattractive and, in a measure, dangerous.

In conclusion, your board feels that no treatment of the Charles River can be entirely satisfactory which does not regard the condition of the river above and in Waltham. At the boundary of that city, by the terms of the act under which we are directed to make our investigation and report, our labors end.

We have not thought that it was necessary to submit herewith the drafts of such legislation as might seem to be required for carrying out our recommendations. We are aware that the very serious changes proposed require the co-operation of the United States, the state and various municipalities. But the questions only differ in degree from some which have already been satisfactorily determined by existing commissions whose organizations are sufficiently complete to enable them to promptly undertake the execution of so much of these plans as it may seem wise to the Commonwealth to enter upon.

HENRY P. WALCOTT,
Chairman.
PHILIP A. CHASE,
WILLIAM B. DE LAS CASAS,
ABRAHAM L. RICHARDS,
Board of Metropolitan Park Commissioners.

HIRAM F. MILLS,
FRANK W. DRAPER,
JOSEPH W. HASTINGS,
GERARD C. TOBEY,
JAMES W. HULL,
CHARLES H. PORTER,
State Board of Health.

BOSTON, MASS., April 27, 1894.

CHARLES F. ADAMS and WILLIAM CHASE of the Metropolitan Park Commission are absent in Europe.

XXV

REPORT OF THE STATE BOARD OF HEALTH UPON A METROPOLITAN WATER SUPPLY

By Dr. Henry P. Walcott

[*Report upon a Metropolitan Water Supply*, 1895, p. ix. — G. C. W.]

The State Board of Health, acting under the authority of chapter 459 of the Acts of 1893, has investigated and considered the question of a water supply for the city of Boston and its suburbs within a radius of ten miles from the State House, and for such other cities and towns as, in its opinion, should be added thereto; and has also made the additional investigations set forth in the second section of the same act, and now desires to submit the following report: —

The act under which the Board has conducted this inquiry apparently provides for the same general treatment of the question of water supply as was adopted by the General Court of 1887 for the creation of a sewerage system for a somewhat smaller district. Substantially all the arguments that were urged by this Board for the Metropolitan Sewerage System, which, built in accordance with our recommendations, is now nearly completed, may be used with even greater force in aid of any well-devised plan for giving to a still larger district a sufficient supply of the best water attainable.

F. P. Stearns, C.E., chief engineer of the Board, has prepared the very full and accurate statement of the present and future resources of water available for this metropolitan district, together with all necessary details as to the structures at the great reservoir, the aqueduct leading from it, the new pipe lines and pumping stations, within the district; and, in addition to the information already in possession of the Board, has been able to state the results of many new inquiries undertaken for the purposes of this report. The financial aspects of the problem are also treated by him in an instructive manner.

J. P. Davis, C.E., who has been for a series of years entirely familiar with all the great municipal works for water and sewerage of the metropolitan district, has made a careful examination of the work of our engineer, and finds it to be well considered and trustworthy. Mr. Davis was for many years city engineer of Boston, and in this capacity designed and had charge of the construction of the works for taking water from the Sudbury River. He has also been consulting engineer to the Aqueduct Commission of the city of New York, and was one of the experts consulted as to the proposed Quaker Bridge Dam.

Dexter Brackett, C.E., has embodied in two appendices the results of observations and studies to which he has devoted many years.

Another appendix contains a description by Desmond Fitz-Gerald, C.E., of plans for the draining of swamps, which are now under consideration for the improvement of the Sudbury watershed.

Dr. Drown's paper upon the influence exercised by organic matter in the soil of reservoirs upon the water stored therein has so much that bears upon the recommendations of this report that we again publish it as an appendix.

All the special information that may be found necessary to explain or support the compressed conclusions of our own report will be supplied by the valuable reports of the eminent authorities above enumerated.

The most familiar experience of this part of the world, at least in the matter of its water supplies, has been the failure of sources originally supposed to be abundant to properly meet the wants of their respective communities for any considerable length of time. The plans of the city of Boston, beginning with its first scheme for a general water supply in the year 1825, have proved no exception to this rule, and yet this city has had the services of the ablest men of their day.

The reason for this constant disappointment is easily discovered. The quantity of water which the householder of today demands for the conveniences as well as for the necessities of his daily life has increased beyond all expectation. If this enlarged quantity can be secured without undue delay and without such injury as may easily be made whole, it is evidently for the general welfare that such provision should be made; for it seems to us reasonable to claim that no small share in the improved and still improving state of the public health may be traced to the measures now adopted for the protection of the purity of waters and to the greater cleanliness of person, clothing and all surroundings which inevitably result from a practically unlimited freedom in the use of water. It is essential, then, to determine, if possible, the amount of water needed at the present day, with such forecast as to future requirements as can be safely made.

It is, of course, true that a comparatively small amount of pure water would meet all the demands for drinking and cooking, and that a water of inferior quality would answer for other domestic purposes as well as for all municipal requirements and the demands of manufactures; but no satisfactory arrangement has as yet been made by which two kinds of water can be economically and safely distributed through the streets and buildings of cities and towns.

It was discovered by this Board, some years since, that no inconsiderable portion of the cases of typhoid fever found in certain manufacturing towns in this state was the result of the careless drinking of a dangerous water, which is used in the mills for mechanical purposes only, is understood to be dangerous and is distinctly so marked; but this inferior water was still used by the operatives, because it was sometimes cooler, was tasteless, and generally more accessible.

The Board has hoped that it might be possible to devise some plan by which the very limited amount of quite pure water really needed in our houses might be secured and distributed; but no satisfactory method has as yet suggested itself, nor with the present outlook for an abundant supply of very good water does such a plan seem to be an urgent need either on grounds of health or economy.

The average daily consumption of water in the metropolitan district for the year 1894 was 79,046,000 gallons, the average daily capacity of the sources now in existence for the supply of this district was only 83,700,000 gallons; that is to say, the average daily supply is only 4,654,000 gallons in excess of the actual needs. Though some of the sources of supply to the district are capable of yielding larger quantities of water than are at present furnished, we are satisfied that even a very thorough development of all these sources will barely carry the district safely through a year of unusual drought, should such a season occur before the date at which the works, hereafter to be described, can be put in condition to increase the supply; and this would be true even though the cities or towns which might find themselves possessed of a surplus supply could transfer it to their neighbor in want.

The population of this metropolitan district was, by the United States census of 1890, 844,814. Estimates which have been carefully made, and with a due regard to the diminution in rate of increase by reason of the depression in business, place the population for the year 1895 at 984,301. The water works of the city of Boston now supply nearly 75 per cent of all the water used in the metropolitan district. The daily average consumption of those cities and towns receiving water from the Boston works was 99 gallons in 1893, and the average for the entire district now under consideration was, for the same year, 83 gallons. It seems to be generally true that the nearer we approach the centres of population the greater becomes the use of water; and, with the inevitable growth of Boston and its suburbs, it does not appear to us wise to calculate upon a requirement per inhabitant of less than 100 gallons for the long period of years for which we seek a supply.

We have not deemed it necessary or advisable to busy ourselves with the insoluble problem of the probable future increase of population in and about Boston. We have assumed that the growth will go on as it has gone on during the last quarter of a century; and for a population determined by such principles we have made provision.

While every effort has been made to reconcile the views of the local authorities with our own as to their respective requirements both in regard to quantity and quality of water needed and their capacity to meet such demands, the Board has in several cases arrived at results quite different from those held by these authorities. It is assumed that no portion of this large and intimately associated community will accept for any length of time a water inferior to that enjoyed by their neighbors, either in healthful qualities or attractive appearance and odor; and it will not be profitable as a municipal investment to offer the stranger seeking a new home anything so essential to his health and comfort as water is, that shall be decidedly poorer than the article distributed on the other side of the town's borders.

It has, therefore, been assumed by us that the various communities under consideration will take, sooner or later, the better water, provided that the cost of taking it is not in excess or greatly in excess of that of an existing and inferior supply.

It will also be found to be true, we think, that a very large amount of the best water can be provided for the district at a price per head far below that at which any municipality within the district, with the exception probably of Brookline, Newton and Waltham, can supply a water of anything like an equal quality. Moreover, in our opinion, the most favored locality in this region has no prospect of obtaining beyond the next twenty or twenty-five years any source of supply that can be favorably compared, either on grounds of health or economy, with the source to be later described. It is by no means certain that Waltham, even with its present abundant and good supply, can continue to depend through a series of years upon water filtered uninterruptedly in ever-increasing quantities from a river more or less polluted.

Of the communities composing the metropolitan district, those using 80 per cent of the full amount of water will need the metropolitan supply nearly as soon as it can be furnished. It is probably possible for those using 10 per cent of the full amount to extend their works so that they may give them a supply for twenty or twenty-five years, and the remaining 10 per cent will need the metropolitan supply within a shorter time.

The works of distribution have been so designed that the first cost will be increased as little as practicable, and that they may be in condition to supply these communities when they shall need the water, by additions to the works first constructed; but some expense must necessarily be incurred at first, on account of the prospective use by these communities.

For the purpose of determining which cities and towns should be included in the district to be formed, a careful review has been undertaken of all the facts within our reach which have a bearing upon this question, — facts which will be found duly stated in the subjoined report of the engineer, Mr. Stearns; and we accordingly recommend that the cities of Boston, Cambridge, Chelsea, Everett, Lynn, Malden, Medford, Newton, Quincy, Somerville, Waltham and Woburn, and the towns of Arlington, Belmont, Brookline, Hyde Park, Lexington, Melrose, Milton, Nahant, Revere, Saugus, Stoneham, Swampscott, Wakefield, Watertown, Winchester and Winthrop, twenty-eight cities and towns, containing, in 1890, 848,012 inhabitants, constitute the metropolitan water district.

Inasmuch as the cities of Cambridge, Lynn, Newton, Waltham and Woburn, and the towns of Brookline, Lexington, Nahant, Saugus, Swampscott and Winchester, together containing, in 1890, 210,252 inhabitants, believe that they have a sufficient supply for some years to come, we do not recommend that they be provided with water from the metropolitan supply until they formally express their wish for it. These municipalities contained about one-fourth of all the people living in the proposed district in the year 1890. We have no hesitation in recording our own belief that the period at which this supply will be demanded by them is much nearer than they now anticipate; but their participation in the scheme is not essential to the success of the undertaking, nor will their absence render the immediate procuring of a new water supply any the less necessary.

After a thorough revision of all the sources of water which have been suggested or which we could discover, we selected three which seemed worthy of critical examination, — Lake Winnipiseogee in New Hampshire, the Merrimack River above Lowell and the Nashua River above Clinton.

Lake Winnipiseogee has for many years been held to be the ideal of all that was needed in the way of a perfect source of pure water, and it is capable of furnishing an abundant and excellent supply. The clear depths of its waters and the apparent freedom from pollution along its shores, unlike many of the artificial reservoirs hitherto constructed, have created so strong a popular belief in its necessary superiority to anything artificial that it may not be out of place to direct attention for a moment to some of the defects to be found even here. The permanent population on the territory draining to the lake is not large, — 35 persons per square mile; but the attractive shores have become the favorite summer camping-ground of thousands, and the amount of the most serious forms of pollution directly entering the water of the lake must be large and ever-growing. Even though the State of New Hampshire might allow a certain amount of water to be taken from this lake for domestic water supply within her own limits, it is not probable that she would consent to the withdrawal of amounts of water so large as to injure her own manufacturing industries, or to give to the people of another state any authority to interfere by police regulations with the unhampered enjoyment by her own citizens of her beautiful pleasure-grounds.

The expense, however, of constructing a conduit over the shortest and best route which it has been possible to discover, and for distributing this water through the district, amounts to $34,000,000. This large sum does not include the cost of the damages inflicted by the diversion of water and charges incident thereto; and we are confident that the water thus obtained would have no greater value than supplies which can be obtained at much smaller cost within the limits of this state and protected by our own laws.

Examinations have also been made with the view of taking the water of the Merrimack River above Lowell, subjecting it to efficient filtration and bringing it down into the metropolitan district. The quantity of water that could be obtained in this way and for this purpose is unlimited; and, if there were no way of obtaining a better supply of water and one which was above suspicion, it would be practicable to introduce water from that source at a cost somewhat less than from any other source considered.

The estimated cost of filtering and conveying this water to the metropolitan district is $17,500,000; but in the opinion of the Board it will be better to pay 10 per cent more for a supply from a source that has not been polluted. The experiments carried on by this Board for a succession of years at an experiment station in Lawrence under the immediate direction of H. F. Mills, C.E., a member of this Board, and the filter constructed in connection with the water works of that city, have shown that waters as polluted as those of the Merrimack can be effectually filtered and rendered safe for domestic use; but it is also true that filtering areas require continuous care on the part of well-trained attendants, and that, in a few instances at least, inefficient administration or inherent defects of construction have allowed disease germs to pass through filters which were assumed, by good authority, to be a sufficient protection.

We are the more easily led to reject the filtered waters of the polluted Merrimack because we have found an entirely satisfactory water in the South Branch of the Nashua River above the city of Clinton. We find that the conduit of the Boston water works was built of much larger capacity than was needed for the conveyance of the amount of water to be derived from the Sudbury River, being capable of taking 50,000,000 gallons a day more than is at present supplied to it. The territory from which an additional supply for this district may be sought is thus moved out to the westerly end of this conduit, or to the westerly end of the valley and reservoir connected with this conduit.

The first source of considerable size found to the west of this point is the above-named South Branch of the Nashua, which, at the city of Clinton, has a watershed of 118.23 square miles, consisting of a sparsely settled district containing but sixty-nine persons to the square mile. The southerly and easterly slopes of Wachusett Mountain which bound this territory to the north and west are not well adapted to agriculture, and offer few inducements to the establishment of manufactures. In this section the rate of increase of population has been very slight, and the distance from centres of population is such that no more rapid rate of growth can be expected in the future.

In this river, a short distance above the Lancaster Mills in Clinton, a dam can be built which will raise the water 107 feet above the surface of the existing mill pond, and flowing to the average depth of 46 feet an area of 6½ square miles, with its high-water mark 385 feet above the level of high tide in Boston harbor. This reservoir will have a capacity of 63,000,000,000 gallons, and the territory draining into it will supply, in a series of very dry years, 111,000,000 gallons of water daily, which, with the 62,000,000 gallons obtainable from the Sudbury and Cochituate watersheds, will make the total capacity of the combined sources 173,000,000 gallons, which is double the capacity of all the sources now utilized by the metropolitan district.

The reservoir can be connected with the new Reservoir No. 5 now constructing by the city of Boston in the Sudbury River system. The connection would be made by an aqueduct a little less than nine miles long, and an open channel about three miles long following the course of an existing brook. This aqueduct is designed to be built low enough to take water from the level of the present mill pond in Clinton; so that, should it become necessary to increase the supply to the metropolitan district before the dam and reservoir are completed, the ordinary flow of the river could be brought down into the Sudbury system as soon as the aqueduct is built.

The very great merit of the plan now submitted is to be found in the fact that this extension of the chain of the metropolitan water supplies to the valley of the Nashua will settle forever the future water policy of the district, for a comparatively inexpensive conduit can be constructed through to the valley of the Ware River, and beyond the Ware River lies the valley of the Swift; and, in a future so far distant that we do not venture to give a date to it, are portions of the Westfield and Deerfield rivers, capable, when united, of furnishing a supply of the best water for a municipality larger than any now found in the world.

The expense of this great scheme is comparatively moderate, because the watersheds in question are sparsely settled, lie among the higher regions of the state, and are not likely to become the seat of manufacturing industries. Moreover, all these streams can be brought down by their own natural flow from appropriate reservoirs to the existing distributing basins in the metropolitan district.

The water in the South Branch of the Nashua River is at present of good quality, and, with the small population upon its drainage area, it will not be difficult to protect it from impurities in the future; but, in the opinion of the Board, the large reservoir to be constructed will serve as a means of very much improving the quality of the water; its area and depth are so great that it will contain, at nearly all stages at which it is proposed to hold the water, a full year's supply when double the quantity now used in the metropolitan district is drawn from it and the Sudbury and Cochituate areas. During the long period through which water remains in this reservoir a bleaching and purifying process will go on, which will probably cause the death of all the disease germs which may be turned into it from contributing streams, and the water thus become more agreeable to the sight and taste, and be, in fact, more wholesome than the present water from any of its contributing streams. In order that this may be the case, the Board has thought best to increase the depth of the reservoir by raising the dam, and to remove from its area the vegetable matter and soil which may cover it, and thus expend about $4,000,000 in rendering the water of the best quality practicable.

So many advantages are offered by larger storage reservoirs, as compared with the smaller basins, which local geographical peculiarities have compelled the metropolitan district to build hitherto, that it has seemed advisable to us to urge the completest possible preparation of this new reservoir.

After this new water has been brought into the Sudbury system, it will pass down into Chestnut Hill Reservoir, where it will for the first time require to be pumped to an elevation of thirty feet, sufficient to give an additional head to the Boston low-service system and to carry over to Spot Pond the supply needed for the northerly portion of the metropolitan district. In our estimates of cost a sum of money has been set aside for the improvement of Spot Pond, principally for removing its shallow flowage, and we believe it will then be a valuable distributing reservoir and restored to its normal height.

It is estimated that no other conduit will be required in addition to the present one from Sudbury River to Chestnut Hill Reservoir for ten or more years; but before the end of this period it will be necessary to build an additional conduit, extending from Reservoir No. 5 of the Boston water works to a point in the town of Weston not far from the Charles River, at such a height that the water may be conveyed in pipes to Spot Pond, and be distributed through the low-service system in the metropolitan district by gravity. This aqueduct will be thirteen and one-half miles long, and is designed to convey 250,000,000 gallons of water per day.

Spot Pond is selected for a general distributing reservoir in order that the low-service district may have a pressure thirty or forty feet greater than would be supplied by Chestnut Hill Reservoir; this increased pressure is rendered necessary in order to include large areas in the district which would be inadequately served by the lower reservoir and by the custom of constructing very high buildings upon the low-lying territory.

The method of distributing the water over the metropolitan district is given in detail in the report of the chief engineer; it is designed to supply to each community within the district a sufficient quantity of water for its use at a pressure sufficient for all requirements within its territory, and it will be feasible to supply all the highest portions of the district more efficiently than at present from a much smaller number of stations and at a much diminished charge for annual maintenance.

In considering the plans for the proposed reservoir above the Lancaster Mills, we have been impressed by the very serious changes which will be produced in the towns of Boylston and West Boylston. It does not appear to us to be a very important objection to our plan that certain mill sites will be eighty feet beneath the surface of the basin, nor that the homes of many industrious people dependent upon these mills for their living will be also submerged, because all these can be paid for, and an equivalent will be given, — damages for which we have caused careful estimates to be made. But we have not deemed it to be within our province to decide upon a plan for making good the many other losses that must of necessity fall upon these sorely diminished townships, — the burden of a town debt for which much of the available security has been taken away, the loss of a near market for the farmer upon the outskirts of the town, and the many other losses which will naturally suggest themselves. We can only state that we recognize the existence of these losses, that we believe some form of compensation should be granted, and that the benefit to the metropolitan district by reason of a pure water supply in abundant quantity will be so great that this district, which contains more than half the taxable property of the state, can afford to pay for all the injury inflicted; at the same time we must leave the suggestion, even, of the nature of the remedy, to the wisdom of your honorable body.

The total assessed valuation of West Boylston for 1894 was . .	$951,610
Assessed value of property to be taken	557,730
The total assessed valuation of Boylston for 1894 was	429,435
Assessed value of property to be taken	165,200

In preparing the estimates for the cost of the great work here sketched out, we have brought to our assistance the best expert aid, and believe that the works can be constructed within the estimates which have been liberally made with the usual allowance for contingencies.

It may also be of interest to you to know that, of the whole watershed of the Nashua River above the city of Nashua in New Hampshire, at which place the Nashua enters the Merrimack, the proposed reservoir cuts off 22 per cent; but, with the provision which is inserted in the draft of an act herewith submitted for allowing a stated quantity of water to be discharged into the mill pond below the reservoir dam, the deprivation of water will not be so extensive as the proportion of reservoir watershed to the whole watershed of the Nashua would indicate.

The estimates of cost have been made by Mr. Stearns, the chief engineer of the Board. They have been made from carefully prepared designs, and are intended to be sufficient to include the full cost of the completed work.

The cost of the works necessary to supply all the communities of the metropolitan district for the next ten years with the main part of the works of sufficient capacity for a long future is estimated as follows: —

Reservoir on Nashua River, including the cost of land, buildings and water rights taken, the relocation of roads and railroads, the removal of all soil from the site of the reservoir, the construction of dams and dikes and all incidental expenses	$9,105,000
Improvement of the watershed of the Nashua River and of the Stony Brook branch of the Sudbury River by the diversion and purification of sewage and drainage of swamps	513,000
Aqueduct from the Nashua River to the Sudbury watershed and open channel from the end of the aqueduct to Reservoir No. 5 .	2,265,000
Additional forty-eight-inch pipe from Dam No. 3 to Dam No. 1 and across the Rosemary valley	78,800
Pumping stations, reservoirs and pipe systems for elevating and distributing water to all of the cities and towns in the metropolitan district, including the improvement of Spot Pond . .	5,584,000
Damages for the diversion of water from the Nashua River and incidental damages not included above	1,500,000
Total first cost of proposed works for supplying water to *all* of the cities and towns in the metropolitan district	$19,045,800

The estimates of damages for the diversion of water from the Nashua River are believed by the Board to be ample to cover all reasonable demands, and are made large enough so that it is probable that some of the more important can be settled within the estimate without litigation.

It is not proposed in the driest year to lower the water in the reservoir more than sixty feet, and there will always be a great fall between the surface of the water in the reservoir and in the aqueduct leading from it. It is estimated that this fall may be utilized to furnish 1,000 horse-power by day and 500 horse-power by night for the first fifteen years, and nearly as much for the following years.

After these twenty years, should the growth of the district be as estimated, additions will have to be made by adding certain tributaries of the Assabet River, or by extending the works to the valley of the Ware River, either of which can be done at a comparatively small cost.

The annual cost for interest, sinking fund and maintenance of the works for supplying the whole district when the works

The estimated first cost of the proposed works for supplying water to all of the cities and towns in the metropolitan district is, as above stated	$19,045,800
Within the next ten years, if the water is used by all of the cities and towns, there will be required an additional expenditure for an aqueduct from Reservoir No. 5 to Weston, and for main pipes and an aqueduct therefrom to the existing distributing system and to Spot Pond of	4,982,000
In the second ten years a further expenditure will be necessary for additional pipes from Weston and for improving a portion of the Sudbury River watershed, not included in the first estimate, of	1,300,000
Total expenditure for full development of Nashua River source, and for a supply of 173,000,000 gallons of water per day distributed to all of the cities and towns in the metropolitan district	$25,327,800

are first completed is estimated to be ninety-three cents per inhabitant, and the cost will decrease with the growth of population.

In conclusion, we desire to again call your attention to our profound conviction of the need of prompt action in entering upon works of construction which cannot for years be completed, and of which the absolute necessity will at an early day be forced upon this community; and we are confident that we have pointed out an economical as well as practicable means of securing one of the most essential conditions for healthy human life.

H. P. Walcott,
J. W. Hastings,
H. F. Mills,
F. W. Draper,
G. C. Tobey,
J. W. Hull,
C. H. Porter,
State Board of Health.

XXVI

A COMPARATIVE STUDY OF THE TOXIN PRODUCTION OF DIPHTHERIA BACILLI

By Theobald Smith, M.D., and Ernest L. Walker

[This paper of Dr. Smith and Mr. Walker resulted in decided improvements in the manufacture of antitoxin. It was an admirable piece of scientific investigation. The long table of results accompanying the paper is here omitted. *Twenty-eighth Annual Report*, 1896, p. 647. — G. C. W.]

Introduction [1]

This inquiry was suggested by the following important problems bearing upon the restriction of diphtheria: —

1. Is there any difference in the pathogenic power of diphtheria bacilli from different localities?

2. Is the pathogenic activity of bacilli producing diphtheria in the summer season different from that of those producing disease in winter?

3. Is there any reduction in the pathogenic power of bacilli in cases in which they persist in the throat after recovery?

4. Are there any differences noticeable between the bacilli of mild and those of severe cases?

The third and the fourth questions have been attacked by other observers, while the first and the second have not been especially investigated. The answers to the third and the fourth questions have been, as a rule, negative. Observers have found little or no difference in bacilli from mild and severe cases, nor have they been able to show any recognizable loss of virulence in the bacilli persisting in the throat after recovery.

The reasons for entering upon this subject again were the opportunity we have had of examining cultures from different towns within the state, and more especially certain improved

[1] The writer wishes to acknowledge the faithful assistance of J. R. Stewart, to whom the preparation of the culture media was chiefly intrusted. As will be seen from what follows, this is not a simple task.

methods of cultivation by which the maximum toxin-producing capacity of each bacillus could be brought out and measured more accurately than had been done heretofore.

The selection of cultures for the study of the questions stated above has not been entirely satisfactory, mainly because much of the clinical information necessary to a proper choice was not accessible at the time the cultures were received, and in some instances obtainable only with difficulty at the last moment when the final results were tabulated. We hope, however, that the material at hand may be supplemented by more in the near future.

THE MODE OF ACTION OF DIPHTHERIA BACILLI

It is now a generally accepted theory that diphtheria bacilli act in the main through the toxins which they produce, and which are rapidly diffused into the fluids containing the vegetating bacilli. The contents of the bacilli themselves seem to be of little moment as pathogenic factors. Park and Williams [1] allowed the washed diphtheria bacilli to soak for a week " in a 0.5 per cent alkaline carbolic solution." The injection of one cubic centimeter did not " produce any marked reaction in a 500-gram guinea-pig," although the bacilli themselves were powerful toxin-producers. Kossel [2] collected the bacillar membranes from cultures, washed the bacilli repeatedly by centrifugalizing with 0.5 per cent sodium chloride; then, after killing them with vapors of chloroform, he extracted them for several days in a few cubic centimeters of weakly alkaline fluids. The extract was only feebly poisonous, for it required 5 cubic centimeters to kill a 360-gram guinea-pig in forty-eight hours.

Brieger and Boer [3] found that shaking diphtheria bacilli with ammonium chloride and allowing them to stand for eighteen to twenty hours removes the toxin from the bodies of the bacilli. The bacilli after extraction were fatal to a 500-gram guinea-pig, in doses of 0.01 gram of bacillar substance. They acted

[1] Journal of Exp. Med., I, p. 174.
[2] Centralblatt f. Bakteriologie, XIX, p. 977.
[3] Deutsche Med. Wochenschrift, 1896.

by producing local necrosis. Brieger states that antitoxin had no effect upon this action of the dead bacilli, and that immunization towards it by gradually increasing doses failed. The poison itself withstood an hour's boiling.

These experimental observations, taken together, show that the toxin in the culture fluid and not the body substance of the bacilli themselves is to be looked upon as the disease agent. The success following the prompt application of antitoxin in sufficient doses is an additional support to this view. Moreover, the bacilli themselves do not penetrate into the body in large numbers, hence need not be specially considered as adding to the toxic effect of their products.

We may, for convenience, regard the disease-producing power of diphtheria bacilli as made up of two elements, — toxicity and virulence. The former represents the rate of accumulation of toxin in culture fluids, and is easily measured; the virulence, on the other hand, which may be regarded as the behavior of diphtheria bacilli toward living tissue, is as yet an unknown quantity. This distinction between the toxic product of diphtheria bacilli and their inherent vital power to cope with living tissue seems to be established, at least experimentally, by the increase in virulence of diphtheria bacilli in their passage through a series of guinea-pigs, which has been reported by various observers. Thus, Aronson[1] states that a culture which was at first fatal to guinea-pigs of medium weight, in 0.1 cubic centimeter doses, was fatal, after some serial inoculations, in doses of 0.008 cubic centimeter. That is to say, its virulence was augmented twelve times. This experiment evidently means not that the toxin formed in the subcutis of guinea-pigs became twelve times stronger in quality at the end of the series, but that the bacilli injected were capable, by an adaptation of some sort, to multiply much more abundantly toward the end of the series, and hence produce more toxin. The other explanation, that the toxin itself had become more potent in quality, could only gain confidence if the bouillon culture produced much more toxin at the end of the experiment than at the beginning, the conditions remaining precisely the same.

[1] Berl. klin. Wochenschr., 1893, Nos. 25 and 26.

To compare the disease-producing power of diphtheria bacilli from different sources, it was, therefore, thought best to study the relative accumulation of toxin in bouillon, and eliminate the bacilli by filtration before the test upon animals. The writer is fully aware of the fact that but an instrument of pathogenic power is here dealt with, and under artificial conditions, since we do not know the nature of the nutritive fluid which the bacilli make use of on mucous membranes, nor, as a consequence, whether the toxin production in bouillon is a true index of the production of toxin on mucous membranes. The problem is, in fact, very complex, as with all infectious diseases, and all we can hope to do at a time is to examine one factor of disease as carefully as possible, while eliminating all the others for the time being. The use of living cultures upon animals is of no service in these experiments, because it introduces at once three variable factors: (1) the bacilli as potential toxin-producers after injection; (2) the poison of their bodies after destruction; and (3) the toxin pre-formed in the culture fluid injected. As a consequence, all who have used cultures find them uncertain in their action, as compared with the toxin alone. The bacilli injected as nearly free from fluid as possible are equally unreliable as measures of toxicity, as the following tests show: —

Two cultures of diphtheria bacilli are selected, which differ considerably in toxin-producing power, the toxin-producing power of one being about three times that of the other. Inclined agar cultures are prepared from each, and after six days' growth the bacilli are removed with a platinum wire, the amount of moist bacilli weighed and stirred in 5 cubic centimeters sterile bouillon, making a moderately cloudy suspension. One cubic centimeter contained by weight about 0.0007 gram of moist bacilli.

Bacillus No. 14. — Five-tenths cubic centimeter of the suspension, injected subcutaneously into a guinea-pig weighing 313 grams, is fatal in five days; 1 cubic centimeter is fatal to a 330-gram pig in six days.

Bacillus No. 40. — Of the suspension made in the way described, 1 cubic centimeter is injected into a guinea-pig weighing 315 grams. Animal just escapes death, and is chloroformed on the sixth day. Another, weighing 330 grams, receives 0.5 cubic centimeter. A slough forms at the place of injection. The guinea-pig remains in fair condition.

Though these tests show a greater activity on the part of Bacillus No. 14, yet we miss here not only the sharp definition in the results obtained by varying the dose of the same culture, but also in comparing the effect of the same doses of cultures from different sources.

A prolonged study of the relative production of toxin in bouillon under certain uniform conditions has shown such remarkably uniform results with the same culture, even after long intervals of time, that the results obtained in this way may be accepted as showing an inherent difference in the various bacilli studied.

The Method Employed in Comparing the Toxin Production of Different Cultures

In a former publication[1] the writer has given the conditions which must be fulfilled in order that a maximum accumulation of toxin may take place in bouillon cultures. The facts there considered and others since then brought out may be very briefly reviewed here. In 1895, Spronck[2] called attention to the fact that the variable amount of sugar present in beef was responsible for the great fluctuations observed in the toxicity of diphtheria cultures. The writer had observed this independently of Spronck, by studying the relation between the amount of toxin in cultures and the amount of sugar as determined by the fermentation test. Sugar is present in all beef, but in perhaps 10 per cent the amount is very small. In bouillon made from such beef the writer obtained very strong toxin. In bouillon from beef containing over 0.1 per cent sugar the toxin was very feeble.

The cause for this difference lies in the acid or acids formed from the dextrose by the diphtheria bacillus, which inhibit the multiplication in a direct ratio to the amount formed. In sufficient quantity the growth may be entirely checked, and finally, when the acidity has reached a certain degree, the bacilli and the toxin are destroyed. Whether there are other causes at work besides mere inhibition of multiplication remains undetermined.

[1] Trans. Association American Physicians, for 1896.

[2] Annal. de l'Institut Pasteur, 1895, p. 758.

A small amount of dextrose, up to 0.05 per cent, is not inimical to toxin production; in fact, it seems to be more favorable than none at all, probably because a certain minimum amount is necessary for the cell life of the diphtheria bacilli. Bearing these facts in mind, we are better able to comprehend the various changes going on in cultures. The life of the culture begins with a rapid multiplication of the bacilli introduced and the formation of a surface membrane usually within twenty-four hours. At the same time, any sugar present is acted upon at once, with the result that the reaction becomes more acid. If the acidity increases beyond 2 per cent of a normal acid solution,[1] the culture is likely to become languid, the surface membrane rifted and settle to the bottom. Some bacilli, by a vigorous surface growth which probably oxidizes the acid products formed, may subdue a large amount of acid, even to 3.5 per cent, and cause a rapid return towards the alkaline level. The toxin appears in greatest concentration when the alkaline level has been reached, usually within eight to twelve days, when sugar is present in small amount only. When sugar is more abundant the acid period is prolonged, during which little growth is evident. After several weeks a slow alkalizing tendency brings the culture to a more vigorous growth and to an alkaline reaction, but without much accumulation of toxin.

Without going into more detail on this subject, we may summarize the conditions under which diphtheria bacilli produce maximum amounts of toxin in the ordinary 1 per cent (Witte) peptone bouillon as follows: —

1. Muscle sugar in the fluid from 0 to 0.05 per cent.

2. Initial reaction from 0.8 to 1.5 per cent normal acid, the lower figure pertaining to bouillon containing the largest amount of sugar, the higher to bouillon containing none.

3. A thin layer of bouillon freely exposed to the air through one or more cotton-plugged openings in the vessel, and quiescent because the surface membrane which forms within twenty-four hours must not be disturbed.

[1] I. e., each 100 cubic centimeters of the culture fluid requires 2 cubic centimeters of a normal solution of alkali to bring the whole to the neutral point as determined by phenolphthalein.

4. The accumulation of toxin should be permitted to go on until the growth is checked by the alkaline reaction. This appears in from eight to twelve days, according to the initial reaction and amount of sugar present, and the growth ceases when the reaction is equivalent to 0.2 to 0.3 per cent normal alkali.

The main difficulty before us, therefore, is to get beef containing only traces of dextrose. The writer's original plan, to select the bouillon in accordance with the fermentation test, is not feasible, because so little can be used. Spronck's suggestion, to allow the beef to lie for several days, in order that a partial decomposition by bacteria may transform the sugar, is better, but suffers from certain difficulties. The kind of bacteria cannot be controlled, and frequently the sugar is found but partially removed. Latterly, the writer has given up this method for one more rapid and certain in its action. The beef infusion is prepared either by extracting the chopped beef at 60° C. for several hours, or over night in the refrigerator. After removal of the beef the infusion is inoculated with a culture of some bacterium which rapidly acts upon dextrose, and placed in the thermostat over night. The writer has tried only B. coli, and found a complete transformation of carbohydrates taking place over night.

In the case of bouillon designed for diphtheria toxin the incubation should be as short as possible, so as to leave a trace of sugar in the fluid. This can be accomplished by placing the inoculated infusion in the thermostat at 10 P.M. and removing early next morning (8 A.M.). The infusion is then made up in the usual way, with 1 per cent peptone, ½ per cent sodium chloride. The final reaction should range, according to the amount of sugar left as stated above, between 0.8 and 1.5 per cent normal acid, phenolphthalein being used as indicator. It can easily be brought to any desired point by adding from sterile solutions the calculated amount of normal acid or alkali (HCl or NaHO). The whole procedure is very simple after it has been put into routine practice. At any rate, the bacteriologist must make up his mind to give up the early slovenly methods of preparing culture media, or else be prepared for constant reverses and failures.

The bouillon must be sterilized finally in the autoclave, since the ordinary steaming frequently fails to destroy certain spore-bearing anaërobes, which begin to multiply after the diphtheria bacilli have formed a membrane and deoxidized the culture medium. These anaërobes inhibit the production of toxin.[1]

Park and Williams claim [2] that the amount of dextrose in beef purchased in New York City is not sufficient to interfere with the maximum accumulation of toxin if the culture be made sufficiently alkaline to begin with. This claim I cannot support by my experience with beef bought in the Boston markets. It may be that these authors had under observation bacilli which had acquired, through surface cultivation, a greater power to promptly oxidize acid products. This power is not possessed, as a rule, by bacilli recently isolated from the throat, with which this article deals.

A number of observers have published studies of the relative virulence of diphtheria bacilli from various sources, and those persisting in the throat after recovery for a variable length of time. It is not the object of this article to re-examine these writings and review the results obtained. For a summary of the literature the reader is referred to the article by J. H. Wright in the *Boston Medical and Surgical Journal*, Vol. 131, 1894, page 329, and *Scientific Bulletin*, No. 1, of the health department, city of New York, 1895. A perusal of the various articles will show that the method of testing the virulence of the diphtheria bacilli was not adapted to give uniform or quantitative results. Thus, Park and Beebe, on page 23 of the bulletin referred to, recommend alkaline glucose bouillon as a culture medium, and the injection of cultures forty-eight hours old. Wright used sugar bouillon very largely. From what we now know of the inhibitory and destructive action of the acids formed from dextrose by diphtheria bacilli, the use of more than 0.1 per cent dextrose in bouillon must be considered as at least unsafe. However, the authors followed

[1] Since writing this, it has been observed that high temperatures in the autoclave may modify the bouillon in such a manner that only little toxin is formed subsequently. This matter is now under investigation.

[2] Journal of Experimental Medicine, I, 1896, p. 164.

general usage at that time, for even Escherich, in his work on diphtheria issued in 1894, page 91, states that dextrose is not decomposed in appreciable manner by diphtheria bacilli, and therefore has no influence on growth.

Authors have not, so far as the writer knows, reported comparative tests of toxin production under conditions as nearly uniform as possible. It was mainly to fill this gap, if possible, that the series of cultures to be described were subjected to a comparative examination from the point of view of toxin production. Table I[1] gives a condensed account of the work done upon which the calculation of toxin production rests. In this table will be found: (1) the amount of acid produced in dextrose bouillon; (2) the condition of the bouillon used for the cultures; and (3) the test of the filtrate on guinea-pigs. The acid production will be dealt with farther on. The facts relative to the bouillon used need some explanation.

The beef used for bouillon, with one exception, was allowed to decompose according to Spronck's suggestion, but the results were not uniform, as stated above. In some of the bouillon the dextrose was absent, in some present in traces, in some in more appreciable amount, according to tests made with the fermentation tube and B. coli. In none was it present in the amount usually found in bouillon made from fresh beef. It is not probable that this slight fluctuation in the amount of dextrose had any appreciable influence on the culture. Where a doubtful result was obtained it was usually supplemented later on with a second test.

The question might be asked, Why not use the same bouillon for all bacilli studied, in place of the many lots actually employed? This would seem the simplest procedure, provided the bouillon did not change with time under the influence of light and air. A diminution in the amount of toxin produced in bouillon which had been standing for some time in a closet not absolutely dark had been casually observed. It is probable that bouillon in vacuo and kept in a dark place might meet the conditions of the problem, but bouillon kept under ordinary conditions would not. Further

[1] This table is not reproduced.

investigations are now in progress to determine more precisely the degree of change produced in bouillon by age.

It might be claimed that different bacilli isolated from the throat would have different rates of growth in bouillon, and that the accumulation of toxin was simply a factor of the rate of multiplication, rather than of any inherent differences in the physiology of the bacilli. To answer this claim a determination of the number of diphtheria bacilli in cultures is not trustworthy, for the reason that diphtheria bacilli clump together, and the number of colonies in plate cultures may not indicate the number of bacilli used in preparing the plate. Again, bacilli may die in the course of growth, and others take their places. The writer has therefore endeavored to estimate the vigor of growth by the amount of change in the reaction produced. Cultures which in a given time in the same bouillon produce nearly the same amount of alkali may be regarded as having performed the same amount of work and grown with equal vigor. The uniformity of reaction in the various groups of bacilli studied together, after ten or twelve days, was such as to leave little doubt that the growth had been equally vigorous. When any culture lagged perceptibly behind, it was usually repeated with other bouillon.

The extent of the alkali production varies with the initial reaction of the bouillon and the presence of dextrose. Cultures containing the latter became at first more acid before swinging back to alkalinity. In Table I, therefore, it was deemed best to give both the initial reaction of the bouillon, the approximate amount of dextrose and the final reaction. Some idea may thus be gained of the amplitude of change which the fluid underwent during the period of growth permitted.

The culture vessel used at first was a large test tube placed in an inclined position after inoculation. This was soon given up for the Erlenmeyer flask, in which the depth of the bouillon was about 1.5 centimeters.

The toxin formed after ten to twelve days was tested upon guinea-pigs. The fluid was passed through filter paper until clear, then diluted with sterile salt solution, so that the quantity of toxin injected was contained in 1 cubic centimeter. Usually 0.1 cubic centimeter of toxin was injected. The place of injection chosen was the left side of the abdomen. Great care was exercised to deposit the fluid in the subcutis, and not to prick the muscles of the abdominal wall. A vascular injection of the omentum or peritoneum is usually a result of the introduction of some of the fluid into the abdomen. When such reddening was noted at the autopsy, the test was repeated upon another animal, since death is hastened somewhat when this occurs. Guinea-pigs weighing between 300 and 350 grams were used whenever possible. When larger ones had to be used, the increase in weight was duly taken into account.

From the results of such inoculations the minimum fatal dose upon a guinea-pig weighing 300 grams was calculated. The calculation when such had to be made was based upon the fact that the minimum fatal dose usually kills a guinea-pig in from three and one-half to six days. If x represents this dose, then a guinea-pig which succumbed in two and one-half days, or sixty hours, received $\frac{10x}{9}$, and one which succumbed in thirty-six hours, $\frac{20x}{9}$. Guinea-pigs of greater weight do not necessarily bear an exact equivalent increase of toxin, but usually somewhat less. In general, it may be said that the values given as the minimum fatal doses may err within 10 per cent, owing to various factors which cannot be controlled. Among these is a slight variation among guinea-pigs in their tolerance of the virus, the darker (black, or black and red) animals being able to stand about 10 per cent more toxin than the white animals. Even if we allow a variation of 10 per cent in the values given in Table I, the general outcome of the comparative study is not made in any sense untrustworthy.

Morphology

The following description of the morphology and the staining peculiarities of the bacilli studied is based on microscopic preparations from cultures of twenty-four hours' growth at 35° to 37° C. on Löffler's blood-serum mixture, uniformly fixed and stained. The cover-slip preparations were dried in open air at room temperature, fixed by heating twenty minutes in a dry-air sterilizer at the temperature of 120° C., and stained eight minutes with Löffler's alkaline methylene blue solution. It may be remarked, however, that experiment shows that the method of fixation has little if any effect on the outline of the bacillus or upon the aggregation of its chromatin, and consequently upon the irregularity of its staining.

In length the diphtheria bacilli vary from 1.5 μ to 13 μ, and for the purpose of description it is convenient to distinguish three groups: short bacilli, including all bacilli under 2 μ in length; bacilli of medium length, including all bacilli between 2 μ and 4.5 μ; and long bacilli, including all bacilli over 4.5 μ in length. Bacilli in culture No. 33 are rather remarkable for their length, averaging 7.5 μ to 10 μ, while a few were found as long as 13 μ.

It may be said of diphtheria bacilli in general that there appears to be a tendency for the shorter bacilli to become swollen at the middle and for the long bacilli to become swollen at the ends; and that the short bacilli are usually straight, while the long bacilli are usually curved or bent at an obtuse angle.

Comparison on the basis of length, outline and manner of staining allows the bacilli of the forty-two virulent cultures to be divided into three types, of which the following description may be given: —

Type I. Bacilli of medium length, straight, cylindrical or slightly swollen in the middle, with blunt ends, and with intensely stained granules in an otherwise uniformly but less deeply stained cell. In the shorter bacilli of this type these granules are usually situated at the ends of the rod, one at each end; but in the longer bacilli there may be, in addition to these polar granules, one or more interpolar granules. These deeply stained bodies are usually of less diameter than the thickness of the bacillus, but may be of greater diameter, swelling the bacillus at the points where they are situated.

Type II. Bacilli long, slender, curved, more or less swollen at one or both ends, and with alternating stained and unstained (or faintly stained) cross-segments.

Type III. This includes seven of the forty-two cultures. Bacilli are of various lengths, swollen in the middle, with tapering ends, and with broad, unstained terminal and intermediate segments. These unstained terminal segments may be so extensive that a body simulating a nucleus in the middle of the cell is the only stained portion. More often the cell may consist of two stained and three unstained cross-bands. The staining of this type differs from that of Type II, in that the alternating segments of Type II are narrow and numerous and the terminal ones are always stained.

Modifications of these types and intermediate forms occur even among bacilli of the same culture, but in nearly every case one form predominates sufficiently to allow the culture to be ranged under one of these three types. In the routine work of bacteriological diagnosis of diphtheria, as carried on under the direction of the State Board of Health, Type I and its modifications are found in about 90 per cent of the positive cases and bacilli of Type II make up the greater part of the other 10 per cent. Bacilli of Type III are very infrequently found. This classification holds good for young cultures on Löffler's serum mixture only.

Bacilli belonging to these three types have so far proved virulent to guinea-pigs when tested according to the methods given in another part of the text. But besides these a certain number of bacilli (Nos. 3, 4, 39 and 44 of the tables) have been isolated which are non-pathogenic, and which belong to the class of pseudo-diphtheria bacilli described farther on.

Toxin-Producing Power

The toxicity of the culture fluid of the forty-six cultures after an incubation at 35° C. for ten to twelve days ranged as follows, the 300-gram guinea-pig being the basis of the computations: —

Table 47

	Cubic Centimeters
In one the minimum fatal dose is	.036–.04
In one the minimum fatal dose is	.045
In five the minimum fatal dose is	.050
In five the minimum fatal dose is	.060
In four the minimum fatal dose is	.070
In four the minimum fatal dose is	.075
In eleven the minimum fatal dose is	.080
In two the minimum fatal dose is	.090
In four the minimum fatal dose is	.100
In five the minimum fatal dose is	.120
In four no toxin was formed	

Leaving aside for the moment the non-pathogenic forms, we notice in this summary, first of all, a considerable uniformity in the toxin-producing power. It is true the strongest toxin producer accumulates three times as much toxin as the weakest, but only one of such strength was found. It will be noticed also that the greater number of bacilli studied produce an 0.08 cubic centimeter toxin. If we group the cultures as follows,

	Cultures
.036–.06 cubic centimeter toxins	12
.070–.09 cubic centimeter toxins	21
.100–.12 cubic centimeter toxins	9

the predominance of the middle group is better brought out.

Cultures of much greater toxin-producing power have been isolated by Park and Williams. Of these, the minimum fatal dose is reported to range from 0.002 to 0.01 cubic centimeter. It is not stated whether these cultures produced this amount of toxin at the outset, or after periods of artificial cultivation.

By comparing these figures with the results of earlier observers, the greater efficiency of the method described appears in striking relief. Experimenters when first preparing antitoxin had some difficulty in finding bacilli whose toxin would yield a minimum fatal dose of 0.08 to 0.1 cubic centimeter. In the series here recorded only five out of forty-two fell below this mark.

Although the clinical records of the cases from which the bacilli came are very meagre, they suffice to show that any direct relation between toxin production and severity of the disease is not obvious. This has been the inference of observers before us (Wright, Park and very recently Timaschew [1]), and we are able to confirm it after the application of more uniform and exact methods. This is what might be expected when we contemplate the complex nature of the disease process, the many factors which may enter into it, both on the part of the patient and the invading bacilli. There is one factor, for instance, which may modify the course of the disease, and therefore make any present-day estimates untrustworthy, — namely, antitoxin. If applied early enough, it may convert a potentially serious case into a mild one,

[1] Centralblatt f. Bakteriologie, XXI, 1897, p. 623.

in spite of a virulent organism. Antitoxin was used in nearly every case from which bacilli were studied, but the time of administration and the number of units injected were not reported excepting in a few cases, so that the facts on hand are not worth any serious study. All that can be said is that the toxin-producing power of bacilli from mild and from severe cases varies but little, and that all throat affections must be regarded equally dangerous if diphtheria bacilli are present.

The Toxin-Producing Power of Bacilli Persisting in the Throat after Recovery

Much interest has been aroused by the patients in whose throats diphtheria bacilli may be found a variable length of time after subsidence of all symptoms of disease. Löffler, in his investigation of the etiology, found diphtheria bacilli in the throat of a healthy child. Roux and Yersin first called attention to the persistence of diphtheria bacilli after recovery, but they disseminated the impression that there was a gradual attenuation going on which eventually made them harmless. That this may be true in certain cases is not disputed, otherwise it would be difficult to account for the presence, in the mouth of some healthy persons, of bacilli in no way distinguishable from those associated with disease processes except by an absence of virulence.[1] This attenuation has not been observed by subsequent investigators, however, and no reliance can be placed upon it to purge the throat of the recovered case of its infectious character.

Among the forty-six cultures studied there were eleven made from the throat fifteen to sixty-two days after the appearance of the disease. Owing to the meagre records returned, it is impossible to state how long *after* the subsidence of the symptoms the bacilli were obtained from the throat; but by a reference to the table, where the relative severity of each case is noted, some idea may be gained by the reader of the probable duration. The following table summarizes these cases. It includes two from which harmless pseudo-forms were obtained: —

[1] Centralblatt f. Bakteriologie, XXI, 1897, p. 37.

TABLE 48

Number of Culture	Date of Earliest Symptoms	Date of Culture	Interval (in Days)	Minimum Fatal Dose of Toxin (Cubic Centimeters)
23	July 12, 1896	Aug. 3, 1896	22	.07
24	July 14, 1896	Sept. 9, 1896	57	.08
26	Aug. 28, 1896	Oct. 19, 1896	52	.05
27	Sept. 27, 1896	Oct. 19, 1896	22	.06
34	Oct. 22, 1896	Nov. 17, 1896	26	.05
36	Nov. 15, 1896	Nov. 30, 1896	15	.08
39	Nov. 22, 1896	Dec. 29, 1896	37	Not toxic
40	Dec. 18, 1896	Jan. 4, 1897	17	.12
42	Dec. 31, 1896	Jan. 16, 1897	16	.07
43	Feb. 20, 1897	March 19, 1897	27	.08
44	Feb. 8, 1897	March 25, 1897	45	Not toxic
45	Feb. 9, 1897	March 23, 1897	42	.08
46	Jan. 29, 1897	April 1, 1897	62	.08

If we exclude the harmless, non-toxic cultures (Nos. 39, 44), which will be discussed farther on, we observe that, so far as toxin production is concerned, the length of time the bacilli have sojourned in the throat has no tendency to reduce it below the average. This is still better brought out by arranging the cultures in the following groups: —

TABLE 49

Group	Days after Beginning of Disease	Number of the Culture	Toxicity (Cubic Centimeters)
I	15 to 20	35	.08
		40	.12
		42	.07
II	20 to 30	23	.07
		27	.06
		34	.05
		43	.08
III	50 to 62	24	.08
		26	.05
		45	.08
		46	.08

Still more to the point are cultures Nos. 22 and 23, which were isolated from the same case, one three, the other twenty-two, days after the onset of the disease. Here the toxin production was practically the same for both cultures.

Pseudo-Diphtheria Bacilli

From the table it will be seen that four of the forty-six cultures isolated were found to be pseudo-diphtheria bacilli. It does not lie within the scope of this paper to discuss at length the relation between the true diphtheria bacillus and the pseudo-diphtheria bacillus. A very good discussion will be found in the work of Park and Beebe, to which the reader is referred. Since its appearance nothing new has been added to this subject. These bacilli, however, influence to a certain degree the interpretation of problems in public sanitation, so that a brief reference to them becomes necessary.

These bacilli, generally known as pseudo-diphtheria bacilli, are short rods (1.5 μ to 3 μ), with rounded or tapering ends (often oval in culture), and uniformly stained, or with a single narrow, unstained cross-segment. A few cylindrical, pear and hour-glass shaped bacilli are occasionally seen; but involution forms are not marked, even in old cultures. They are distinguished from diphtheria bacilli by being shorter, smaller, more uniform in size, shape and manner of staining, and, as pointed out by Escherich, by a tendency to lie parallel in cover-slip preparations. These bacilli are of occasional occurrence, both in the throats of patients suffering from non-diphtheritic throat affections and in true diphtheria mingled with the Klebs-Löffler bacilli. They are, however, almost always present in small numbers, while the diphtheria bacilli, in recent cases, are usually present in large numbers and well differentiated. It is only in convalescent cases of long duration that the pseudo-diphtheria bacilli are likely to cause doubt. They might be mistaken for the last few remaining diphtheria bacilli, or the reverse might occur. A few remaining virulent forms may be regarded as pseudo-forms. Diphtheria bacilli directly from the membrane from the throat, or from cultures scarcely at all developed, sometimes resemble quite closely the pseudo-diphtheria bacilli in morphology and staining.

The morphological differences are reënforced by at least two biological differences of importance, — the absence of any power to produce acids in bouillon containing dextrose, and the lack of pathogenic power. In Table I,[1] it will be seen that all toxin-producing bacilli, when multiplying in bouillon containing 1 per cent dextrose, produce a considerable amount of acid, ranging from 3.5 to 5 per cent of a normal acid solution when phenolphthalein is used as an indicator. A few cultures were found which produce between 5 and 6 per cent. The pseudo-diphtheria bacilli produced no acid under the same circumstances. The culture slowly becomes more alkaline, as shown in the table (Nos. 3, 4, 39, 44). The culture fluid of these bacilli was likewise free from toxin. Guinea-pigs which received from six to twelve times the average fatal dose of the virulent cultures showed no trace of infiltration at the place of injection and no loss in weight.

Though there are these three distinctive features of pseudo-diphtheria bacilli, — characteristic morphology, absence of acid and of toxin production, — it is not a simple matter to recognize them as such promptly under the microscope when taken from throat cultures, unless the observer has had considerable training. It is highly probable, therefore, that Roux and Yersin in their earlier work may have mistaken pseudo-diphtheria bacilli for true diphtheria bacilli, when they found virulent and non-virulent forms together in the throats of convalescents. This may explain their at that time quite natural position, — that the virulent forms were being transformed into non-virulent forms. In two of the cases tabulated above (Nos. 39 and 44) the pseudo-diphtheria bacilli were isolated respectively thirty-seven and forty-five days after the beginning of the disease. Here, without a more profound study of the cultures, the belief might gain the upper hand that the cultures represented diphtheria bacilli which had lost their virulence. This position can no longer be upheld, and we must accept or at least act upon the presumption that the pseudo-

[1] This table is not reproduced.

diphtheria bacilli belong to a wholly different group of bacilli, and that a loss of pathogenic power of the genuine forms does not take place in the mouth for months after the subsidence of the disease, when such forms persist after recovery.

Of the non-virulent but otherwise characteristic diphtheria bacilli, described by Park and Beebe and by others more recently, none have come under observation.

XXVII

SANITARY CONDITION AND IMPROVEMENT OF THE NEPONSET MEADOWS

[Written by Dr. H. P. Walcott, chairman of the Board. *Special Report*, 1897, pp. v–x. — G. C. W.]

THE State Board of Health, acting under chapter 83 of the Resolves of 1895, has investigated the sanitary condition of the meadows on the Neponset River in the towns of Canton, Sharon, Norwood, Dedham, Milton, and Hyde Park, and herewith submits the results of that examination, together with recommendations for the improvement of the sanitary condition of these meadows and the removal of nuisance therefrom.

These meadows are shown upon Plan No. 1,[1] and cover an area of 3,662 acres. Of this surface hardly more than 600 acres appear to be in a condition adapted to profitable agriculture. From the remaining territory crops of hay are obtained occasionally, or not at all. The condition of the meadows seems to have grown worse in recent years, and many of the larger owners have abandoned the attempt to secure some degree of drainage by the maintenance of open ditches, on account of the steadily diminishing returns from the crops.

At an earlier day and for a succession of years a grass known as the fowl meadow or false redtop grew on these meadows, — the first name still is used to designate the locality, — and, proving to be a valuable forage plant, gave a high value to the lands upon which it flourished. The present condition of the territory, however, is evidently not so favorable as it once was to the growth or preservation of this grass, and it is also probable that cheaper transportation has brought into this market hay of a better quality at a price lower than that at which this marsh grass could be profitably sold. As a result of either or both of these conditions, the value of these lands has steadily fallen.

[1] This map is not reproduced.

While it might be expected that the meadows should be uninhabited, as they are, it is not at first so easy to understand why the higher grounds in the vicinity should be still unoccupied by the rapidly increasing suburban population which seeks and finds acceptable building sites at distances from the business centre of Boston more considerable than any portion of the area in question. The facilities for transportation by convenient railroads are at least as good as can be found in other directions from Boston, and the towns which make up the district appear to be desirable places of residence. There has, however, for years existed a popular belief that the meadows have become a source of sickness, and this feeling seems recently to have increased. Intelligent observers report that these meadows are at times the source of disagreeable odors and the direct cause of much sickness. The examinations by this Board have shown that the upper portion of the stream was very seriously polluted, and the opinions of the physicians residing and practicing in the valley, which have been from time to time collected, indicate a general belief on the part of the medical profession that the conditions affecting health here are more unfavorable than they formerly were.

The valley of the Neponset River has twice before been the subject of extended examinations by the State authorities, — first by the State Board of Health in 1875, and subsequently by the Massachusetts Drainage Commission in 1885. In addition to these examinations, a description of the Neponset River basin, with statistics relating to its pollution and analyses of its waters, may be found in the special report of the State Board of Health on the examination of water supplies, 1890, and in the twenty-second annual report of the Board. So much of the great body of facts collected by the Board as may be necessary for the purposes of this report will be found in the report of the engineer.

The earliest notices of these meadows give evidence that even then there were prolonged periods of flooding, and that it was found necessary to clear the bed of the stream from time to time of its obstructions, consisting of fallen trees and shrubs with the entangled rubbish. With the increasing pollution of the stream, however, another and more persistent interference with the current became operative. The waste matters of human life and the refuse of manufactories, when added to the waters of the stream, became efficient fertilizers for the vegetable substances that find a home there, and their increased quantity became a mechanical hindrance to the current, promoted deposits in the bed of the stream, and finally, by their decay, gave to the atmosphere odors which common experience as well as scientific knowledge declare to be injurious to health.

An accurate estimate of the amount of sickness produced by the condition of these meadows, founded upon statistical inquiry, is almost impossible, and largely for the reason that the common-sense of the people and their freedom to select more salubrious locations have prevented settlements in the immediate vicinity of these low lands. We find here, at an average distance of thirteen miles from the State House, an area of more than eleven square miles which is uninhabited. The people have not had the same objections to residence near the great salt marshes which line our coast, where the conditions of flooding and soil moisture are apparently as serious as they can be in the Neponset valley, but are not associated with a seriously polluted water or excessive growth and decay of vegetable matters.

We are of the opinion that the condition of these meadows and of the beds, shores and waters of the Neponset River is injurious to the public health. The opinions of the physicians of this district, as ascertained by an inquiry instituted by the Board, are also distinctly to the effect that the conditions which now exist here are unfavorable to health and that the unhealthful conditions are increasing in amount from year to year.

One disease has attracted considerable attention in recent years in many portions of this state, — malarial fever, — and portions of this valley have suffered from it, and severely, when the limited population is taken into account.

One farmhouse was found not far removed from the meadows, but lying many feet above their level, which, well built and well cared for, had failed to offer adequate protection against an influence which, originating beyond the immediate surroundings of the house itself, was sufficiently potent to affect more than half of the ten occupants of the house.

We find that malarial diseases are uniformly prevalent in the Neponset basin, though no distinct concentration of cases has been anywhere observed except in the case of the farmhouse above cited. This is a condition of things which points distinctly to some influence which pervades the whole district, and the obvious origin of such an influence is the condition of the Fowl Meadows, with the polluted river and large areas of stagnant water. While the current theories upon the subject of malarial diseases may sufficiently explain the occurrence of these diseases in a marshy region, with stagnating water and the inevitable accompaniment of decaying vegetation, we are well aware that future scientific examination may find the really essential factor in some hitherto unsuspected condition of such territories. But it fortunately is true that malarial diseases where once prevalent have disappeared upon the removal of conditions such as those now found through the Neponset valley, and that the general healthfulness has been distinctly and immediately increased thereby.

Attention is also called to the report contained in the appendix[1] prepared by the chemist of the Board. With the co-operation of the owners of the larger manufactories on the river, a very complete examination has been made of methods for diminishing the pollution of the stream by treatment of the effluents from these establishments, and it has been found that these effluents, either by themselves or when mixed with ordinary town sewage, can be satisfactorily purified upon properly prepared sand filters. It is advisable, however, to remove by sedimentation from the factory effluent, before it reaches the filter, so much of the sludge contained therein as is possible. This sludge can be removed from the sewage by means of a settling basin of moderate dimensions, and, as it contains much more nitrogen than ordinary sewage, could probably be readily disposed of.

For the present, at least, the sparsely settled districts adjoining the meadows do not appear to be in pressing need of extended systems of sewage; but the time will come when the same pro-

[1] This is not reproduced.

vision which is here recommended for the factory refuse should be made for the collection and purification of domestic sewage. There appear to be in the valley areas of land suited to intermittent filtration, and sufficient in quantity for the needs of the district.

Portions of the banks of the stream in the town of Hyde Park are at present in an unsanitary condition; but legislation subsequent to that authorizing this inquiry by the Board has provided a sufficient means for the relief of this state of things, through the construction of a sewer system having an outlet into the metropolitan system of sewerage.

The measures which we recommend for the remedy of the conditions injurious to health now existing in the Neponset valley are these: —

(1) Such additional legislation as will prevent the entrance into this stream of sewage and manufacturing wastes which have not been satisfactorily purified.

(2) The permanent removals of the flashboards of the dam of the Mattapan Mills, the enlargement of the cross-section of the river at points indicated on Plan No. 3,[1] together with a deepening and reconstruction of the channel at such places as may be found necessary for making a channel of such width and grade as will prevent the flooding of the meadows during the times of high flows in late spring and summer.

A conservative estimate of the cost of making this improvement, irrespective of land and water damages, is, in round numbers, $125,000. The engineer also presents some figures to show the increase in the value of meadow lands reclaimed, and to this sum should also be added the enhanced value of the now neglected building sites immediately adjoining the meadows. It can thus be demonstrated, we think, that the work of improvement would be justifiable from a money standpoint alone. We have not considered it within our province to present the agricultural advantages of a drainage of this expanse of meadows. Land so well adapted, as this would be when drained, to the purposes of market gardening must always have a value near a great market far in advance of any price now paid for land in this district.

[1] This map is not reproduced.

When we limit ourselves, however, to considerations of health, it scarcely seems necessary, now that a considerable portion of the state has acquired a knowledge of the depressing and disabling effects of malarial diseases, to insist upon the economical value of a freedom from the conditions that favor their prevalence. We do not hesitate, therefore, to recommend the improvement of this district, the healthfulness of which is vital to the immediate residents therein, as well as to the occupants, present and future, of the lands lying about it.

It will be remembered that, in accordance with the recommendations of the Massachusetts Drainage Commission, legislation was had now embodied in chapter 375 of the Acts of 1888. Under the provisions of this act the State Board of Health has the general oversight and care of all inland waters. The commission which suggested the legislation above referred to used these words in their report to the Legislature of 1886: —

Let these guardians of inland waters be charged to acquaint themselves with the actual condition of all waters within the state as respects their pollution or purity, and to inform themselves particularly as to the relation which that condition bears to the health and well-being of any part of the people of the Commonwealth. Let them do away, as far as possible, with all remediable pollution, and use every means in their power to prevent further vitiation. They shall put themselves at the disposal of manufacturers and others using rivers, streams or ponds, or in any way misusing them, to suggest the best means of minimizing the amount of dirt in their effluent, and to experiment upon methods of reducing or avoiding pollution. They shall warn the persistent violator of all reasonable regulation in the management of water of the consequences of his acts. In a word, it shall be their especial function to guard the public interest and the public health in its relation with water, whether pure or defiled, with the ultimate hope, which must never be abandoned, that sooner or later ways may be found to redeem and preserve all the waters of the state.

The suggestions contained in these sentences have governed the action of this Board during the ten years which have passed since the State Board of Health was made the official guardian of the inland waters of the Commonwealth. It is our opinion that all reasonable efforts have been exhausted in the attempt to do away with the remediable pollution of these waters, and that the time has come when the state must take more effective measures for the prevention of the pollution of the streams not now used as sources of domestic water supply, but still capable of injurious effect upon the public health.

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H. F. MILLS,
F. W. DRAPER,
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J. W. HULL,
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J. A. MEAD.

XXVIII

A MASSACHUSETTS LIFE TABLE FOR THE FIVE YEARS 1893–97

By Dr. Samuel W. Abbott

[Dr. Samuel W. Abbott was not only an efficient secretary, but a very able statistician. At this time when renewed interest is being taken in the subject of vital statistics, Dr. Abbott's study of life tables with special reference to Massachusetts is worth reviewing. *Thirtieth Annual Report*, 1898, p. 810. — G. C. W.]

The usefulness of life tables is not confined to the work of life insurance. A life table also serves as an index of the sanitary condition of the community out of whose data it is constructed.

Life tables differ for the same group of population from year to year, and they also differ when calculated from the statistics of different portions of a group of inhabitants, as, for example, the city of Boston, compared with any of the outlying districts beyond its borders.

The work of constructing a life table for any American state or city is necessarily less satisfactory in its results than the work of making a similar table for any of the civilized nations or communities of Europe, since most foreign populations are much more stationary than our own.

The English life tables, compiled by Dr. Farr, which have proved universally useful as standards of good work in this direction, were usually calculated from the living population at two successive census enumerations and from the deaths occurring in the intervening period. The factor of migration, however, in an American state affects the accuracy of such a calculation; hence a somewhat different method has been employed in constructing the following table, and a shorter period of five years has been selected. Massachusetts has an advantage not enjoyed by many communities in having an intervening state census five years after the national census, and this advantage is especially useful in any state whose population is far from stationary.

The materials selected as the basis of the table below are the census of 1895, and the deaths, numbering 240,215, which were registered in the state in the five years 1893, 1894, 1895, 1896, and 1907. The mid-year of this period (1895) was the census year, and the census was taken very near the middle of that year (in

TABLE 50

POPULATION OF MASSACHUSETTS, 1895, AND DEATHS, 1893–97

Age Periods	Population, 1895			Deaths, 1893–97		
	Total	Males	Females	Total	Males	Females
0–5	235,647[1]	118,453[1]	117,194[1]	78,779	42,710	36,069
5–10	224,119	112,296	111,823	6,730	3,345	3,385
10–15	202,900	101,574	101,326	3,460	1,655	1,805
15–20	225,881	110,565	115,316	6,305	2,899	3,406
20–25	265,983	123,692	142,291	9,982	4,899	5,083
25–35	465,943	227,630	238,313	20,148	10,103	10,045
35–45	341,535	168,997	172,538	18,832	9,619	9,222
45–55	245,586	118,417	127,169	19,377	9,895	9,482
55–65	157,651	72,766	84,885	22,334	11,278	11,056
65–75	90,088	41,040	49,048	25,561	12,694	12,867
75–85	35,405	15,460	19,945	20,547	9,675	10,872
85–95	6,123	2,180	3,943	7,105	2,713	4,392
Over 95	308	77	231	559	152	407
Age unknown	3,014	1,554	1,460	496	378	118
Total	2,500,183	1,214,701	1,285,482	240,215	122,006	118,209

[1] The population figures in this line (0–5) were not used in the construction of the life table, but the figures employed were estimated from the registered births and the deaths under 5 years of age.

the months of May and June). The mean annual number of deaths at each age is compared with the population maintained at such age.

The limitations which affect the accuracy of a life table for Massachusetts are the following: —

1. *The Effect of Migration.* The natural increase of the population, or that which results from the excess of births over deaths, has for many years constituted only a portion of the total increase from year to year. The census enumerations of 1890 and 1895 showed an increase of 261,240, of which number the excess of births formed only 36 per cent, the balance, 64 per cent, being the

difference between the numbers of immigrants and emigrants; or, in other words, the effect of migration exceeded that of natural increase in the ratio of nearly 2 to 1.

Moreover, the increment by means of immigration is not uniform at the different age periods, fully one-half of the immigrants being between fifteen and thirty years of age, while the numbers at the extremes of life are comparatively small.

Table 50 presents the classified material out of which the life table is constructed.

2. *Defects of the Census.* Mr. Henry Gannett, in a paper contributed to the " Publications of the American Statistical Association " (Vol. IV, p. 99), estimates a " shortage in the census of 1890 of negro children of about a quarter of a million," and of the native white children " about the same." If this be correct, the entire shortage or deficiency in the total population, including that among foreign whites, must leave at least a million unaccounted for in the United States.

A careful examination of the last two census enumerations of Massachusetts (those of 1890 and 1895) shows that Mr. Gannett's estimate is probably none too large.[1]

It is possible to supply the actual deficiency for the first four or five years of life, with some degree of accuracy, from the registered births; but beyond this period of life it is hardly practicable to make estimates which are of greater value than mere conjectures.

3. *The Practice of incorrectly reporting the Ages of the Living and the Dead.* This error is of two kinds: (*a*) It invariably happens that greater numbers of persons are reported at the even ages, 20, 30, 40, etc. (both of the living and the dead), than at 19, 21, 29, 31, etc., in consequence of the common habit of using round numbers instead of giving the more accurate ages. This is in a measure eliminated by employing the periods used in England, 25–35, 35–45, etc., instead of 20–30, 30–40. (*b*) The habit, especially noted among unmarried females, of understating the ages of the living. This appears to a greater or less degree to be a

[1] Mr. E. B. Elliott also assumes an approximate shortage for the first five years of life alone of 100,000 in the United States census of 1870. Volume on "Vital Statistics," p. 522.

common practice in all countries where census enumerations are made.

4. *Defects in Birth and Death Registration.* These defects, so far as Massachusetts is concerned, are probably insignificant, and in this respect the material collected by the registration officers of cities and towns compares favorably in its accuracy with that of foreign nations and communities having established systems of registration. Great pains are taken in most of the municipalities to obtain accurate and full returns, since a pro rata fee is allowed to the local officers for them; moreover, the certifiers of births and deaths (physicians, midwives, and undertakers) are compelled, under penalty, to comply with the statutes requiring such returns.

There is also a comparatively small number of persons included in the census whose sex and ages are unknown, and the same may be said of the registered deaths, the latter being probably mostly deaths of prematurely born infants, and a small number of bodies of unknown persons found dead.

Certain comments and explanatory statements are necessary in relation to the construction of the tables which follow.

The figures for the first five years of life have been compiled from the births, and from the deaths which occurred among children under five years of age. The census figures for these five years were disregarded, for the reasons already stated in former reports, and in accordance with the common usage in other countries.[1]

Dr. Farr says, in regard to this subject: "We can scarcely feel surprised to find, in the various censuses of Europe, errors in the statements of age, traceable to ambiguities of language. In the early years of life these mistakes demand attention, otherwise they may lead us into such grave mistakes as we have to notice." These well-known defects may be corrected without serious difficulty for the first years of life.

An exact and accurate life table of any population or community can be made only by taking a definite number of persons,

[1] Twenty-sixth Annual Report Massachusetts Board of Health, p. liv; also Dr. Farr's "Vital Statistics," Memorial volume, p. 207.

say 100,000 or 1,000,000 at birth, and following their life history, noting the age of each person at death, until the entire number has ceased to live. Such a process is impossible, especially in an American community, subject, as it is, to the variable effect of migration.

In view of this manifest impossibility, it is therefore necessary to construct an approximate table from such data as are accessible, bearing in mind the limitations, to which reference has been made, and making such corrections of errors as are customary in the construction of similar life tables for other communities. Starting with a hypothetical 1,000,000 or 100,000 births, this generation of persons of both sexes may be followed, with a reasonable degree of accuracy, to the extinction of the last survivor, at the age of one hundred or more, by the application of the rules which it is customary to employ. In the case of Massachusetts, we have selected the number 100,000 as the basis of the table, since this is the largest round number near the exact number of annual births in the state. The sexes at the time of birth are unequally distributed, the males being in the ratio of 51.350 and the females 48.650 out of each 100,000 born during the period selected for the construction of the table. These numbers are therefore taken as the numbers at birth of the two sexes, out of the hypothetical 100,000 born.

In order to eliminate the effects of epidemic years or of abnormal conditions existing in the census year 1905, the mean annual deaths of the five years, 1893–97, are employed to obtain the death-rates at each year of life. In the English life tables it has been customary to estimate the population at the middle of a given year for life-table purposes, the census being taken on the first of April. The State census of Massachusetts being taken at a time quite near the middle of the year, no allowance has been made for the few days elapsing between the time of such taking and the mid-year, since such allowance would at most only affect the second place of decimals in a death-rate expressed as a ratio per 1,000 living of a given age. Moreover, the population enumerated in May, near the middle of a five-year period, differs much less from the actual mean than that which is taken near the middle of a ten-year period, as compared with a mean of the two extremes of such period.

Dr. Billings says, in his introductory remarks in the twelfth volume of the tenth census, 1880 (page cxliii): "The preparation for any given locality, race or occupation, in this country, of a life table which shall accurately represent the tendency to death or the probability of survival at each age, is practically impossible, because of the want of accuracy in the necessary data, and because of the irregular migrations of the population. It should be clearly understood that all tables of vital statistics, including data derived from large numbers of people, even when these are obtained by the most accurate census possible, and by the most complete system of registration which can be enforced, give probabilities only, and that scientific accuracy in this field is practically unattainable." The foregoing remarks apply with less force to Massachusetts than to the United States as a whole, since our own state has had a system of registration in existence since 1842, the results of which may now be considered as fairly accurate. Dr. Billings therefore publishes an approximate life table in the volume referred to for Massachusetts and for certain other communities, from such data as were obtainable for the census year 1880.

In the life table pains have been taken to make it as accurate as possible from the data at hand. The compiler is entirely responsible for whatever errors or inaccuracies it may contain.

One hundred thousand infants, followed throughout their first year during the period named, in Massachusetts, yield 90,250 years of life. To obtain this mean of the infants living throughout the first year, the following method was employed: —

All of the deaths of infants under one month old which occurred in the years 1893–97 were tabulated from the mortality returns in the office of the Secretary of State, also those of infants who died in the second and the third month of life separately, then those of infants who died in the three succeeding months of life (3–6) in one group, and then those who died in the succeeding six months in another group. From these data, and from the births registered in the five years ending with June 30, 1897, the figures for the first year of life were calculated after the method shown by Dr. Farr in his life table No. 3, page xxiii.

The foregoing mean, 90,250 (the arithmetical mean of the series $l_0, l_{\frac{1}{12}}, l_{\frac{2}{12}} \ldots l_1$), is used as the first term of column P (see tables 53 and 54). All of the succeeding terms in the column for the years 1, 2, 3, 4, etc., are the means of the terms in the preceding column l_x, using the formula $P_x = \frac{l_x + l_{x+1}}{2}$.

The total number of persons living under five years of age in the state in 1895, as stated by the census, was 235,647; but the number as calculated from the living births in these years was 294,604, or 58,957 more than the figures of the census would indicate. No allowance is made in this estimate for migration, which would slightly increase the difference. The effect of migration at this period of life, however, is much less than at later ages, especially from fifteen to thirty years.

TABLE 51

POPULATION UNDER 5 YEARS

State Census of 1895		Calculated from the Births and Deaths under 5	Difference
Males	118,453	149,582	31,129
Females	117,194	145,022	27,828
	235,647	294,604	58,957

Description of the Tables

In tables 53 and 54, column x, ages, presents the ages for each sex from birth up to 100 years.

Column d_x presents the numbers of those dying in each age of life for each sex.

Column l_x presents the survivors of each sex, out of 100,000 of both sexes, at each age of life, beginning with 51,350 males and 48,650 females at birth.

Column P_x presents the population maintained by the numbers in column l_x.

Column Q_x shows the aggregate number of years which the persons at each age in the table will live, until their extinction by death.

Column $E_x \left(= \frac{Q}{l_x}\right)$ is the mean future life time of the persons living at each age in the table, the expectation of life.

Column m_x (Table 55), the mortality column, presents the mortality per unit of the population at each age of life, the figures being obtained by dividing the deaths in each age by the population at such ages, the proper corrections and interpolations having been applied. From this column (m_x) the probability of living at each year of age (p_x) (Table 55) is obtained by the formula $p_x = \frac{2 - m_x}{2 + m_x}$ applied to each year of the series.

Column l_x is obtained by the formula $l_x \times p_x = l_{x+1}$, and column P_x is obtained by the formula $\frac{l_x + l_{x+1}}{2}$.

What may be learned from these Tables

It appears that, out of 100,000 children born alive in Massachusetts in 1895, 16,000, or nearly one-sixth, die before arriving at the age of one year; 78,963, or nearly four-fifths, attain the age of three years; 77,051 survive the age of five years, or 77 per cent; 50,126, or a little more than one-half, attain the age of fifty-three years; 25,406, or a little more than one-fourth, live to the age of seventy-two years.

These figures present very decided differences as compared with those which were published for 1855 by Mr. E. B. Elliott (*Sixteenth Massachusetts Registration Report*, 1857). In those reports it was shown that the numbers dying before the close of the first year out of 100,000 born were 15,510, or very nearly the same as those for the year 1895 for the same age. At the end of three years the survivors were only 74 per cent, instead of 79 per cent, as in 1895, and that one-half had died before the close of the forty-first year, instead of surviving to the fifty-third, as in 1895.

In consequence of the fact that the numbers of each sex are unequal at birth, the males continue in greater numbers until the fifty-third year, when the greater death-rate of the males has reduced their number below that of the females, and the females continue in excess throughout the remainder of life. Observing the table more closely, it appears that the comparative intensity of the death-rate of the sexes varies at different points in the table. For the first five years the death-rate of males exceeds that of females. From age five to age nineteen inclusive the rate of females exceeds that of males, and from age twenty to the end of life the death-rate of females is less than that of males.

In Table 55 are presented two columns in which are shown the probability of living one year from each age and the mortality per unit of the population at each year. At birth the probability of living a year is for males .82569 and for females .84939, that of boys at birth being about the same as for men of eighty-six, and that of girls about the same as that of women at eighty-six or eighty-seven.

The probability of living a year is at its highest point for boys at age twelve (.99722), and for girls it is about the same for age eleven as at age twelve (.99695 and .99693).

A comparison of the death-rates of Massachusetts at different periods presents certain points worthy of notice.

The death-rate of children under five and especially of those under one year of age has not undergone very marked changes (see table); but that of all ages from five to forty has very perceptibly diminished, while that of ages above forty has increased. This result has been produced by the great reduction in the number of deaths from infectious diseases, including consumption, which occur in the early period of life, from two years up to thirty. By this means a much larger ratio of the population than formerly survives to live throughout the useful and wage-earning period of life. This causes a material increase in the number of years lived at the later ages of life.

These persons being spared from the diseases incident to childhood, the relative mortality from the diseases of adult life of old age is naturally increased.

This decided increase in the number of survivors throughout the useful ages of life has a marked effect upon the vitality of the population. It is undoubtedly due in no small degree to the increased attention which has everywhere been given in the past twenty-five years to public hygiene.

The population of almost any one of the United States differs essentially from the more stationary populations of the old world in the fact that it is constantly being recruited by the addition of considerable numbers of immigrants at the healthy ages of life. These additions constitute a selected class, not only on account of their age distribution (50 per cent are between the ages of fifteen and thirty), but also because many of the weaklings must be left behind, in consequence not only of their inability to become wage-earners but on account of the exclusive action of the immigration laws.[1]

One consequence of this is the comparatively large number of persons at the later ages of life, an effect which has been produced by the long continuance of immigration.

The table and diagram below present the numbers of survivors at each of several age periods in Sweden, England, Spain, and Massachusetts (in the latter for the year 1855 and for the period of 1893–97). Sweden is selected as a country having a very low death-rate, and also because it is occasionally selected as a standard of a healthy population. Spain, on the contrary, has a high death-rate, chiefly due to excessive mortality in the early years of life.

In consequence of the close contiguity of the lines in the first five years of life, the figures for the first five years are given upon a separate diagram, in which the divisions representing the age periods are increased tenfold.

A brief review of the life tables of Massachusetts shows that quite marked changes have taken place from year to year in the life history of the population.

The earliest life table in existence pertaining to the population of Massachusetts is that of Edward Wigglesworth, D.D., of Harvard University, made from records of bills of mortality collected

[1] "If on examination there shall be found among such passengers any convict, lunatic, idiot or any person unable to take care of himself or herself, without becoming a public charge, . . . such person shall not be permitted to land." (Extract from immigration act of August 3, 1882, section 2.)

TABLE 52

DATA FOR CONSTRUCTION OF DIAGRAM OF SURVIVORS

Table showing Survivors at Different Ages of Life out of 10,000 born

	Sweden[1] 1881–90	England and Wales[2] 1881–90	Massachusetts 1893–97	Massachusetts[3] 1855	Spain[4] 1878–82
0	10,000	10,000	10,000	10,000	10,000
1	8,895	8,536	8,400	8,449	8,083
2	8,586	8,067	8,054	7,733	7,060
3	8,399	7,878	7,896	7,424	6,433
4	8,258	7,758	7,786	7,258	6,151
10	7,882	7,495	7,487	6,873	5,747
15	7,713	7,423	7,366	6,726	5,602
20	7,551	7,281	7,167	6,437	5,413
25	7,338	7,090	6,906	6,100	5,164
30	7,109	6,844	6,615	5,748	4,908
35	6,876	6,550	6,308	5,408	4,596
40	6,628	6,216	5,988	5,078	4,378
45	6,349	5,839	5,651	4,748	4,088
50	6,043	5,405	5,275	4,409	3,765
55	5,687	4,891	4,821	4,022	3,381
60	5,239	4,275	4,272	3,597	2,914
65	4,658	3,534	3,622	3,065	2,327
70	3,900	2,684	2,869	2,475	1,666
75	2,948	1,786	2,042	1,833	997
80	1,872	970	1,266	1,059	465
85	894	388	654	437	149
90	275	100	259	118	40
95	....	14	67	20.5	....
100	....	.9	9	2.2	....

[1] For convenience of comparison with Mr. Elliott's table of 1855, the figures of this table are reduced to a scale of 10,000, while the diagram is made upon a scale of 100,000.
[2] Fifty-fifth Report of Registrar General. Supplement, vol. 1, p. xiv. Vol. 10, part 1, p. 75.
[3] Sixteenth Registration Report, Massachusetts, 1857.
[4] Bulletin de l'Institut international de statisque.

NOTE. — In consequence of corrections made after the construction of the diagram, the line for Massachusetts survivors, 1893–97, should be placed one to two millimeters lower, after age 15.

prior to 1789.[1] The total number of deaths employed in the construction of this table was 4,893.

Its defects consisted mainly in the limited numbers used for computation, in the crude method of recording the ages of the

[1] Published in the second volume of the Transactions of the American Academy, 1793.

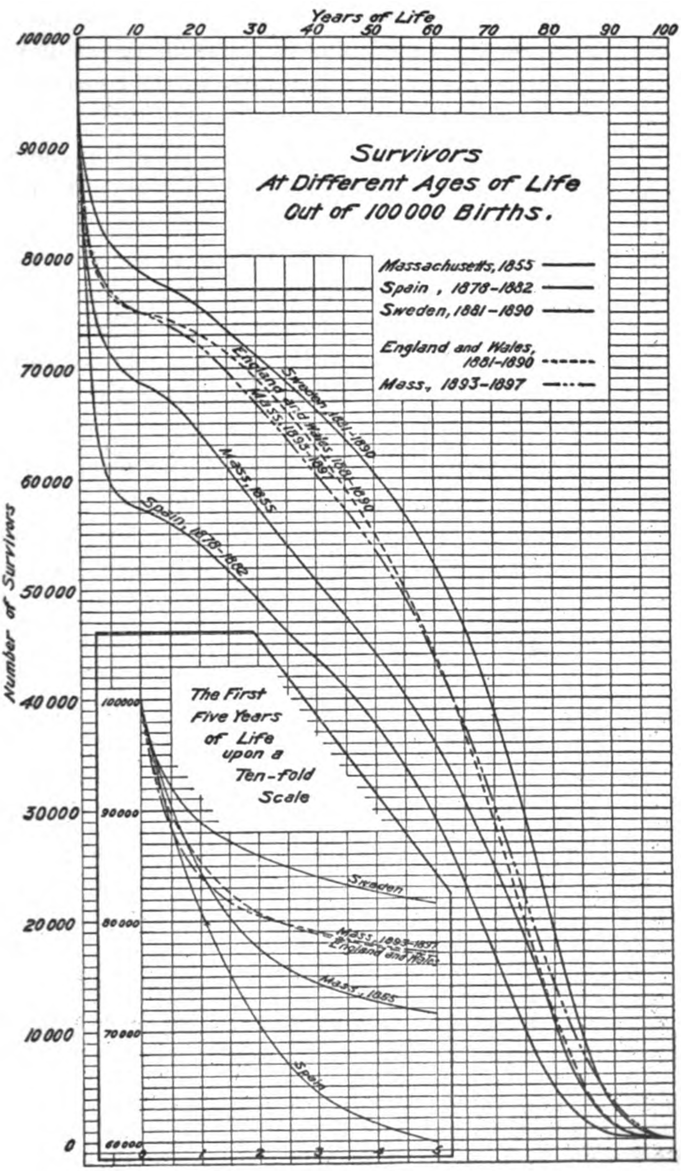
Years of Life
0
10
20
30
40
50
60
70
80
90
100
100000
90000
80000
70000
60000
50000
40 000
30000
20 000
10 000
0
Number of Survivors
Survivors
At Different Ages of Life
Out of 100 000 Births.
Massachusetts, 1855
Spain, 1878-1882
Sweden, 1881-1890
England and Wales, 1881-1890
Mass., 1893-1897
Sweden 1881-1890
England and Wales 1881-1890
Mass. 1893-1897
Mass. 1855
Spain, 1878-1882
The First
Five Years
of Life
upon a
Ten-fold
Scale
100000
90000
80000
70000
60000
Sweden
Mass., 1893-1897
England and Wales
Mass., 1855
Spain
0
1
2
3
4
5

Fig. 17

population by the first census (in five periods only, all under 10, 10–16, 16–26, 26–45, and all over 45), and in the fact that the table was framed on the assumption of a stationary population. This table was for many years an authority in the courts of the Commonwealth.

In 1855 a table for Massachusetts was published in the Sixteenth Registration Report (1857) by the eminent statistician, Mr. E. B. Elliott. This table is calculated from 16,086 deaths, which occurred in 166 towns of Massachusetts in the year 1855.[1]

In the tenth census of the United States, Vol. 12, part 2, pp. 773–791, Dr. Billings publishes approximate life tables for the population of Massachusetts and other states, and for certain cities. Those of Massachusetts are for the white population of the state, and for the census year 1880, comprising 31,341 deaths, and also for the whole population of the state for the five years ended June 30, 1882, and comprising 171,639 deaths.

The statement of Dr. Josiah Curtis in the Sixteenth Registration Report of Massachusetts (1857)[2] as to the value of life tables is worthy of note. He says: "There are weightier reasons for desiring correct information concerning the comparative mortality of our communities. The governing powers and enlightened statesmen are enabled better to discharge their high and responsible duties to the people by a correct knowledge of the physical powers, possessions and resources of the inhabitants.... The Christian philanthropist and sanitarian will be enabled to give some definiteness and efficiency to their labors, by a correct knowledge of where, and to what purpose, the laws which prevail over life and death teach them to direct their laudable efforts. The question here forcibly arises, Have the records of registration in Massachusetts, or in any considerable portion thereof, ever been sufficiently complete to enable any one to determine with reliable accuracy what law or laws do prevail over the mortality

[1] The calculation was limited to the returns of these 166 towns, since the system of registration then in practice in the state was not believed to be "sufficiently complete to furnish data for a life table for the whole state." These 166 towns constituted two-thirds of the population of the state in 1855 (Sixteenth Registration Report, Massachusetts, p. 199).

[2] P. 197.

TABLE 53

MASSACHUSETTS LIFE TABLE. BASED ON THE MORTALITY OF THE FIVE YEARS, 1893–97

Males

Age	Dying in Each Year of Age	Born and Surviving at Each Age	Population or Years of Life lived in Each Year of Age	Years of Life Lived in and above Each Year of Age	Expectation of Life at Each Year of Age	Age	Dying in Each Year of Age	Born and Surviving at Each Age	Population or Years of Life lived in Each Year of Age	Years of Life Lived in and above Each Year of Age	Expectation of Life at Each Year of Age
$x.$	$d_x.$	$l_x.$	$P_x.$	$Q_x.$	$E_x.$	$x.$	$d_x.$	$l_x.$	$P_x.$	$Q_x.$	$E_x.$
0	8,849	51,350	46,343	2,264,048	44.09	50	448	26,459	26,235	543,144	20.53
1	1,794	42,501	41,604	2,217,705	52.18	51	466	26,011	25,778	516,909	19.87
2	818	40,707	40,298	2,176,101	53.46	52	483	25,545	25,303	491,131	19.23
3	559	39,889	39,609	2,135,803	53.54	53	502	25,062	24,811	465,828	18.59
4	424	39,330	39,118	2,096,194	53.30	54	520	24,560	24,300	441,017	17.96
5	316	38,906	38,748	2,057,076	52.88	55	539	24,040	23,770	416,717	17.33
6	252	38,590	38,464	2,018,328	52.30	56	561	23,501	23,220	392,947	16.72
7	205	38,338	38,235	1,979,864	51.64	57	585	22,940	22,647	369,727	16.12
8	170	38,133	38,048	1,941,629	50.92	58	608	22,355	22,051	347,080	15.53
9	146	37,963	37,890	1,903,581	50.14	59	636	21,747	21,429	325,029	14.95
10	123	37,817	37,755	1,865,691	49.33	60	659	21,111	20,781	303,600	14.38
11	110	37,694	37,639	1,827,936	48.49	61	677	20,452	20,113	282,819	13.83
12	104	37,584	37,532	1,790,297	47.63	62	691	19,775	19,429	262,706	13.28
13	111	37,480	37,424	1,752,765	46.76	63	709	19,084	18,729	243,277	12.75
14	135	37,369	37,301	1,715,341	45.90	64	729	18,375	18,010	224,548	12.22
15	159	37,234	37,154	1,678,040	45.07	65	748	17,646	17,272	206,538	11.70
16	181	37,075	36,984	1,640,886	44.26	66	769	16,898	16,513	189,266	11.20
17	195	36,894	36,796	1,603,902	43.47	67	789	16,129	15,734	172,753	10.71
18	211	36,699	36,593	1,567,106	42.70	68	810	15,340	14,935	157,019	10.24
19	226	36,488	36,375	1,530,513	41.94	69	827	14,530	14,116	142,084	9.78
20	241	36,262	36,141	1,494,138	41.20	70	840	13,703	13,283	127,968	9.34
21	255	36,021	35,893	1,457,997	40.48	71	845	12,863	12,440	114,685	8.92
22	268	35,766	35,632	1,422,104	39.76	72	847	12,018	11,594	102,245	8.51
23	280	35,498	35,358	1,386,472	39.06	73	842	11,171	10,750	90,651	8.11
24	289	35,218	35,073	1,351,114	38.36	74	831	10,329	9,913	79,901	7.74
25	296	34,929	34,781	1,316,041	37.68	75	816	9,498	9,090	69,988	7.37
26	301	34,633	34,482	1,281,260	37.00	76	794	8,682	8,285	60,898	7.01
27	305	34,332	34,179	1,246,778	36.32	77	769	7,888	7,503	52,613	6.67
28	309	34,027	33,872	1,212,599	35.64	78	741	7,119	6,748	45,110	6.34
29	313	33,718	33,561	1,178,727	34.96	79	707	6,378	6,024	38,362	6.01
30	316	33,405	33,247	1,145,166	34.28	80	672	5,671	5,335	32,338	5.70
31	318	33,089	32,930	1,111,919	33.60	81	632	4,999	4,683	27,003	5.40
32	319	32,771	32,611	1,078,989	32.93	82	590	4,367	4,072	22,320	5.11
33	319	32,452	32,292	1,046,378	32.24	83	546	3,777	3,504	18,248	4.83
34	320	32,133	31,973	1,014,086	31.56	84	499	3,231	2,981	14,744	4.56
35	322	31,813	31,652	982,113	30.87	85	452	2,732	2,506	11,763	4.31
36	325	31,491	31,328	950,461	30.18	86	402	2,280	2,079	9,257	4.06
37	328	31,166	31,002	919,133	29.49	87	353	1,878	1,701	7,178	3.82
38	331	30,838	30,672	888,131	28.80	88	307	1,525	1,371	5,477	3.59
39	334	30,507	30,340	857,459	28.11	89	263	1,218	1,086	4,106	3.37
40	337	30,173	30,004	827,119	27.41	90	220	955	845	3,020	3.16
41	341	29,836	29,665	797,115	26.72	91	181	735	644	2,175	2.96
42	346	29,495	29,322	767,450	26.02	92	146	554	481	1,531	2.76
43	352	29,149	28,973	738,128	25.32	93	116	408	350	1,050	2.57
44	359	28,797	28,617	709,155	24.63	94	88	292	248	700	2.40
45	368	28,438	28,254	680,538	23.93	95	66	204	171	452	2.22
46	379	28,070	27,880	652,284	23.24	96	48	138	114	281	2.04
47	393	27,691	27,494	624,404	22.55	97	33	90	73	167	1.86
48	410	27,298	27,093	596,910	21.87	98	23	57	45	94	1.65
49	429	26,888	26,673	569,817	21.19	99	15	34	26	49	1.44
						100	9	19	14	23	1.21

TABLE 54

MASSACHUSETTS LIFE TABLE. BASED ON THE MORTALITY OF THE FIVE YEARS, 1893-97

Females

Age	Dying in Each Year of Age	Born and Surviving at Each Age	Population or Years of Life lived in Each Year of Age	Years of Life Lived in and above Each Year of Age	Expectation of Life at Each Year of Age	Age	Dying in Each Year of Age	Born and Surviving at Each Age	Population or Years of Life lived in Each Year of Age	Years of Life Lived in and above Each Year of Age	Expectation of Life at Each Year of Age
x.	d_x.	l_x.	P_x.	Q_x.	E_x.	x.	d_x.	l_x.	P_x.	Q_x.	E_x.
0	7,151	48,650	43,907	2,267,469	46.61	50	395	26,292	26,094	581,072	22.10
1	1,662	41,499	40,668	2,223,562	53.58	51	410	25,897	25,692	554,978	21.43
2	763	39,837	39,455	2,182,894	54.79	52	423	25,487	25,275	529,286	20.77
3	544	39,074	38,802	2,143,430	54.83	53	437	25,064	24,845	504,011	20.11
4	385	38,530	38,337	2,104,637	54.62	54	457	24,627	24,398	479,166	19.46
5	318	38,145	37,986	2,066,300	54.17	55	476	24,170	23,932	454,768	18.81
6	250	37,827	37,702	2,028,314	53.62	56	494	23,694	23,447	430,836	18.18
7	206	37,577	37,474	1,990,612	52.97	57	512	23,200	22,944	407,389	17.56
8	170	37,371	37,286	1,953,138	52.26	58	530	22,688	22,423	384,445	16.95
9	147	37,201	37,127	1,915,852	51.50	59	550	22,158	21,883	362,022	16.34
10	129	37,054	26,990	1,878,725	50.70	60	572	21,608	21,322	340,139	15.74
11	113	36,925	36,868	1,841,735	49.88	61	588	21,036	20,742	318,817	15.16
12	113	36,812	36,755	1,804,867	49.03	62	606	20,448	20,145	298,075	14.58
13	123	36,699	36,637	1,768,112	48.18	63	625	19,842	19,530	277,930	14.01
14	146	36,576	36,503	1,731,475	47.34	64	644	19,217	18,895	258,400	13.45
15	172	36,430	36,344	1,694,972	46.53	65	665	18,573	18,240	239,505	12.90
16	195	36,258	36,160	1,658,628	45.74	66	689	17,908	17,563	221,265	12.36
17	206	36,063	35,960	1,622,468	44.99	67	715	17,219	16,861	203,702	11.83
18	218	35,857	35,748	1,586,508	44.24	68	743	16,504	16,132	186,841	11.32
19	230	35,639	35,524	1,550,760	43.51	69	771	15,761	15,375	170,709	10.83
20	241	35,409	35,288	1,515,236	42.79	70	793	14,990	14,593	155,334	10.36
21	251	35,168	35,042	1,479,948	42.08	71	809	14,197	13,792	140,741	9.91
22	255	34,917	34,790	1,444,906	41.38	72	821	13,388	12,977	126,949	9.48
23	261	34,662	34,531	1,410,116	40.68	73	825	12,567	12,154	113,972	9.07
24	265	34,401	34,268	1,375,585	39.99	74	824	11,742	11,330	101,818	8.67
25	269	34,136	34,001	1,341,317	39.29	75	818	10,918	10,509	90,488	8.29
26	274	33,867	33,730	1,307,316	38.60	76	806	10,100	9,697	79,979	7.92
27	278	33,593	33,454	1,273,586	37.91	77	790	9,294	8,899	70,282	7.56
28	282	33,315	33,174	1,240,132	37.22	78	768	8,504	8,120	61,383	7.22
29	286	33,033	32,890	1,206,958	36.54	79	742	7,736	7,365	53,263	6.89
30	290	32,747	32,602	1,174,068	35.85	80	711	6,994	6,638	45,898	6.56
31	294	32,457	32,310	1,141,466	35.17	81	678	6,283	5,944	39,260	6.25
32	297	32,163	32,014	1,109,156	34.48	82	640	5,605	5,285	33,316	5.94
33	301	31,866	31,715	1,077,142	33.80	83	600	4,965	4,665	28,031	5.65
34	302	31,565	31,414	1,045,427	33.12	84	559	4,365	4,085	23,366	5.35
35	306	31,263	31,110	1,014,013	32.43	85	518	3,806	3,547	19,281	5.07
36	308	30,957	30,803	982,903	31.75	86	476	3,288	3,050	15,734	4.69
37	312	30,649	30,493	952,100	31.06	87	434	2,812	2,595	12,684	4.51
38	315	30,337	30,180	921,607	30.38	88	393	2,378	2,181	10,089	4.33
39	318	30,022	29,863	891,427	29.69	89	351	1,985	1,810	7,908	3.98
40	320	29,704	29,544	861,564	29.00	90	310	1,634	1,479	6,098	3.73
41	324	29,384	29,222	832,020	27.62	91	270	1,324	1,189	4,619	3.49
42	326	29,060	28,897	802,798	27.62	92	232	1,054	938	3,430	3.49
43	329	28,734	28,570	773,901	26.93	93	194	822	725	2,492	3.03
44	332	28,405	28,239	745,331	26.24	94	160	628	548	1,767	2.81
45	335	28,073	27,905	717,092	25.54	95	129	468	403	1,219	2.60
46	346	27,738	27,565	689,187	24.85	96	100	339	289	816	2.41
47	354	27,392	27,215	661,622	24.15	97	77	239	200	527	2.20
48	367	27,038	26,854	634,407	22.78	98	55	162	134	327	2.02
49	379	26,671	26,481	607,553	22.78	99	40	107	87	193	1.80
						100	27	67	53	106	1.58

Table 55

Massachusetts Life Table. Based on the Mortality of the Five Years, 1893–97

Age	m_x. Annual Mortality per unit at Each Year of Age		p_x. Probability of living One Year from Each Age		Age	m_x. Annual Mortality per unit at Each Year of Age		p_x. Probability of living One Year from Each Age	
x.	Males	Females	Males	Females	x.	Males	Females	Males	Females
0	.19095	.16287	.82569	.84939	50	.01708	.01514	.98307	.98498
1	.04313	.04087	.95778	.95995	51	.01808	.01596	.98208	.98417
2	.02030	.01933	.97990	.98085	52	.01909	.01674	.98109	.98340
3	.01411	.01403	.98599	.98607	53	.02023	.01759	.97997	.98256
4	.01084	.01004	.98922	.99001	54	.02140	.01873	.97888	.98144
5	.00815	.00835	.99188	.99168	55	.02268	.01989	.97758	.98031
6	.00655	.00663	.99347	.99339	56	.02416	.02107	.97613	.97915
7	.00536	.00550	.99464	.99452	57	.02583	.02231	.97450	.97793
8	.00447	.00456	.99556	.99546	58	.02757	.02364	.97280	.97664
9	.00386	.00396	.99616	.99606	59	.02968	.02513	.97075	.97518
10	.00326	.00349	.99675	.99652	60	.03171	.02683	.96878	.97353
11	.00292	.00306	.99709	.99695	61	.03366	.02835	.96689	.97205
12	.00277	.00307	.99722	.99693	62	.03557	.03008	.96505	.97037
13	.00297	.00336	.99703	.99665	63	.03786	.03200	.96285	.96850
14	.00362	.00400	.99640	.99601	64	.04048	.03408	.96032	.96648
15	.00428	.00473	.99573	.99528	65	.04331	.03646	.95761	.96419
16	.00489	.00539	.99511	.99464	66	.04657	.03923	.95449	.96152
17	.00530	.00573	.99471	.99429	67	.05015	.04241	.95107	.95848
18	.00577	.00610	.99425	.99392	68	.05424	.04606	.94719	.95498
19	.00621	.00647	.99381	.99356	69	.05859	.05015	.94307	.95108
20	.00667	.00683	.99335	.99320	70	.06324	.05434	.93869	.94710
21	.00710	.00716	.99292	.99286	71	.06793	.05866	.93430	.94301
22	.00752	.00733	.99251	.99268	72	.07306	.06327	.92951	.93867
23	.00792	.00756	.99212	.99249	73	.07833	.06788	.92462	.93435
24	.00824	.00773	.99179	.99230	74	.08383	.07273	.91954	.92983
25	.00851	.00791	.99153	.99212	75	.08977	.07784	.91409	.92508
26	.00873	.00812	.99131	.99192	76	.09584	.08312	.90854	.92020
27	.00892	.00831	.99112	.99170	77	.10249	.08877	.90251	.91500
28	.00912	.00850	.99092	.99154	78	.10981	.09458	.89591	.90969
29	.00933	.00870	.99072	.99134	79	.11736	.10075	.88915	.90408
30	.00950	.00890	.99054	.99114	80	.12596	.10711	.88150	.89834
31	.00966	.00910	.99039	.99094	81	.13496	.11406	.87357	.89209
32	.00978	.00928	.99026	.99077	82	.14489	.12110	.86490	.88581
33	.00988	.00949	.99017	.99055	83	.15582	.12862	.85544	.87915
34	.01001	.00961	.99004	.99043	84	.16739	.13684	.84554	.87192
35	.01017	.00984	.98988	.99021	85	.18037	.14604	.83455	.86390
36	.01037	.01000	.98968	.99005	86	.19336	.15607	.82369	.85523
37	.01058	.01023	.98948	.98982	87	.20752	.16724	.81199	.84567
38	.01069	.01044	.98927	.98962	88	.22392	.18019	.79863	.83470
39	.01101	.01063	.98905	.98942	89	.24217	.19392	.78399	.82322
40	.01123	.01083	.98881	.98923	90	.26036	.20960	.76963	.81028
41	.01150	.01109	.98857	.98897	91	.28106	.22708	.75357	.79607
42	.01180	.01128	.98827	.98878	92	.30353	.24733	.73647	.77989
43	.01215	.01152	.98792	.98855	93	.33143	.26759	.71569	.76399
44	.01255	.01176	.98753	.98831	94	.35484	.29197	.69863	.74522
45	.01302	.01200	.98706	.98802	95	.38596	.32010	.67647	.72406
46	.01359	.01255	.98650	.98753	96	.42105	.34602	.65218	.70502
47	.01430	.01301	.98581	.98708	97	.45206	.38500	.63128	.67715
48	.01513	.01367	.98498	.98643	98	.51111	.41045	.59292	.65944
49	.01608	.01431	.98404	.98579	99	.57692	.45977	.55224	.62617
					100	.64286	.50943	.51351	.59399

of the inhabitants of the state, or such portions of it? We consider this question, and its answer, taken in their broader sense and application, as the most important practical consideration connected with our system of registration, and it affords extreme gratification to be able to give an affirmative answer to the question. Aside from its intrinsic value, it is creditable to the state of Massachusetts, because it is the first instance where such data have been thus furnished and thus used in any considerable community on this continent. The great practical results in the variety of their applications of such laborious deductions will furnish, not only immediately, but for years to come, the government and intelligent statesmen, as well as others, with the means of determining many social and political questions of high practical value hitherto undeterminable."

The following table presents the mean annual death-rates at each of thirteen periods or groups of years, beginning with birth, for the five years (1893–97). To these are added as a matter of convenience the death-rates at certain other groups (1–4, 0–9, etc.).

TABLE 56

MEAN ANNUAL DEATH-RATES AT CERTAIN PERIODS OF LIFE

Age Periods	Persons: Death-rate at Each Period	Males: Death-rate at Each Period	Females: Death-rate at Each Period	Age Periods	Persons: Death-rate at Each Period	Males: Death-rate at Each Period	Females: Death-rate at Each Period
0–4	56.23	60.12	52.22	45–54	15.78	16.67	14.88
5–9	5.75	5.69	5.82	55–64	28.18	30.42	26.00
10–14	3.25	3.11	3.40	65–74	55.34	59.67	51.37
15–19	5.48	5.29	5.68	75–84	107.22	116.20	99.88
20–24	7.40	7.48	7.32	85–94	199.71	223.50	184.81
25–34	9.06	9.33	8.78	95 +	384.43	429.20	367.07
35–44	10.97	11.19	10.74				

ADDITIONAL GROUPS OR PERIODS

1–4	21.86	22.38	21.33	1–19	8.61	8.62	8.60
0–9	31.93	33.97	29.83	20–59	12.24	12.73	11.74
1–9	13.10	13.31	12.89	60 and over	66.29	69.50	63.42
0–14	22.73	24.09	21.35				

XXIX

REPORT OF THE STATE BOARD OF HEALTH UPON THE GENERAL SUBJECT OF THE DISCHARGE OF SEWAGE INTO BOSTON HARBOR

[This report relates to the establishment of the South Metropolitan Sewage System. *Special Report*, 1900, p. 5. — G. C. W.]

By chapter 65 of the Resolves of the General Court of Massachusetts of 1899, the State Board of Health is directed to consider the general subject of the discharge of sewage into Boston harbor and the disposal of sewage for the Metropolitan districts of the Commonwealth, and to report a plan for an outlet for a high-level, gravity or other sewer for the relief of the Charles and Neponset River valleys.

Sewage is now discharged into Boston harbor at two points, one being at the northern limit of the outlet of the harbor near Deer Island Beacon and the other in a more central position nearer the main land on the north side of Moon Island.

At the outlet near Deer Island Beacon, which is four and two-thirds miles from Long Wharf in Boston, and in the northerly edge of the main ship channel, sewage from the North Metropolitan district is allowed to discharge as it comes at all stages of the tide. The quantity of sewage discharged in twenty-four hours now reaches about 50,000,000 gallons; and this quantity, while distinctly visible along the northerly edge of the channel for a half mile toward the city on the incoming tide and toward the sea on the outgoing tide, gradually becomes less distinct at greater distances from the outlet, and disappears entirely within a distance of one and a quarter miles.

With the increase of population in the North Metropolitan district the amount of sewage discharged will increase and will spread over a somewhat larger area; but the Board sees no reason to anticipate any trouble from this for many years in the future upon any inhabitable shores, and believes that the only objection that can be raised to the continual discharge of sewage here will be by those sailing through or near to the stream of sewage within a mile of the outlet.

At Moon Island is now discharged sewage from the main drainage works of Boston, including that from the lower valley of Charles River and from a part of Neponset River valley, amounting to a maximum of about 100,000,000 gallons a day.

This outlet is about one and three-quarters miles farther west than the outlet at Deer Island Beacon, and much nearer the main land, and so situated that if sewage were allowed to discharge upon the incoming tide it would be brought to habitable shores and become a nuisance; for this reason the sewage is conveyed to reservoirs on Moon Island during the incoming tide and discharged only during certain hours of outgoing tide, when the currents are most favorable for conveying the sewage-laden water toward the sea through channels which render its passage the least objectionable.

By storing sewage in reservoirs, even for the hours between tides, it becomes more offensive; and the large amount which must be discharged in the short time of favorable outgoing currents renders the locality of the outlet and the surrounding area of a half mile radius much more objectionable than the steady discharge of fresh sewage at Deer Island Beacon. These conditions limit the amount of sewage that may be concentrated at this point without creating a nuisance.

The tunnel connecting Old Harbor Point and Squantum in the line of the Boston main drainage system has a maximum capacity for conveying about 150,000,000 gallons of sewage per day; and this is about the amount of sewage that may be expected forty years hence from the low-level area of Boston for which these works were designed. This amount will be about 50 per cent more than the present maximum discharge, and in the opinion of the Board this should be regarded as about the maximum amount that can be concentrated at Moon Island outlet without giving unreasonable offence.

We think the Metropolitan Sewerage Commissioners have done well in seeking another outlet for the South Metropolitan system, with the view of ultimately removing from the Moon Island outlet all of the areas now drained which were not contemplated in the original design for the low-lying area of Boston. With the limitation above indicated, we regard the outlet at Moon Island a suitable point of discharge for the sewage of the low-lying portion of Boston.

From a careful study of the channels and currents of the harbor and of the whole area which may in future be included in the South Metropolitan system, we conclude that the Metropolitan Sewerage Commissioners, in their report upon a high-level gravity sewer of February 11, 1899, have designated the channel in the harbor best suited to receive the sewage of the South Metropolitan system, viz., the channel along the northwesterly side of Peddock's Island; but after an extended study of the locality we would advise moving the outlets they propose about 2,000 feet further north, so that both will be one mile from Nut Island, one directly north from the middle thereof and the other 1,500 feet more easterly, as indicated upon the plan. Here the sewage will be discharged about 30 feet below the surface at low tide into a strong and deep current, by which it will be kept well away from inhabited shores until it disappears by commingling with enormous quantities of ever-changing salt water.

The paths that will be taken by the sewage discharged at these points with their limitations upon varying conditions of wind and tide are shown upon the maps of the report of the chief engineer of the Board; and, from a study of the actual conditions existing at the present outlets, we conclude that the sewage of the South Metropolitan system can be discharged at these points continuously without offence except to those who are sailing in the stream of mingled sewage and water, or near its leeward side within a mile of the outlets, and that they are the most suitable points for the discharge of the sewage of the South Metropolitan system.

The plan of outlet designated on pages 77 and 78 of the report of the Metropolitan Sewerage Commissioners of February 11, 1899, to the General Court, with the change of position herein presented, is recommended for adoption by this Board.

In considering the general subject of the disposal of sewage for the Metropolitan districts of the Commonwealth, as required by the resolve, question has arisen as to what areas were intended to be included in this study.

There are areas north and northeast from the North Metropolitan sewerage system which are nearer to Boston than some of the areas which have been considered; but, as the question of discharge of sewage into Boston harbor from these territories is not likely to arise, except for some small areas which may become adjuncts to the North Metropolitan system, for which provision is made under existing laws, no consideration is given to these areas in this report; but examination has been made of all territory in regard to which may arise question as to whether its sewage had better be discharged into Boston harbor.

After a very complete study of all of the towns of the upper Charles and Neponset River valleys, a brief statement of which is given in the report of the chief engineer of the Board, it was found that, with few exceptions, to be mentioned, it will be more economical to dispose of the sewage of these towns (which are not designated by law as belonging to one of the Metropolitan districts) by filtration upon land in each town, or by a combination of two or more towns, than by conveying it to Boston harbor.

The exceptions are areas of small extent in the towns of Wellesley, Needham and Weston, lying near to Charles River, the sewage from which can be conveyed across the river and into the Newton main sewer and thence to the Charles River valley sewer of the Metropolitan system.

These are the only additions that it may be well to make in this direction to the South Metropolitan system.

South from Quincy and east from Canton are the towns of Randolph, Holbrook, Braintree, Weymouth and Hingham, whose natural drainage is into Boston harbor. Randolph and Holbrook, when they need to dispose of sewage, can do so economically upon land within their respective territories; but Braintree, Weymouth and Hingham can best discharge their sewage into the sea through the outlets of the high-level sewer. Plans by which this may be accomplished are presented in the report of the chief engineer of the Board.

The change of the outlet herein recommended does not require the presentation of a bill for action by the General Court, because chapter 424 of the Acts of 1899, section one, provides that no part of said proposed outlet shall be constructed until plans of said outlet shall be further considered by the Metropolitan Sewerage Commissioners and adopted and approved by the State Board of Health.

It is further provided, by section two of the same act, after describing the limits of the South Metropolitan system, that "nothing herein shall be construed to vest any rights which cannot be extended to cities and towns or parts thereof other than those herein named, upon such terms and conditions as may hereafter be imposed by legislative enactment," and, as the sections of the towns of Wellesley, Needham and Weston and the towns of Braintree, Weymouth and Hingham which are not now included in the South Metropolitan system can under this section be admitted into the system when they may in the future need to dispose of their sewage, and they can then be allowed to enter without modification of the works already planned, it does not appear necessary or expedient to prepare a bill at this time under which they may then enter.

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XXX

EXAMINATION OF SEWER OUTLETS IN BOSTON HARBOR AND OF TIDAL WATERS AND FLATS FROM WHICH SHELLFISH ARE TAKEN FOR FOOD

By X. H. Goodnough

[*Thirty-seventh Annual Report*, 1905, p. 411. — G. C. W.]

The work done upon the examination of sewer outlets and the investigation of the condition of shellfish in the flats and waters of the Commonwealth during the year 1905 has been confined to Boston harbor. The effect of the discharge of sewage from each of the principal sewer outlets into the harbor has been examined and numerous chemical and bacterial analyses have been made of water both from the neighborhood of the sewer outlets and from other parts of the harbor. The shores of the harbor and of the island therein and the flats exposed at low water have also been carefully inspected, and numerous samples of shellfish (clams) have been collected and analyzed. The results of the investigation are presented in the following report.

The examinations of the sewer outlets and the general condition of the harbor have been made with the assistance of Mr. Laurence Bradford, who has had many years' experience in this work. The samples of shellfish and of the harbor waters generally were collected by Mr. Henry E. Mead.

The principal sewer outlet in Boston harbor is at Moon Island, where the sewage of the Boston main drainage works has been discharged since 1884. At the present time about 100,000,000 gallons of sewage are ordinarily discharged daily at this outlet. The sewage is discharged only during the second and third hours of the outgoing tide, and reservoirs have been provided on Moon Island to store the flow of sewage at other times. At the present time, consequently, about 50,000,000 gallons of sewage are discharged into the harbor at Moon Island on each tide, the discharge lasting about two hours, so that the rate of discharge is approximately 25,000,000 gallons per hour.

The sewage from the city sewers on its way to Moon Island passes first through large deposit sewers or tanks for the removal of heavier matters, then through a tunnel about a mile and a quarter in length under Dorchester bay, and is subsequently stored in the reservoirs for a period of several hours, and in consequence the sewage is much decomposed when it reaches the outlet.

Observations of the area covered by the discharge of sewage from Moon Island show that the sewage passes out of the harbor chiefly around the southerly end of Long Island, between Long and Rainsford Islands; but a portion passes north of Long Island, at least at times, and a portion also south of Rainsford Island. The outlines of the area affected by sewage are quite well defined on calm days by the greasy film or sleek upon the surface of the water.

The next main sewer outlet of importance is that at Deer Island, where the sewage of the North Metropolitan Sewerage District has been discharged continuously into the harbor at all stages of the tide since 1895. There are no reservoirs or deposit sewers along the line of the main sewer leading to this outlet, and the sewage is considerably fresher than that discharged at Moon Island. The quantity of sewage discharged at Deer Island at the present time amounts to about half that discharged at Moon Island, or about 50,000,000 gallons per day; and, as the discharge is continuous, the rate of discharge is consequently approximately 2,000,000 gallons per hour, or a little less than one-twelfth the rate of discharge at Moon Island when the reservoirs are emptied there. The outlet is located at the end of a long sand bar exposed only at low water. On the outgoing tide the sewage at Deer Island flows rapidly to sea in a narrow field, and is rarely traceable at any considerable distance from the outlet except in calm weather, when it can be noted in the water for perhaps a mile under favorable conditions. As the tide turns, the flow of sewage turns southerly and then westerly, and after the water has risen over the bar the flow is established generally in a narrow field in the direction of Apple Island; and toward high water the sleek can be noticed for a mile from the outlet on calm days, lying between the main ship channel and Deer Island. On the turn of the tide the sewage quickly passes to sea, and evidences of it disappear from this area.

A third main sewer outlet, known as the Peddock's Island outlet, was completed last year, and is the place of disposal of the sewage of the South Metropolitan District. At this outlet the sewage is at present discharged alternately at two points, one located about 1 mile due north of Nut Island, and the other 1,500 feet farther east, both outlets being a short distance northwest of the southerly end of Peddock's Island. At Peddock's Island, as at Deer Island, the sewage is discharged continuously without storage at any point; and during the past year about 20,000,000 gallons of sewage per day have been discharged at all stages of the tide, the rate of flow here being a little over 800,000 gallons per hour, or about two-fifths the rate at which sewage is discharged at Deer Island. The observations during the past year show that the presence of the sewage in the water can ordinarily be detected only in the immediate neighborhood of the outlet.

In addition to the sewage discharged at these main outlets, a large quantity of sewage overflows at times of rain from the combined sewer systems in Boston, Cambridge, Somerville and Chelsea, and large quantities of sewage are discharged at such times into the Charles and Mystic rivers and into the upper harbor, and a small quantity into the estuary of the Neponset River. In addition to this sewage, a considerable quantity of sewage is discharged directly into the harbor or its tributaries from a few sewers not connected with the metropolitan systems, chiefly in Chelsea. These sewers are described in the annual report of the State Board of Health for the year 1902, pages 294, 295 and 309. A very large proportion of the sewage of the city of Chelsea (population in 1905, 37,289) is discharged into the tidal waters about that city, at the head of Boston harbor, and causes very serious local nuisances, besides polluting the harbor. Connections have already been made by which the sewage from the principal sewers in this district could be discharged into the metropolitan sewerage system; but these connections have been shut off, on account, apparently, of the neglect of the Chelsea authorities to maintain their sewers in proper condition. Besides the sewage from these outlets and from the storm overflows of combined systems, the harbor receives also a considerable quantity of direct pollution by sewage from buildings and wharves along its shores and from vessels, and a small quantity of sewage is also discharged into the harbor from public institutions on the islands. The flats about Spectacle Island, on which a garbage disposal plant and a rendering establishment are located, are very foul.

Visible Effects of the Discharge of Sewage into Boston Harbor

The sewage from the Moon Island outlet greatly discolors the water for a distance of half a mile to a mile from the outlet; but it is very difficult to trace it under favorable conditions for more than two miles, even by careful inspection.

The sewer outlet at Moon Island is located at the northwesterly corner of the island, and the sewage is discharged at the level of the water. A sea wall extends for about 1,500 feet southwest from the outlet, and when the sewage is discharged it eddies against this wall throughout its length, and deposits of organic matter take place in the shallow water here during the summer season. These deposits are usually removed by the heavy easterly storms of the fall and winter, but they reappear again in the summer; and the existence of these deposits, combined with the effect of the eddy, is probably responsible in part for the constant presence of a slight excess of organic matter in the waters in this region above those of other parts of the harbor. On the incoming tide the polluted water in the neighborhood of the wall passes up along the south shore of Moon Island toward Quincy bay. Under some conditions in summer, especially on the incoming tide, a small quantity of sewage is said to work up along the northerly side of the island and deposits form at times near the shore on the northerly side of the outlet. These deposits do not appear to be permanent, and are removed by the waves and currents from time to time. With the exception of the deposits noted in the neighborhood of the wall, no other noticeable deposits appear to take place in the neighborhood of this outlet.

Sewage from the Deer Island outlet discolors the water for a distance of about half a mile from the outlet under favorable conditions, and is traceable for a mile to a mile and a quarter under such conditions; but at these distances the indications of sewage are so slight that they are difficult to trace, and can only be detected in places. The sewage from the Peddock's Island outlet can be traced under the most favorable conditions for less than a mile from the outlet.

The odor from the Moon Island outlet is offensive for a distance of about half a mile from the outlet, and is noticeable at times at greater distances. At Deer Island an odor is rarely noticeable for a distance of more than a quarter of a mile, while at Peddock's Island an odor is observable under present conditions only immediately about the outlet.

Chemical Examination of the Harbor Water about the Moon Island and Deer Island Sewer Outlets

In order to determine more definitely the area in the harbor materially affected by the discharge of sewage at the Moon Island and Deer Island sewer outlets, samples of sea water were collected for chemical analysis at 24 stations in the vicinity of Moon Island and at 14 stations near Deer Island in August and September, and the results are presented in tables and a map appended hereto.[1] All of the samples were collected at the surface of the water, which at times was affected considerably by the wind.

The first series at Moon Island was collected just before the discharge of sewage from the reservoirs, and consequently about ten hours after the previous discharge had ceased. The results show that the free ammonia at the stations, within the area which have usually, by observation, appeared to be affected by the sewage from this outlet, was considerably higher than at the stations outside, although at the times these samples were collected there were no visible evidences of sewage in the water except in the neighborhood of the outlet and along the sea wall.

[1] These are not reproduced here.

It should be stated here that in all cases a persistently high free ammonia was found in a station close to Spectacle Island, the presence of which is apparently due to local pollution from the garbage disposal plant and rendering works on this island.

A second series of samples, collected between four and five hours after high tide, and consequently from one to two hours after the discharge of sewage had ceased, gave results similar to those just described, in that approximately the same area was affected which was found to be affected before the discharge had taken place; but in the latter series of samples both the free and albuminoid ammonia were decidedly higher at practically all of the stations affected than at the previous time.

A third series of samples, collected from one to two hours after low water, and consequently from four to five hours after the last discharge of sewage had ceased, shows a similar result. A slight effect of the sewage can be detected from these analyses on both sides of Moon Island and along both sides of Long Island to the edge of the main ship channel. It is also noticeable in the area around Rainsford, Gallup's and George's Islands. An area having a slightly greater amount of free ammonia is also noticeable about Hangman's Island in Quincy bay. This may be due to the discharge of sewage from Peddock's Island sewer, which may go in this direction for a short time after low water.

A fourth series of samples, collected from three to four hours after low water, or from six to seven hours after the previous discharge of sewage had ceased, showed approximately the same results as were shown by the first series of samples already described.

The results of this examination show that the sea water in the area over which sewage flows twice daily from the outlet at Moon Island contained constantly at this time a slightly greater quantity of organic matter than is found in the adjacent harbor waters not reached by the sewage from this outlet.

In the area toward which sewage flows on the incoming tide from the Deer Island outlet, in the portion of the harbor north of a line drawn from Deer Island Light to Fort Independence, four samples of water were collected at regular intervals at 14 stations, one sample being collected about two hours after low tide, a second about five hours after low tide, a third about two hours after high tide and a fourth about five hours after high tide. The samples collected two hours and five hours, respectively, after low tide, represent the conditions existing when sewage from the Deer Island outlet is flowing toward the section of the harbor examined. The samples collected about two hours and five hours, respectively, after high tide, represent the condition of the water in this area when the sewage from Deer Island is flowing out to sea.

An examination of the results of the analyses shows, in general, that the quantity of free ammonia in the water of this area was greater about two hours after low tide than at any other time, while the least quantity was found in the samples collected five hours after low water. The differences in the quantities of free ammonia present in the water in different parts of the area were not large. The greatest quantities were present in the samples collected two hours after low water along the southerly edge of the area, i. e., along a line drawn from the sewer outlet toward the southerly end of Governor's Island. North of this line the quantities were less, as the following table shows: —

TABLE 57

TABLE SHOWING QUANTITIES OF FREE AND ALBUMINOID AMMONIA IN WATERS OF BOSTON HARBOR NORTH OF THE MAIN SHIP CHANNEL. (1905.)

[Averages of results at stations in lines parallel with the ship channel.]

Stations	Two Hours after Low Water		Five Hours after Low Water		Two Hours after High Water		Five Hours after High Water	
	Free	Albuminoid	Free	Albuminoid	Free	Albuminoid	Free	Albuminoid
4, 5, 14......	.0177	.0118	.0043	.0103	.0095	.0093	.0128	.0107
3, 6, 13......	.0130	.0105	.0072	.0098	.0102	.0100	.0107	.0095
2, 7, 8, 9....	.0136	.0109	.0072	.0102	.0092	.0100	.0115	.0100
Average ..	.0148	.0111	.0062	.0101	.0096	.0098	.0117	.0101

Grouping those stations at approximately equal distances from the outlet, it appears that at two hours after low water the quantity of free ammonia in the water was less at stations 10, 11, and 12, farthest from the outlet, than at the stations nearer the outlet; while at five hours after low water the opposite was true, i.e., the quantity of free ammonia was highest at stations 10, 11, and 12, farthest from the outlet. The quantity of free ammonia present in the water two hours after high tide was also greatest at the stations farthest from the outlet, — a condition which is probably due in part at least to pollution coming down the harbor from points above. The results of these groupings are shown by the following table: —

TABLE 58

TABLE SHOWING QUANTITIES OF FREE AND ALBUMINOID AMMONIA IN WATERS OF BOSTON HARBOR NORTH OF THE MAIN SHIP CHANNEL. (1905.)

[Averages of results at stations at approximately equal distances from the Deer Island sewer outlet.]

Stations	Two Hours after Low Water		Five Hours after Low Water		Two Hours after High Water		Five Hours after High Water	
	Free	Albuminoid	Free	Albuminoid	Free	Albuminoid	Free	Albuminoid
2, 3, 4......	.0140	.0102	.0073	.0107	.0073	.0095	.0080	.0095
5, 6, 7......	.0150	.0120	.0045	.0097	.0102	.0100	.0102	.0098
8, 9, 13, 14. .	.0149	.0110	.0070	.0101	.0109	.0099	.0155	.0106
10, 11, 12....	.0128	.0113	.0122	.0092	.0112	.0097	.0122	.0097
Average...	.0132	.0111	.0077	.0099	.0099	.0098	.0115	.0099

CHEMICAL AND BACTERIAL ANALYSES OF THE WATER IN DIFFERENT PARTS OF BOSTON HARBOR

In the latter part of September an examination was made to learn the general condition of the water in all parts of Boston harbor. For this purpose 60 stations were selected, distributed as evenly as practicable in all parts of the harbor, but including a few stations outside its entrance, and at each of these stations samples of water were collected both on the incoming and outgoing tide for chemical and bacterial analysis. The work covered a period of about five days, between September 14 and 29.

During the period covered by the harbor examinations in September, 1905, there was no considerable rainfall, and the waters of the upper harbor were not being polluted by the overflow of considerable quantities of sewage during this period, as would be the case in wet weather.

The outermost station at which samples of water were collected was at Three and One-half Fathom Ledge, six miles east of Deer Island Light; and the next nearest station was located about half a mile north of Outer Brewster Island, four miles from Deer Island Light. At these two stations samples collected on the outgoing tide showed the presence of 27 and 24 bacteria per cubic centimeter respectively, and no coli. A sample collected on the incoming tide in the main channel a little over a mile east of Deer Island Light showed the presence of 22 bacteria per cubic centimeter, and no coli. A sample collected on the incoming tide in the Black Rock channel showed the presence of a larger number of bacteria than at the other stations just referred to, and a larger number was also found in a sample collected between Boston Light and Point Allerton, but no coli were found in either of these samples. All of these stations are outside the harbor.

The only stations within the harbor from which samples of water free from coli were obtained, either upon the incoming or outgoing tide, were in a small channel between Crow Point and Slate Island, Hingham, where a sample collected on the incoming tide was found to contain 36 bacteria per cubic centimeter, and no coli, and at the bridge at Quincy Point, where a sample collected on the incoming tide was found to contain 65 bacteria, but no coli.

The greatest numbers of bacteria found in any of the samples were present in those collected over the sewer outlet at Deer Island, in the neighborhood of the sewer outlet at Moon Island, in the estuary of the Neponset River, and in the main ship channel between Boston and East Boston. The effect of the sewer outlet near Peddock's Island was also marked by the presence of a much larger number of bacteria at a station near this outlet than was found at the other stations in this neighborhood.

Grouping the results in general accordance with the main divisions of the harbor waters, we find that the smallest average number of bacteria found in samples collected within the harbor — i. e., within a line drawn from Deer Island Light to Point Allerton — was in those collected in Hingham bay. In 15

TABLE 59

CHEMICAL AND BACTERIAL ANALYSES OF WATER FROM DIFFERENT PARTS OF BOSTON HARBOR. (1905.)

Location	Bacteria		B. Coli		Free Ammonia		Albuminoid Ammonia		Numbers of Stations at which Samples were collected[1]
	Incoming Tide	Outgoing Tide	Incoming Tide	Outgoing Tide	Incoming Tide	Outgoing Tide	Incoming Tide	Outgoing Tide	
Inner harbor	1,043[2]	1,098	28	30	.0253	.0340	.0131	.0144	9–15
Middle harbor	526	587	29	12	.0174	.0205	.0132	.0110	4–8
North side of main ship channel	258	197	24	14	.0089	.0126	.0134	.0116	1–3, 18, 19
Dorchester bay	330[3]	251[3]	33	62	.0161	.0195	.0143	.0206	20–30
Quincy bay	327	797	143	117	.0103	.0131	.0115	.0136	32–38, 43, 44
Hingham bay	71	86	4	1	.0076	.0073	.0096	.0108	46–60

[1] Station numbers refer to the map.
[2] Omitting station 11. [3] Omitting stations 29 and 30.

samples collected on the incoming tide in this bay the average number of bacteria was 71, and in 13 samples collected on the outgoing tide the average number found was 86.

Next to Hingham bay, the lowest numbers of bacteria found in the water of any large section of the harbor were found in the region north of the main ship channel between East Boston and Deer Island. The highest numbers were found in the samples collected in the inner harbor and the next highest in those collected in the middle harbor, i. e., in the region around Governor's Island.

The greatest numbers of B. coli were found in the water of Quincy bay, and a larger number was found in Dorchester bay than in any other section of the harbor except Quincy bay. The reason for this is doubtless the fact that some of the stations in Quincy and Dorchester bays were within the area affected by the discharge of sewage at Moon Island. The smallest numbers of coli were found in the waters of Hingham bay.

The results of the chemical analyses correspond very closely to the results of the bacterial analyses. The greatest quantities of free ammonia present in the water of any considerable section of the harbor were found in the waters of the inner harbor and the next highest in the waters of the middle harbor.

The results show that the worst polluted section of Boston harbor at the present time is the portion known as the inner harbor, extending from the neighborhood of Governor's Island and City Point up to the mouths of the Charles and Mystic rivers.

XXXI

INSPECTION OF DAIRIES

By Dr. Charles W. Harrington

[In recent years the milk situation has been vigorously discussed in Massachusetts and, in fact, throughout the country. Dr. Harrington was one of the pioneers in this agitation. This paper is a good summary of prevailing ideas in 1905. *Thirty-seventh Annual Report*, 1905, p. 519. — G. C. W.]

The causal relation of unclean milk to infantile death-rates is one of the established facts of preventive medicine; and experience has shown, both in this country and abroad, that improvement in the sanitary conditions of milk production, handling, storage, transportation and distribution is followed by such marked diminution in the loss of infant life as to make it the imperative duty of public health authorities to give to this much-neglected subject the fullest possible attention. Laws against fraudulent adulteration of milk have been long in existence in most parts of the civilized world, but until very recently the more important question of wholesomeness has been confined within the limits of academic discussion, and only in a small number of cities and towns have regulations been made by local authorities, having no power of supervision beyond the limits of their respective communities. In no state in the Union and in no foreign country has the central authority thus far enacted and enforced the strict legislation necessary for the protection of the public health against the consequences of the use of milk contaminated by the exciting causes of infective diseases, especially of cholera infantum, at the place of production and during storage, transportation and sale. These causes are in part inherent in the cow (garget, tuberculosis of the udder, etc.), but to a far greater extent they gain access to the milk, therein to multiply, through preventable filth and dust. The production of clean, wholesome milk is dependent upon the maintenance of health in the cow; upon cleanliness of the cow, the cow stable, the milkers and the utensils employed; and upon the methods followed in cooling, handling, storage, transportation and distribution. Clean milk cannot be produced from diseased cows nor from cows encrusted with their own excrement, which in the process of milking must, to some extent at least, become dislodged as fine dust or in large particles and fall into the milking pail; and, even though the larger particles and hairs be removed in the process of straining, the harm has been done. It cannot be produced, even from clean cows, if the milking be done by milkers with unclean hands and unclean clothing, from which the infective organisms may be communicated to the contents of the pail. It cannot be produced where the milking pails, cans and other utensils are not kept in a scrupulously clean condition, and protected from bacteria-laden dust particles. Even under the most perfect sanitary conditions complete exclusion of the various fermentative organisms is impossible, but their almost inconceivably rapid multiplication can be prevented by rapid cooling of the milk and maintenance of a low temperature thereafter, since warmth is the one most important favoring condition for growth. Therefore, proper and efficient methods and means of cooling and storage are most essential.

Since milk is very sensitive to odors, which it very readily absorbs to such an extent as to affect its taste, the proximity of pigs, horses, swill, stored manure and other sources of foul odors is inconsistent with prime quality.

The physical condition of the cow having a direct influence upon the quality of her milk, the conditions of the stable as to ventilation, light and other influences affecting health should receive a generous measure of attention.

It will be seen, therefore, that the production of milk fit for human, and especially infant, consumption, requires proper housing of healthy stock, general cleanliness and careful handling.

Recognizing the well-demonstrated importance of an improved milk supply in its relation to the public health, the Board, acting under its general authority, began, on March 1, 1905, a systematic investigation of dairies and the conditions under which milk is produced for public sale. As stated in a previous report, the examination embraces an inquiry into the health and condition of cleanliness of the cows, the sanitary condition of the stables, the water supply, the methods of drawing, cooling, handling and transportation, and other matters germane to the subject.

A separate report is made on each dairy by the inspector to the secretary of the Board, who determines what changes, if any, in conditions or methods are desirable, and communicates his suggestions directly or indirectly to the person responsible in each instance. The investigation demonstrated from the start its necessity, for a condition of affairs was disclosed which is not creditable to the Commonwealth. It is true that in most cases the objectionable conditions reported were susceptible of improvement without the expenditure of money, and without involving anything more than ordinary care in the matter of common cleanliness; but in many instances the conditions which obtained were found to be most revolting in character.

The worst existing conditions were not, as might be supposed, found always in the poorer country districts, but often within the limits of cities. One of the worst places visited was situated within five miles of the State House, and presented the following conditions: In a barn with 9,000 cubic feet of air space, with no cellar, and inadequately lighted, were found 3 horses and 14 filthy cows, the latter being fed on brewers' grains, rotting potatoes and a little grain. The store of potatoes was kept in an adjoining yard, which could not be crossed except by walking through mud and filth nearly 6 inches in depth. In one corner of this yard was an equally filthy pen containing ducks. The liquid manure and other drainage of the barn and yard were conducted in shallow ditches to a small creek, which constituted the sole water supply of the place for watering the stock and washing the milk pails, cans and glass jars used in delivery. The room in which the milk was cooled and handled was thoroughly in keeping with its surroundings, being filthy in all particulars, and exceedingly foul-smelling. The attention of the local boards of health of the cities in which this milk was being sold was called to the impossibility of producing clean and wholesome milk in such surroundings.

Numerous cases, equally bad in some respects, less so in others, and worse in still others, have been reported in various parts of the area covered thus far by the inspector.

Condition of Cows

In cases where it was possible to do so, the cows were examined as to condition of health and as to condition of cleanliness, but during the warmer months, when the cows were out, this part of the inspection necessarily could not be pursued. Of the cows examined indoors, but 46 were found to be tuberculous; 20 were afflicted with garget to such an extent that the milk contained large amounts of pus; and 10 had retained foetal membranes, with consequent purulent discharge which reached the udder. The attention of the Chief of the Cattle Bureau was called in each case to the existence of tuberculosis, and in all of the above cases the owners were warned to withhold the milk of the particular animals from the market, attention being called at the same time to the fact that the sale of milk from a diseased animal is punishable by fine.

The majority of herds observed were found to be kept in a condition far removed from cleanliness. In some cases an entire herd would be found to be encrusted, chiefly on the hinder parts, with wet and dry excrement. In many barns the conditions were found to be such that a cow, however clean she might be on introduction, could not fail to be dirty to an objectionable extent within twenty-four hours. As though the natural opportunities afforded for becoming filthy were not already ample, in no fewer than 182 cases was horse manure employed as a bedding material.

Inquiry developed the fact that on most farms not only are the cows never groomed, but usually not even their udders are wiped off before the process of milking is begun.

Condition of Stables

Light. It is remarkable to what extent the importance of light, both as a purifying agent and as a necessary condition to health and well-being of cows, is neglected. In a large number of the cow stables no provision whatever existed for the admission of light, the open door being its only point of ingress. In some instances what was formerly a glass window had been replaced by a board, or the glass, having been broken, had been replaced with wood or a bundle of straw or other material, to prevent draft. Cases were found where the single window provided had lost its utility through being obstructed by accumulated manure. In many cases an insufficient number of windows, or a sufficiently large number of windows, of inadequate size, were found. The total number of suggestions sent concerning improvement in lighting was 536.

Ventilation. Contrary to expectation, the proportion of ill-ventilated barns was found to be small. In only 79 cases was it found necessary to advise the provision of better facilities for removal of foul air and admission of fresh air, and in only 5 instances were the cattle found to be so crowded as to have a far too small allowance of cubic space per head.

General Cleanliness. In the great majority of stables general uncleanliness was the rule. Obviously, the parts most likely to be unclean were the platforms and the spaces back of the cows. In very many cases, however, the condition of every part of the barn was one of filth.

Of the 1,720 stables which showed defects of one kind or another, no fewer than 1,437 were in need of general cleaning and whitewashing. Other objectionable conditions which were made the subject of correspondence were 106 cases of accumulated manure back of or near the cows; 17 cases of accumulation of liquid manure in depressions in the barn floor; 3 cases of absolute blocking of windows with manure; 132 cases of proximity of open privies to the tie-up; 7 cases of deposits of human excrement over the floors; 3 cases of presence of exceedingly filthy calf pens; 2 cases of use of the tie-up for slaughtering purposes, the blood and refuse being improperly cared for; 39 cases of floors so far out of repair as to preclude all chance of cleanliness; and 14 cases of need of a proper system of drainage.

In not a few instances, while the cow barn and all its appointments may be maintained in a properly clean condition, its cellar appears to be regarded as of little importance; but a dirty cellar, especially in summer, when insect life is active, may be quite as prolific of trouble as a dirty tie-up. In 255 cases the owner was requested to provide some means for the suitable draining of the cellar, and in 284 cases to remove the accumulated manure. In one instance the cellar contained the accumulation of three years, and in another of fifteen months.

In no first-class dairy would the keeping of other animals than those which ordinarily belong there be tolerated; but in many of our cow barns it appears to be regarded as not objectionable to stable horses, to fatten pigs, and to allow sheep, goats and fowls to wander unrestrained. Letters were sent to 272 individuals, requesting the separation of the horses from the cow tie-up by means of suitable partitions; and to 227, requesting the removal of swine and their pens to a proper distance. In 47 cases the cow barn was used for the storage of ordinary city swill, and in one case this material was stored wholesale, the owner being a city scavenger, and dealing in swill, as merchandise, with his neighbors. In all these cases, and in 31 in which fermenting and rotting brewers' grains were stored, 3 in which fertilizers were stored, 16 where rotten fruit and vegetables were scattered about, and 8 in which dead fowl were undergoing decomposition, the removal of all offensive material was directed. Letters were sent to 14 individuals, suggesting that sheep, goats or poultry be confined, and not allowed access to the tie-ups.

Condition of Cow Yards. Partly due to carelessness and partly to natural difficulties in the way of drainage, it happens not infrequently that the cow yard, which should be at least a proper place for outdoor exercise of the stock if desired, is converted into a slough from which the gaseous products of decomposition of liquid and solid manure are given off in such amounts as to be perceptible hundreds of feet distant. In 52 cases the owner was requested to clean his cow yard; and in 149 to drain off the pools of liquid, foul-smelling manure, and to fill in the depressions and make the place less of a public and private nuisance.

Water Supplies. Inasmuch as the water supply of the cow barn is frequently employed for purposes of cleansing the utensils used in the production and sale of milk, it is of extra importance that this should be protected from pollution. Ordinary polluted water may cause no injury whatever in animals that drink it, but it may be productive of disastrous effects in man when used for the cleansing of cans, if the polluting material contain the germs of infectious human diseases; and experience has shown that not a few epidemics of typhoid fever have occurred in this state and elsewhere in consequence of the pollution of the water supply by the excreta of persons sick therewith or convalescent therefrom; and in a number of instances it has been proved that milk responsible for the dissemination of typhoid fever has been produced at farms where persons, either sick or convalescent, were employed about the cows. Letters were sent in reference to water supply as follows: advising the protection of the well from surface drainage, 37; condemning the use of well water on account of obvious contamination, 15; advising the protection of the milk trough in which the milk is cooled, 9; advising a change in the method of disposal of the kitchen drainage, 6; directing the closure of an open cesspool, 2; and directing attention to the fact that pigs were wallowing in the water used not only for the watering of stock but for the cleansing of utensils, 1.

Care of Milking Pails and Other Milk Utensils. It is generally recognized that dirty milking pails and other utensils beget sour milk, with consequent loss to the producer; therefore, in most cases these vessels are looked after with reasonable diligence. But it is not enough that they should be made clean; they should be kept in a suitable place, and under such conditions that they may not become invaded by dust, containing, as is always the case, bacteria of various kinds. The necessity of providing a milk room for the proper handling and storage of milk was brought to the attention of 637 owners. On some of the worst-kept farms the grossest carelessness was observed in the treatment of cans and other vessels. In 24 instances cans were observed scattered over the floor; in 6, scattered about the yard; in 2, lying about in the dirty cellar; in 3, standing in manure. At 11 places cans and other utensils, strainers, etc., were found standing in unwashed condition, in the middle of the day, apparently ready for use again. In one case the milking pail was found doing service in what passed for a laundry.

Other matters called to the attention of producers were as follows: the undesirability of keeping cows in the house cellar, 2; the washing of milk cans and pails in dirty water, 1; the cooling of milk (*a*) in dirty water, 2; (*b*) in a butter tub, 1; (*c*) in a wash tub, 1; (*d*) in a dirty tub, 3; (*e*) in a tub standing in the sun, 5; (*f*) in a manure cellar, 13; (*g*) in a house cellar, 2; (*h*) in a drinking trough, 12; the presence of a decomposing dead horse in the cow yard, 1; the presence of rotting ensilage in the tie-up, 2; the presence of decomposing cow entrails underneath the tie-up, 1; the necessity of raising barn to such a height from the ground that liquid manure would not spurt up between the boards of the floor under the weight of a person crossing the same, 3; the use of cotton waste as bedding, 8.

XXXII

A REVIEW OF TWENTY-ONE YEARS' EXPERIMENTS UPON THE PURIFICATION OF SEWAGE AT THE LAWRENCE EXPERIMENT STATION

By H. W. Clark and Stephen DeM. Gage

[The complete paper, of which this is a part, covers nearly three hundred pages. It gives an account of the principal results obtained at the Station from 1887 to 1908. *Annual Report*, 1908, p. 251. — G. C. W.]

The year 1908 is the twenty-first of the operation of the Lawrence Experiment Station. The act of the Legislature, under which the systematic work of the Massachusetts State Board of Health on the examination of water supplies, the purification of sewage and water, etc., was begun, was passed in 1886. The report of the Board for the year 1887 contained an account of the establishment of the experiment station and of the preliminary work done there. A chemical laboratory was installed in 1888 and a laboratory for bacteriological and microscopical work in 1890. These laboratories have been enlarged and improved from time to time, and in them about 50,000 chemical and 150,000 bacterial analyses have been made during the past twenty years, and new and more accurate chemical, biological and physical methods have been developed for the study of water, sewage, sands, soils, etc. Beginning with studies upon intermittent sand filtration of sewage and water, together with laboratory investigations upon nitrification, the causes of the reduction of bacteria by filtration, etc., the work of the station has grown constantly, and at the present time includes experimental investigations tending toward the development of scientific methods of sewage purification, of the purification of manufacturing wastes of many kinds, and other special investigations in sanitary science which will be referred to later.

It may be said fairly that the investigations at the Lawrence Experiment Station laid the foundations for the scientific treatment of sewage and have given the initiative for similar investigations in this and other countries. The work was planned by Hiram F. Mills, A.M., C.E., a member of the State Board of Health, and has been carried on under his general supervision. A full account of the early equipment of the station and of the work done there during the years 1888, 1889 and 1890 is to be found in a special report of the Board for 1890 prepared by Mr. Mills. This special report has been for many years the most widely known work upon sewage purification. The work of subsequent years has been published in the annual reports, and detailed information should be sought in these documents.[1] It is hoped to give here, however, a clear idea of the main work carried on at the station during the past twenty-one years.

Résumé of Work in Different Years

The report by Hiram F. Mills, A.M., C.E., mentioned above, covers thoroughly the investigations made during 1888, 1889 and 1890 upon the subject of sewage purification. During these three years, sewage had been filtered intermittently through gravel-stones, through filters made of various grades of gravel and through sand, even through a fine sand averaging but 0.004 inch in diameter, — a fine granular dust, — as well as through soils

[1] At the beginning of this work, Dr. Thomas M. Drown of the Massachusetts Institute of Technology was appointed chemist to the Board and given general supervision of the chemical work, both at Lawrence and Boston. When, in 1895, Dr. Drown became president of Lehigh University, he was made consulting chemist to the Board, and served in that capacity until his death in 1904. At the station Mr. Allen Hazen was in charge until March, 1893, when he was succeeded by Mr. George W. Fuller. Since August, 1895, a period of fourteen years, Mr. H. W. Clark, who had been connected with the Lawrence work almost from its start, and who also succeeded Dr. Drown as chemist to the Board, has been in charge at the station, and since 1896 of the Boston laboratories of the department of water supply and sewerage. Mr. Fred B. Forbes and Mr. W. R. Copeland have been prominent among the many assistants at the station during the first twenty-one years, and Mr. Forbes is still in the employ of the Board as chief assistant in the laboratories at the State House. Mr. Stephen DeM. Gage, biologist, and Mr. George O. Adams, chemist, are the chief assistants at the station at the present time, Mr. Gage having been connected with the work since 1896 and Mr. Adams since 1900. For short periods in the beginning, the bacterial work was in the charge of various biologists; but in November, 1888, Dr. William T. Sedgwick was appointed biologist to the Board, and so remained until 1896.

and peats. It was found that, with all the filters, from the coarsest to the finest, purification by nitrification took place best when the sewage applied was adapted to the working ability of the filter, and the surface not allowed to become clogged by organic matter, to the exclusion of air. It was shown, furthermore, that fine soils retained water so long that the quantity of sewage which could be applied was small, although such a filter might give an effluent free from bacteria. With thicker layers of these fine soils, moreover, it was found that nitrification did not take place, and that the organic matter in the effluent was nearly as great as in the sewage, although no bacteria probably passed through the filter. It was found that peat filters, though but one foot in depth, were practically impervious to liquid, and that intermittent filtration with such material was impracticable. Experiments with gravel-stones gave the best illustration of the essential character of intermittent filtration of sewage. Filters were constructed of stones, so large that even the coarser suspended particles of the sewage were not removed; yet " the slow movement of the sewage in thin films over the surface of the stones, with air in contact, caused a removal for some months of 97 per cent of the organic nitrogenous matter as well as 99 per cent of bacteria." These filters were the forerunners of the sprinkling or trickling filters now so well known in sewage purification. It was found also, and stated in the special report for 1890, that " the mechanical separation of any part of a sewage by straining through sand is but an incident which, under some conditions, favorably modifies the results, but the essential conditions are very slow motion of very thin films of liquid over the surface of the particles that have spaces between them sufficient to allow air to be in contact with the films of liquid. . . . With these conditions it is essential that certain bacteria be present to aid in the process of nitrification." It appeared, furthermore, and was so stated in the same report, that the " filters gave an effluent some time before nitrification began which contained from 20 to 40 per cent as much free and albuminoid ammonia as the sewage. During the cold months of the very cold winter in which the first filters were started there was an important step in purification going on. This was the conversion of albuminoid ammonia to free ammonia, or, to state the case more definitely, it was the burning up of a part of the organic matter by the combination of oxygen with some of the carbon, producing carbonic acid, and leaving the nitrogen and hydrogen that were contained with this carbon to form ammonia, thus reducing the amount of combined nitrogen which in our analyses appears as albuminoid ammonia. This is as complete a destruction of organic matter, as far as it goes, as if the free ammonia were again oxidized, forming nitric acid or nitrates, but this process seldom, if ever, carries the destruction of the organic impurities of the sewage to such an extent that the resulting liquid contains as little impurity as when nitrification takes place. We find further that this process of reducing the albuminoid ammonia is not so destructive to bacteria as the more complete process of nitrification. It is, however, a process of purification, and the conditions of intermittent filtration are those most favorable to this step in purification."

This special report for 1890 gave the results observed in all the sewage filters, nineteen in number, that were operated up to the end of 1890. It gave also many data in regard to special investigations concerning the mechanical and physical characteristics of the materials employed in filtration; the storage of nitrogen; time of flow of sewage through filters five feet in depth, this being measured by the change in chlorine contents of the effluent; special studies upon nitrification and nitrifying organisms; articles upon the chemical and biological work at the station, chemical precipitation of sewage, etc.

The report for 1891 took up the subjects of the permanency of filters; the mechanical composition of materials used in filters, together with the conclusions drawn from a study of the materials and the results of filtration, as showing the capacity of each material to purify sewage; the best method of applying sewage to different grades of sand, etc., together with further experiments on the bacterial efficiency of the filters at that time in operation. Early in this year a gravel filter was operated at a rate of 220,000 gallons per acre daily, the sewage being applied in sixty or seventy doses per day. Good nitrification results were obtained without artificial aëration of the filter; in fact, this was a true trickling filter as now known.

In 1892 and 1893 special studies were made of the care of sewage filters; stratification and the effect of horizontal layers; filtration of sewage containing dyestuffs; the rate of filtration through various materials; the causes of clogging of sewage filters, and the removal of this clogging matter from the sand. In these years, also, studies of rapid filtration aided by artificial aëration of the filters were begun. The report for 1892 contained, in addition, a very important article upon the physical properties of sands and gravels with especial reference to their use in filtration.

In 1894 a general review of the work upon sewage purification at the station up to and including that year was given. Special investigations were made at that time upon the composition of sewage and the changes which occurred in sewage as it ages. It was shown, for instance, that storage of fresh Lawrence sewage for twenty-four hours doubled the free ammonia and decreased the organic nitrogen present one-half. Other changes, such as an increase in the number of bacteria present, also took place. This work antedated the operation of septic tanks. At this time a series of sewage samples were collected at different periods of the day from various sewage-disposal areas and institutions in the state, and were examined to show the varying strengths of the sewage at different hours, and the amount of organic matter of different kinds in the sewage per person contributing to the flow.

In 1895 investigations were continued as to the best methods of treating sewage filters to insure permanency; on the best preliminary treatment of sewage to remove sludge before filtration and the different methods of aërating sewage filters. In this year, also, were made the first experiments upon the purification by filtration of industrial sewage as seen in tanneries, paper mills, wool-scouring works, etc. The stable character of the effluents from trickling filters operated at high rates and aërated a portion of the time by means of a current of air was first shown at this period. It was found that " the organic matter in the liquids, after rapid filtration combined with aëration, is of a different character from the organic matter in the sewage resulting from other sludge-removing processes. That is to say, even when the organic matter, as shown by the albuminoid ammonia, is present in quantities as great as in the other partially purified sewages, it has passed through such chemical and biological changes that it develops offensive odors very slowly on standing." These observations were made prior to the English studies upon the stability of the effluents of such filters. In this year, furthermore, certain filters of coarse materials, gravel-stones, pieces of coke, etc., were operated at rates of 1,000,000 gallons per acre daily, and were aërated generally only from one to two and one-half hours daily. The effluents of these filters contained high nitrates, were generally stable, and, in fact, were practically similar to those afterwards obtained from filters of like materials operated at high rates without even the slight aëration given to these filters.

In 1896 and 1897 much time was devoted to the study of the purification of industrial sewage, and practicable methods for the purification of some of these wastes are definitely described in the reports for these years. From the first, studies looking to the removal of the matters in suspension in sewage by sedimentation, chemical precipitation and coke straining were made. In 1897 more elaborate experiments were begun on the purification of sewage by so-called contact filters, although one such filter had been studied at the station in 1894. During this year (1897) a trickling filter of clinker was operated also. To this the sewage was passed by means of overhead pipes and was aërated and distributed by the dash-plate method. This trickling filter, and all others started after this date, received no artificial aëration.

In 1898 studies were continued on the disposal of sewage, both fresh and stale, when treated in septic tanks; on the purification of industrial sewages; on the purification of sewage both by sand and contact filters. Early in 1899 there was put into operation a trickling filter ten and one-half feet in depth, constructed of broken stone and operated at the rate of 2,000,000 gallons per acre daily. In 1899, also, studies of septic tanks and of the purification of septic sewage were continued, and the first tank for the treatment of sludge alone, after preliminary treatment of the sewage in ordinary settling tanks, was put into operation and continued for several years. This variety of septic tank and method of sludge disposal has since become well known. The first hydrolytic tank was started also at the station in 1898, " as it had become evident that the greatest work in septic tanks occurred where the bacteria were most numerous, — as on the sides, bottom and top of the tank, — it was considered that a tank filled with coarse, broken stone would afford a very extensive foothold and breeding place for the classes of bacteria necessary for sludge disposal,"[1] and the tank was so arranged that the sewage passed upward through this stone. As the result of other researches, it was shown that prolongation of anaërobic action might impede subsequent purification by filtration. There were made also this year special studies relating to the purification of the wastes from creameries, and to the action of iron and iron oxides on the purification of sewage by filtration.

In 1900 analyses and measurements of the gas produced by septic tanks were made and investigations concerning the efficiency of septic treatment of different classes of sewage; also experiments upon the sterilization of septic sewage to show whether or not the air that it was necessary to introduce into some classes of septic sewage, before efficient purification by filtration could be assured, was required because of the rapid use of the oxygen by bacteria or because of its absorption by organic matter and gases. Operation of the hydrolytic tank, together with various trickling filters, and the study of purification of manufacturing wastes were continued.

In 1901 a thorough investigation was made of the stability of the effluents and of the organic matter left in the effluents of contact and trickling filters, together with observations on the improvement of such effluents when mixed with river water. The rate and degree of clogging of contact filters and the methods necessary to remove this clogging material were studied also. In this year contact filters of roofing-slate and brick, with regular spaces between each pair of slates or bricks, were first put into operation. Two of these filters are described in the report for

[1] P. 426, report for 1899.

1901, the slate filters being similar to those operated in more recent years in England by Dibdin.

In 1902 studies of contact and trickling filters, especially those of the latter, were continued, together with special investigations concerning nitrification and the removal of organic matter from the upper layers of sand filters.

In 1903 special efforts were made to learn the cause of the poorer winter nitrification in the older intermittent sand filters, in order to improve the work of these filters. Studies of septic tanks and of the operation of contact filters constructed of different materials and depths, with special regard to permanency of operation, were continued, together with allied studies upon the stability of their effluents. Studies were made also of the purification of sewage by trickling filters of different materials and different depths, and investigations in regard to the stability of the effluents of these filters and experiments upon sedimentation, secondary filtration, etc., of these effluents were undertaken. Numerous experiments were made on the purification of dye liquors and the waste from gas works, together with studies on methods of analysis with special regard to the comparative value of albuminoid ammonia and Kjeldahl determinations of nitrogen; of incubation of effluents; and of the nitrification and denitrification caused by sand, effluents and species of bacteria from filters in which either nitrification or reducing actions were occurring.

The year 1904 was devoted largely to the improvement of the sand filters that had been in operation for sixteen years, and to studies of methods for the disposal of nitrogenous and other organic matters by these filters; special studies of nitrification; studies of the respective amounts of nitrogen and carbon oxidized, stored or liberated from experimental and municipal sand filters; studies of the determination of acidity or alkalinity as an index of the degree of purification of filter effluents; studies of the bacteriology and biochemistry of sewage purification. A new method for the determination of turbidity of the effluents of filters and of water was developed and first used during this year. Studies were made also of the time of passage of sewage through trickling filters constructed of different materials and of different depths, and of the rapidity of oxidation and purification of these filters.

In 1905 a continuation was made of the studies of the organic matters, nitrogen, fats, carbon, etc., in sludge and in sewage, and of the same substances stored in filters; studies of the relative amounts of nitrogen, carbon and fatty matters in sewage, sludge and the effluents of trickling and contact filters and appropriate methods for their analysis. Moreover, special studies were taken up again as to the refiltration of trickling filter effluents through sand filters.

In 1906 a complete résumé was given of the comparative value of sand, contact and trickling filters for the disposal of organic matter, and the comparative rates at which such filters can be operated; of the rate of filtration and amount of suspended matter in sewage applied to sand filters as related to volume of sand removed; of the coagulation and mechanical filtration of the effluents of trickling filters, together with more complete studies of methods for the application of sewage to trickling filters; of the comparative rates of filtration maintained by sand filters; of continued studies on the purification of industrial wastes.

In 1907 the most important special work was a continued study of methods for the distribution of sewage upon trickling filters and observations on the refiltration of trickling filter effluents through sand, coagulation and mechanical filters.

The number of filters at the station — sand, contact and trickling filters — has increased steadily until, at the end of 1908, two hundred and fifty filters for the purification of sewage have been in operation. Since 1895, moreover, much attention has been given to the purification of wastes from manufacturing industries, and, as a result, reasonable and efficient methods for the treatment of most of these wastes have been developed and published in the annual reports. Among the wastes studied have been those from tanneries, paper mills, carpet mills, paint mills, woolen mills, wool-scouring works, dye works, shoddy mills, creameries, yeast factories, glue works, gas works, etc.

XXXIII

THE OCCURRENCE OF INFANTILE PARALYSIS IN MASSACHUSETTS, 1907–12[1]

By Dr. Mark W. Richardson

[*Forty-fourth Annual Report*, 1912, p. 555.]

It is not the purpose of this communication to present a detailed discussion of the disease known as anterior poliomyelitis, or infantile paralysis. Its scope will be restricted, rather, to a consideration of those facts and observations which have been noted in the experience in Massachusetts for the years 1907–12, inclusive, and which have seemed rather unusual and therefore possibly worthy of special emphasis.

In the first place, if one looks at the map of Massachusetts and observes the incidence of this disease, he will notice that there seems to be a distinct preference for localities situated along the river beds. In 1907, for instance, the incidence of the disease

[1] Investigation in Massachusetts of the disease known as anterior poliomyelitis, or infantile paralysis, was begun in 1907, at the instigation of Dr. Robert W. Lovett, who had been appointed in that year a member of the State Board of Health. The work has been continued ever since along lines which have constantly broadened, and the Board has called to its service in these investigations the assistance of a considerable number of investigators and advisers. In carrying out details of the work the Board has been fortunate in having the advice of such men as Dr. Henry P. Walcott, chairman of the Board, Dr. Robert W. Lovett, member of the Board, Professor Theobald Smith, Professor Milton J. Rosenau, Professor John L. Morse and Dr. J. Homer Wright. In the field work Dr. Philip A. E. Sheppard has been largely concerned. The State Inspectors of Health in their respective districts have investigated many cases, and special epidemics have been the subject of more detailed investigation by Dr. Herbert C. Emerson of Springfield, Dr. Lyman A. Jones of North Adams and Dr. Thomas P. Hennelly of Pittsfield. Special lines of investigation have been pursued, also, by Professor Theobald Smith, Professor Milton J. Rosenau, Dr. Robert B. Osgood, Dr. William P. Lucas, Dr. Arthur W. May, Dr. Benjamin Wood, Dr. J. W. Hammond, Jr., and Mr. Charles T. Brues, instructor in economic entomology in Harvard University. A paper read at the Fifteenth International Congress on Hygiene and Demography, Washington, D. C., September 26, 1912.

was especially noticeable in the Berkshire district along the banks of the Hoosac and Housatonic rivers. Furthermore, the valley of the Merrimack seemed also to be especially affected. In 1908 the valley of the Deerfield River was the seat of an especially marked epidemic. It may be, of course, that this apparent predilection for river beds is of no special significance, and may mean only that river beds are more likely to be more densely populated and more likely to have ordinary roads, trolley roads and railroads running through them and are therefore associated with greater possibilities of contact for larger bodies of people. In this connection, however, it must be borne in mind that bodies of water may become the breeding places for a great variety of insects, and the incidence of this disease in the neighborhood of bodies of water may be shown by further investigation to be due to a greater prevalence in those districts of such insects.

Another fact brought out by the map of 1907 would seem to be that the distribution of infantile paralysis corresponded in a general way to the density of the population, and in this connection an interesting comparison was made with the incidence of cerebro-spinal meningitis. The two diseases coincided in localization for 1907. In 1908, however, the grouping was largely different, cerebro-spinal meningitis still being more prevalent where the population was dense, whereas infantile paralysis saw its greatest epidemic in a rural community. Furthermore, it was shown that the maximum incidence of infantile paralysis in 1907 took place in September, whereas in cerebro-spinal meningitis the maximum incidence occurred in March. As far as this comparison went, therefore, there seemed to be no parallel between these two diseases as far as epidemiological factors were concerned.

The year 1908 was remarkable for a small but well-marked epidemic in the northwestern part of the state, affecting especially the towns on and adjacent to the Deerfield River. In fact, the history of this epidemic shows that per 1,000 of the population the town of Colrain in this epidemic suffered far and away the most serious damage ever noted in the State of Massachusetts. In 1910 there occurred what seemed at the time to be a very marked epidemic in the city of Springfield, in which epidemic at least 150 cases were reported, that is to say, an incidence of 1.6 per 1,000 of the population; and yet in 1908 the town of Colrain, above mentioned, with a population of 1,800 had 24 cases of infantile paralysis, that is to say, 13 cases per 1,000 of the population. It would seem, in a community so severely attacked as this incidence would indicate, that there would be abundant evidence as to the high degree of its contagiousness; and yet careful inquiry during the investigation of 67 cases, in which there was little or no attempt at isolation, shows that there were 166 children in families affected, only 4 of which later acquired the disease. In addition there were 86 children among the neighbors and friends, making a total of 252 children. Indeed, the total number of children that were more or less intimately exposed to the 66 cases was probably twice or three times the number of known exposures.

Another point of interest in this connection, it seems to me, is the following: The Colrain district in 1908 was situated only thirty or thirty-five miles from the city of Springfield. It was in comparatively intimate relation with said city through the agency of highroads, trolley roads and railroads. There was, therefore, constant interchange of population between these two districts, and yet in 1908 there were in the city of Springfield but two cases of infantile paralysis, and the intervening towns along the Connecticut River showed at most three cases in Holyoke, one in Chicopee and one in Hatfield. In view of this experience it seems to me that whatever one may think of its contagiousness as affecting persons in immediate contact with patients, transfer of the infection by indirect contact through third persons must be very rare, if it ever occurs.

Another interesting point which has been noted by others is that a region once severely infected is not apt to be stricken during the succeeding year, and the Massachusetts maps of 1907 and 1908 show this phenomenon quite plainly. You will see that, for instance, in 1907 the Berkshire district had a considerable number of cases, whereas in 1908 there were very few. Furthermore, you will note that the Colrain district, which was severely affected in 1908, has been practically free from the disease ever since. In 1909 it is apparent that the Berkshire district again became severely affected, and again in 1910 the number of cases dropped off very markedly, even though the valley of the Connecticut River at this time showed a very large number of cases.

The experience in Massachusetts has been that the disease is less readily transmissible than scarlet fever, typhoid fever or diphtheria, but of course in such a comparison the abortive cases of infantile paralysis were not included. Even if such cases were included, however, I have little doubt that infantile paralysis, as compared with the diseases mentioned, is very much less contagious.

Another point which seems to stand out very sharply in the Massachusetts investigations is that the disease is very distinctly one of suburban or rural communities rather than one affecting more especially the cities. This statement rests upon the observations of 2,138 cases which have been analyzed in this regard for the years 1907–10. The average population for the first twenty-five cities and towns most affected proved to be 5,205, whereas the average population of the twenty-five cities and towns least affected was 52,674, that is to say, cities and towns where the disease was relatively least frequent were ten times as large on the average as those where it was most frequent. As a control to this table cases of scarlet fever reported in the state for the year 1910 showed that in the twenty-five cities and towns in which scarlet fever was most prevalent the average population was 6,446, whereas in the twenty-five where it was least prevalent the average population was 7,633. In other words, there would seem to be some conditions radically different in the spread of infantile paralysis as compared with scarlet fever. This fact, taken in connection with the experience detailed above in the relation to cerebro-spinal meningitis, which disease, together with scarlet fever, is well known to be spread by contact with the nasopharyngeal secretions, must be given very weighty consideration when we come to estimate the rôle of these same secretions in the spread of infantile paralysis; for the conditions favoring the transfer of these secretions, that is to say, the density of population, school attendance, overcrowding in winter time and unhygienic surroundings — in other words, conditions found most prominently in city life — are not those which favor, apparently, the spread of infantile paralysis. Infantile paralysis, therefore, being in Massachusetts, at least, a country disease, one would look for some determining cause in country conditions as the reason for this apparent predilection for the rural districts, and as a result of investigation it is found that country children are exposed very much more strongly to any possible influence which animal disease might have upon them than city children. For instance, in the twenty-five cities and towns where the disease was least prevalent, that is to say, in the larger cities and towns, there was one cow to very eighty-four inhabitants and one horse to every thirty-two inhabitants; in the twenty-five cities and towns where the disease was most prevalent there was one cow to eleven inhabitants and one horse to fourteen inhabitants. This table became very much more striking when a comparison was made of the numbers of swine, fowls and dogs. Now it is known that all these animals are subject at times to paralysis of varying types, and in a considerable number of instances paralysis in animals has been associated with paralysis in human beings. A considerable number, however, of paralyzed animals have been examined, and emulsions of their spinal cords have been injected into monkeys by Professor Theobald Smith, but as yet with no positive results. In this connection, furthermore, it is apparent that country children are much more subject to the bites of insects than city children, and the possibility that insects may act as intermediate hosts for the virus of infantile paralysis, and may convey this virus from infected animals or infected human beings to other animals or human beings, must always be strongly borne in mind. In 1911 an investigation along this line of eighty-eight cases in seventeen cities and towns showed that in all instances the ordinary stable fly, *Stomoxys calcitrans*, was present in or about the house of the infected individual. Experiments looking to the possible infection of monkeys through the bites of this fly will be reported upon later by Professor Rosenau.

Meteorological records show that since 1904 Massachusetts has been subject to a constant deficiency in rainfall. Such a deficiency would naturally be associated with a considerable increase in the amount of dust. When it is considered, however, that the disease has affected greatly other portions of the country in which there has been no such deficiency in rainfall the importance of this failure in the rain supply cannot be considered to be great.

An investigation as to the occurrence of this disease in institutions for children showed that such children were much less liable to the disease than those leading an ordinary manner of life. They would seem to enjoy as a result of their somewhat complete isolation a freedom from infection.

Osgood and Lucas found an active virus in the nasopharyngeal membrane of the monkey five and a half months after an acute attack, and in the tonsils of a human being six months after an attack. These observations have naturally a very important bearing upon the question of contagion. In the first place, it suggests very strongly that the disease is transmitted by the secretions of the nasopharyngeal membranes, and, furthermore, that danger of contagion may persist for many months, and possibly longer; this in spite of the fact that Rosenau, Sheppard and Amoss failed to demonstrate the virus in the mouth and nose of eighteen patients in various stages of the disease. It is, of course, well known that positive results have apparently been secured recently by Kling, Wernstedt and Petterson. In other words, we have to do here, as in other infectious diseases, with the question of chronic carriers of disease and their relation to its propagation. Its importance becomes especially marked when we consider the number of cases which have been in contact with chronic cases of infantile paralysis previous to infection.

This persistence of the virus in the body of the infected individual may be important from another point of view, for there are a number of cases on record in the experience in Massachusetts in which the patient has apparently suffered from a second attack of the disease a few weeks, months or even years after the first attack. If such a second infection or reinfection may occur, it must be considered as possible that the patient between attacks may be a chronic carrier of the disease and therefore possibly responsible for secondary cases in others. Certain it is that very closely circumscribed localities may suffer from the disease over a considerable period of years. For instance, in one of the larger cities in Massachusetts, within a very small circumscribed area, two cases occurred in 1903, two cases in 1908, one case in 1909 and one case in 1910. The suggestion that a chronic carrier of infection was responsible for this situation is very strong. As is seen from the map for 1910 the city of Springfield, which up to that time had suffered a considerable and unexplained immunity from this disease, suffered from a quite severe epidemic. Furthermore, investigation as to the mortality from this and other acute diseases in said city showed very interesting results in that the mortality from cholera infantum, whooping cough and scarlet fever was also very much increased during this year. In fact, the mortality rate for cholera infantum, which for 1907, 1908 and 1909 had averaged twenty-seven, in 1910 jumped up to one hundred and six. The suggestion is, of course, that a number of these cases of death reported as cholera infantum may have been and probably were typical cases of infantile paralysis of the gastro-intestinal type.

As far as therapeutics are concerned little new has been learned through the Massachusetts investigations. Osgood and Lucas, to be sure, made some experiments upon monkeys, with a certain number of specific sera and vaccines, to see whether the specific immunity brought about by these sera and vaccines might not give a partial immunity to infantile paralysis. The results, however, were negative. Hexamethylenamin has been recommended to the profession of Massachusetts strongly as a possible prophylactic against the disease, and quite generally employed.

A unique experiment with this drug was carried out at a certain boys' school in our state, an experiment which may be worthy of repetition by others under similar circumstances: At the opening of this school in the fall a boy arrived who had been in Europe and was in intimate contact with at least twenty-five of his fellow pupils for a period extending over ten days or two weeks. He then developed infantile paralysis, much to the discomfort of the school authorities. The boy was isolated immediately, and all the other pupils given hexamethylenamin in their drinking water. Whatever may have been the effect of this medication no other cases developed in this school. On the other hand, we have had one or two other similar experiences where cases in prodromal stages have been in intimate contact with school children and where no secondary cases have occurred, even though hexamethylenamin was not administered, — facts which make us very conservative in estimating the effect of simple contact in the spread of the disease.

As regards prognosis, the experience in Massachusetts has shown this to be much better than was previously supposed. In fact, the following conclusions seem justified: "In anterior poliomyelitis complete recovery or function recovery occurs in over 25 per cent of cases examined at the end of four years. Atrophy may exist without impairment of function. In about one-half of the recovered cases the onset was mild. The distribution of the paralysis in such recovered cases was not essentially different from that in cases which do not recover. Recovery in many instances required months and in several cases from one to three years."

Another interesting possibility is that herpes zoster may be a form of anterior poliomyelitis, due to an unusual localization of the virus. Coincidence of this disease with epidemics of infantile paralysis has been noted, especially in recent years, by English observers. In the experience in Massachusetts certain striking cases have occurred. For instance, in 1912 there has occurred, coincidently, in the same individual, anterior poliomyelitis and herpes zoster. Furthermore, we have a history, also, of anterior poliomyelitis in the child at the same time with herpes zoster in the father. Pathologists maintain that the changes occurring in the posterior ganglia of the spinal cord in herpes zoster resemble almost exactly those found in poliomyelitis in the anterior horns of the cord, and the hypothesis that the two diseases are due to the same virus with different localizations is certainly one worthy of further investigation.

Finally, the experience of Massachusetts has not been such as to support the theory that infantile paralysis is spread from person to person by direct or indirect contact. The rural preponderance of the disease, the comparative immunity of children confined in institutions and hospitals, the summer incidence, the failure of the disease to find its greatest incidence in cities and localities where density of population and overcrowding are most marked, and the irregular distribution have all militated against the acceptance of such a theory. In fact, the feeling among Massachusetts observers has been strong for some time that the epidemiology of this disease was best explained through the intermediate action of some biting insect, and evidence in support of this theory will be presented by Professor Milton J. Rosenau of Harvard University. (See below.)

Some Experimental Observations upon Monkeys Concerning the Transmission of Poliomyelitis through the Agency of Stomoxys Calcitrans [1]

The work we are about to report was done for, and under, the auspices of the State Board of Health of Massachusetts.

We should like to have it distinctly understood, and therefore emphasize the fact right in the beginning, that this announcement is to be considered as a preliminary report, for the work is still in progress. Certain results have been obtained which it seems advisable to announce at this juncture. In taking this action in announcing work before it is completed we have not assumed the sole responsibility, but have taken counsel with older and wiser heads, friends for whose judgment we have the highest regard.

When we first took up the study of this disease — infantile paralysis — with the State Board of Health of Massachusetts, we considered all possible modes of transference of the virus from the sick to the well, but gradually focused our attention upon the

[1] A preliminary note by M. J. Rosenau, Professor Preventive Medicine and Hygiene, Harvard Medical School, Boston, Mass., and Charles T. Brues, Instructor in Economic Entomology, Bussey Institution of Harvard University. Remarks made by Professor Rosenau in the discussion of the previous paper.

fact that the disease seemed to be spread rather directly from person to person. In other words, the disease appeared to us at first blush to be a " contagious " disease, but one in which mild or abortive cases, missed cases, and third persons probably played an important rôle in the transfer of the infection. We were probably prejudiced in favor of this viewpoint on account of the splendid work of Wickman, whose publications we studied with care. We were further influenced to regard poliomyelitis as a " contagious " disease owing to the views of Flexner, who compared it to epidemic cerebro-spinal meningitis, and who regarded that it spread in the light of a contact infection through the secretions from the mouth and nose. The analogy to meningitis was a very close one, and the experimental fact that the virus could be demonstrated in the nasal mucosa of monkeys (Osgood, Lucas and others) seems to corroborate the suspicion that we are in fact dealing with an infection spread very much as cerebro-spinal meningitis is spread.

If these assumptions were correct then the virus should be demonstrable in the secretions from the nose and throat. Rosenau, Sheppard, and Amoss therefore injected eighteen monkeys with the nasal and buccal secretions obtained from eighteen persons who were suffering with the disease at the time, or in the stage of convalescence, or from persons suspected of acting as carriers. These results were negative. At the same time Straus of New York had a series of negative results, and other American workers were also unable to find the virus where we assumed it should be. These negative results seemed to us to have positive significance, and was the first definite indication that we were upon the wrong trail.

That poliomyelitis is not a " contagious " disease was clearly brought out by Dr. Richardson and other observers who have spoken this morning, all of whom have emphasized the point that the disease shows little or no tendency to spread in crowded districts, in schools, in institutions, in asylums, in camps and in other places where one would expect a disease spread by contact through secretions of the mouth and nose to spread more readily. We have in mind the fact that many cases of the disease have been brought into asylums and hospitals throughout the State of Massachusetts, in all stages of the infection; yet secondary cases have not occurred under such circumstances. On the contrary the disease prevailed in Massachusetts more particularly in rural and country districts sparsely settled.

Another reason that led us away from the theory of contacts, and made us believe that we were not dealing with a contagious disease in the ordinary sense of that term, was the close analogy between rabies and poliomyelitis. All investigators in laboratories who have worked with these two viruses have been struck with the similarity between rabies and poliomyelitis. Both viruses are diffused widely throughout the body, both exist in special concentration in the central nervous system, both are filterable, etc. Rabies being a wound infection made us conjecture that poliomyelitis may also be similarly transmitted.

Our experience with yellow fever, perhaps more than anything else, influenced us concerning the probable mode of transmission of poliomyelitis. It had been the privilege of one of us to work with yellow fever both before and after the mosquito days, and many analogies came to mind which made us believe that poliomyelitis also was not a contagious disease.

All the various reasons that influenced us in turning from contagion to some other mode of transference need not engage our attention now, for the history of this part of the work has been ably and accurately given by Dr. Richardson in the paper which he has just read. In justice to Dr. Richardson we desire to state that all the essential conclusions of his paper were arrived at before he knew of the results in the laboratory with the monkeys.

The work which we now briefly desire to report consists in exposing monkeys during all stages of the disease to the bites of *Stomoxys calcitrans*. The monkeys were infected in the usual way by bringing an emulsion of a known virus obtained from human sources in direct association with the central nervous system. After the flies had had abundant opportunity to bite these infected monkeys during the various stages of the disease, including the period of incubation, healthy monkeys were then exposed to the bites of these same flies. Of twelve healthy monkeys indications of the disease have been obtained in six, three of them in a virulent form, resulting in death, the other three with transient tremblings, partial paralysis, diarrhoea and recovery. It is interesting to note that several of the monkeys had diarrhoea, therein the disease resembles the human disease more closely than when monkeys are simply inoculated with the virus into the brain, for gastro-intestinal upsets in children are frequently associated with infantile paralysis.

In these experiments it is important, we think, to use the proper technic in order to obtain successful results. The flies should be handled as little as possible. It is much better to handle the monkeys and leave the flies alone. In our experiment the flies were caught in nature, some of them were bred, placed in a large cage about six feet long by five or six feet wide, and some three or four feet high. The monkeys are stretched out at full length and wrapped in chicken wire. In this way they can be placed in in the cage and the flies have full opportunity to bite. The flies appear to need a feed of blood about every day or two. They sometimes visit water which is kept in the cage, but apparently cannot be induced to eat any other food than the blood. At least, in our experiments, bananas, fruits, and other substances exposed apparently were little visited by the flies. Furthermore, in our experiments a very large number of flies were used.

In conclusion we desire simply to summarize the fact that we have apparently transferred the virus of poliomyelitis from monkey to monkey through the bite of the stable fly, *Stomoxys calcitrans*. We would like to emphasize the fact that this does not appear to be simply a mechanical transference, but rather a biological one, requiring a period of extrinsic incubation in the intermediate host.

What conclusions can we draw from these facts ? At present it seems to us we would not be justified in drawing any conclusion — the significance of the facts if confirmed is self-evident.

Transmission of Poliomyelitis by Means of the Stable Fly (Stomoxys Calcitrans) [1]

As a result of the thorough epidemiologic studies of poliomyelitis conducted by the Massachusetts State Board of Health from 1907 to 1912, under the direction of Dr. Mark W. Richardson, secretary of the board, evidence was collected which led the investigators to strongly suspect that the common stable fly (*Stomoxys calcitrans*) played an important part in the spread of this disease.

At the joint session of sections I and V of the Fifteenth International Congress on Hygiene and Demography in Washington, September 26, 1912, Dr. Milton J. Rosenau, of the Harvard Medical School, who has been working in conjunction with the Massachusetts State Board of Health, announced the result of an experiment which seemed to confirm most strikingly the inferences drawn from the epidemiologic work above mentioned.

Dr. Rosenau stated that he had infected several monkeys with poliomyelitis by intracerebral inoculation, exposed them daily — from the time of inoculation till death — to the bites of several hundred *Stomoxys*, at the same time exposing twelve fresh monkeys to the bites of the same flies. At the time the announcement was made six of these twelve monkeys were reported as having developed symptoms characteristic of poliomyelitis, i. e., illness followed by more or less extensive paralysis. Of these six monkeys, two had died, three were paralyzed at that time, and one recovered after a brief illness. In the cord of one of the monkeys that had died were found the characteristic lesions of poliomyelitis, that is, perivascular infiltration and destruction of the motor cells of the anterior cornu. The cord of the other monkey was reported to have shown changes less characteristic of poliomyelitis, namely, degenerations of the motor cells without perivascular infiltration.

At the time of announcement a sufficient interval had not elapsed to determine the result of the attempt to transmit the

[1] By John F. Anderson, Director Hygienic Laboratory, and Wade H. Frost, Passed Assistant Surgeon United States Public Health Service. Reprinted from Public Health Reports, Washington, D. C., October 25, 1912.

infection to other monkeys by inoculation with the cord of one of the two that had died.

This experiment, giving an altogether new direction to the experimental study of poliomyelitis, appeared of sufficient importance to warrant an immediate attempt at confirmation.

In the experiment below reported it has been our object to repeat, as nearly as possible, the conditions of that reported by Dr. Rosenau, and we are indebted to him for assistance and advice in the details of the experiment.

On October 3, rhesus No. 242 was inoculated intracerebrally with an emulsion of the cord of a monkey which had died of poliomyelitis. The virus used is a strain originally obtained from the Rockefeller Institute for Medical Research, kept at the hygienic laboratory for nearly two years, during which time it has been passed through a large series of monkeys.

Two hours after inoculation the infected monkey was exposed to the bites of about three hundred *Stomoxys* recently collected in Washington. Thereafter until death, on October 8, this animal was exposed daily for about two hours to the bites of the same flies, plus additional fresh *Stomoxys* added from time to time as caught. This monkey (No. 242) developed characteristic complete paralysis on the afternoon of October 7 and died at 2 A.M. October 8.

Another monkey (rhesus No. 246), similarly inoculated on October 5, was then exposed daily to the bites of the same flies, beginning October 7. This monkey developed paralysis on the morning of October 9, soon becoming completely paralyzed and dying that afternoon.

Thus, from October 4 to October 9, inclusive, the flies used had access to two monkeys inoculated with poliomyelitis, first, rhesus No. 242, then rhesus No. 246. It may be noted that the incubation period in both these monkeys was very short — four days from inoculation to the development of paralysis.

Beginning October 4, two fresh monkeys (rhesus No. 243 and Java No. 241) were exposed daily for about two hours to the bites of these same flies; and beginning October 5, a third fresh monkey (rhesus No. 244) was similarly exposed. All three of these animals subsequently developed symptoms of poliomyelitis, as follows: —

Java No. 241 was found completely paralyzed on the morning of October 12 and died a few hours later. At autopsy tubercles were found in the lungs, liver, and spleen.

Rhesus No. 244 showed paralysis of the hind legs on the same day (October 12), but was, nevertheless, exposed again to the bites of the *Stomoxys* from 10 A.M. till 2 P.M. At 3 P.M. the animal, being almost completely paralyzed, was chloroformed. At autopsy tubercles were found in the lungs, liver and spleen, but apparently not sufficient to have been the cause of death.

Rhesus No. 243, which had appeared well on the morning of October 13, was found at 4 o'clock that afternoon to have a partial paralysis of the right hind leg. The following morning the hind legs and right fore leg were almost completely paralyzed. By 3.30 P.M. the neck also was paralyzed and the intercostal muscles somewhat affected. The animal was then chloroformed. At autopsy the internal organs appeared normal, except the spinal cord, which was edematous, the gray matter being congested. Sections of the cord, histologically examined, showed typical well-marked lesions of poliomyelitis; perivascular round-cell infiltration; foci of dense infiltration in the gray matter of the anterior horn; and destruction of some of the motor neurons.

The histologic examination of the cords of monkeys Nos. 241 and 244 has not yet been completed, but it is believed, on the clinical evidence, that they died of poliomyelitis.

To summarize: three monkeys exposed daily to the bites of several hundred *Stomoxys*, which at the same time were allowed daily to bite two intracerebrally inoculated monkeys, developed quite typical symptoms of poliomyelitis eight, seven and nine days, respectively, from the date of their first exposure.

In order to confirm the diagnosis of poliomyelitis in rhesus No. 243, one cubic centimeter of an emulsion of the cord of this monkey was injected intracerebrally on October 14 into a healthy monkey (rhesus No. 250). This animal recovered promptly from the operation and remained apparently quite well till the morning of October 17, when a partial paralysis of the right fore leg was noted, progressing somewhat during the day. On the morning of October 18 both fore legs were completely paralyzed and the hind legs weak. In the afternoon of the same day the right hind leg was completely paralyzed, the left very weak, and the neck paralyzed. The monkey died at 10.30 P.M. and was immediately placed on ice until autopsy could be made at 9 A.M., October 19.

At the autopsy there was found some congestion of the lower lobe of both lungs, most marked on the left side, upon which the animal had been lying after paralysis developed. The meninges of the cord were markedly congested. On section, the cord appeared edematous, and the gray matter congested, showing minute hemorrhages. The site of inoculation appeared normal except for a slight clot. Cultures from this site have shown no growth. The other organs were normal in appearance.

Histologic examination of the cord showed lesions characteristic of poliomyelitis, intense congestion and perivascular infiltration, foci of round-cell infiltration here and there in the gray matter, destruction of the cells of the anterior cornu, and small hemorrhages in the anterior and posterior cornu.

Conclusion

These results, in confirmation of those announced by Dr. Rosenau, would seem to demonstrate conclusively that poliomyelitis may be transmitted to monkeys through the agency of the stable fly (*Stomoxys calcitrans*).

It remains for further work to decide whether this is the usual or the only method of transmission in nature.

XXXIV

FOOD AND DRUG INSPECTION OF THE MASSACHUSETTS STATE BOARD OF HEALTH

By Hermann C. Lythgoe

[This is the most recent summary of the work of the Food and Drug Department and shows the improvements which have resulted from the constant supervision by the State Board of Health. *Public Health Bulletin*, 1914, p. 262. — G. C. W.]

For thirty-one consecutive years the State Board of Health has enforced the laws relating to the sale of adulterated food and drugs, which has resulted in an improvement in the quality of the food and drug supply of the state. The prevailing popular opinion is that the food law is something new, and that our foods are adulterated in such a manner and to such an extent that the American public is in great danger of degeneration and extermination. These views are no doubt due to the fact that the federal food law, which is but seven years old, has been extensively advertised, the reports of the prosecutions of the Department of Agriculture and the disposition of decomposed samples being published in a somewhat sensational manner in the newspapers. Furthermore, many sensational and untrue statements about our food supply have been published in papers and magazines. During the period from January 1, 1907, to December 31, 1912, the Department of Agriculture has reported the completion of 2,391 prosecutions under the United States food and drug act of 1906, and during the same period the Massachusetts State Board of Health has made 1,601 prosecutions for violations of the Massachusetts food laws, — nearly two-thirds as many as the national authorities have made. When one considers that the United States Department of Agriculture operated during this time the general laboratory in Washington and twenty-one branch laboratories, many of which were larger than the food laboratory of the State Board of Health, it is surprising that the number of prosecutions carried on by the state is so large.

State food laws deal with sales made within the state, and the national law deals with sales made between the states; both laws are independent of each other. The New Hampshire law cannot prevent the manufacturer in that state from shipping adulterated food into Massachusetts, and the United States law cannot easily convict a person who ships to himself or to his partner although goods so shipped may be subject to seizure and confiscation; but under the Massachusetts law the person selling such food in this state can be prosecuted. This illustration shows the vital necessity of state laws, which, as a rule, owing to local conditions, cannot be in uniformity with the national law. Shortly after the passage of the United States law many states enacted a law modeled upon it almost verbatim, yet today hardly a state possesses a law uniform with the national law, owing to the necessary changes made by the different states.

There was published in the report for 1912 a chart[1] showing the variation in adulteration of samples of milk, foods, exclusive of milk, spices and drugs, examined by the Board during thirty years. A chart of this nature naturally would give a false impression of the amount of adulterated matter upon the market, owing to the fact that particular attention was paid to the collection and examination of those substances which experience has shown to be most liable to adulteration. Furthermore, large numbers of samples are collected from suspected persons, which practice has a tendency to increase above the normal the ratio of adulteration of the samples examined. This chart shows the value of inspection, however, for one can readily perceive what would happen if inspection were to cease.

The actual value of the work of the department in suppressing adulteration can be shown by the statistics of those classes of food which have been examined continuously during a period of years by the same methods of analysis. For this purpose the statistics of honey, cream of tartar, coffee, molasses, and spices have been chosen. Honey, cream of tartar, and spices have been examined for thirty-one years. No adulterated samples of spice and honey have been obtained in eight years, and of cream of tartar during three years. The largest amount of adulterated

[1] This chart is not reproduced.

spices was obtained in 1883, when two-thirds of the samples were adulterated. After five years the adulteration of spices was reduced to less than one-fifth, and since 1908 it has been nil. The large majority of the adulterated samples of spices were manufactured outside this state, and in such cases warning letters were sent to the dealers, — prosecution being resorted to only when the dealers did not heed the warning. In the collection of such food as spices the inspectors soon became acquainted with the reliable brands, and from dealers carrying such goods no samples were taken.

During 1910 four samples of cream of tartar were reported adulterated, of which three were sold as cream of tartar substitutes without any statement of the per cent of ingredients, and have not been included in the chart. The other sample is included in the chart, and was in a can, which, judging from its appearance, may have been on the shelf of the dealer for a number of years.

Coffee has been examined continuously since 1890, and the highest amount of adulteration (45 per cent) occurred in 1890. For six years no sales of adulterated coffee have been obtained when coffee was asked for. A number of samples of compound coffee have been obtained, but in all these cases compound coffee has been asked for, and the packages have been labeled "compound coffee"; but in many instances the per cent of the ingredients, as required by law, have not been stated upon the package. These sales of compound coffee are not included in the chart.

Molasses has been examined for the presence of glucose since 1887. Previous to that time the examination had been confined to the detection of tin salts used in clarifying and decolorizing dark, thick molasses. Since 1907 no illegal sales of molasses containing glucose have been obtained in this state by our inspectors.

Preserved Foods

Since 1904 certain classes of food have been systematically examined for preservatives, and the results of these examinations are shown in the chart. The percentage of adulterated samples does not show the extent of the use of preservatives in these foods, but shows the per cent of samples containing these substances when sold without the necessary label stating the name and per cent of the added preservatives. Certain classes of food, such as hamburg steak and sweet cider, invariably contain antiseptics, unless the article is prepared in the presence of the customer. In fact, it would be impossible to sell in a grocery store sweet cider free from preservatives unless the cider was sterilized and bottled in that condition, as the presence of alcohol would in one or two days become sufficient to render the dealer liable under the liquor law for selling an intoxicating beverage without a license. The use of a preservative in hamburg steak is principally for the purpose of preventing the meat from becoming dark upon standing. Sodium sulphite is used for this purpose in amounts from 0.5 to 1 per cent, although occasionally samples have been found containing as much as 2 per cent. Meat treated with this substance will retain its bright red color until the antiseptic is destroyed. Recently sodium benzoate has been to some extent substituted for sodium sulphite in this article of food. With the exception of these two substances the use of antiseptics in food is declining. In the foods in which the presence of antiseptics was formerly the rule, such as sausages, clams, oysters, and beer, these substances are now very rarely found, and the use of preservatives is diminishing in jams, ketchup, canned and bottled fruit products, in which antiseptics are unnecessary for commercial preservation. The use of antiseptics in milk has practically ceased. Since 1908 but two samples of preserved milk have been found in this laboratory, one sample during 1912 and one during 1913, both of which contained formaldehyde.

Drugs

Drugs must conform to certain standards laid down in books on materia medica, one of which, the United States Pharmacopoeia, is specifically mentioned in the statutes. If a sample of drug is deficient to the standard, although its deficiency is too slight to substantiate a prosecution in court, the records of the department must show it to be adulterated. For this reason drugs would naturally show a higher ratio of adulteration than foods which, with the exception of milk and vinegar, need not conform with specific standards, but this does not account for the excessive adulteration found in drugs, the only explanation of which would be fraud, incompetency or carelessness. It is of course manifestly impossible to expect all drugs prepared by the retail dealers to be exactly standard, and a reasonable allowance must be made for possible errors in manufacture. For example, spirit of peppermint should contain 10 per cent by volume of peppermint oil. If two samples were examined and found to contain 9.7 per cent and 5 per cent of peppermint oil, respectively, they must both be classed as adulterated, although the former is for all practical purposes pure, and the latter is adulterated to an extent of 50 per cent. One of these samples should be the subject of a prosecution, and the other is not even poor enough to merit the sending of a warning letter to the dealer from whom it was obtained. It has been the practice in this state to obtain for analysis a number of drugs which are prepared by the retail druggist, experience having shown that the largest amount of fraudulent adulteration and substitution is practiced by the small dealers. Judging from the rapidity of the improvement in the quality of the drugs examined it would appear as if the druggists watch the bulletins of the State Board of Health to find out what particular drugs are being examined, because after the publication of the results of the first prosecution of a drug, the character of which has been but recently investigated, the sale of pure and full-strength samples of this particular drug increases with great rapidity. For this reason changes in the character of drugs examined are necessary, and there has been no one variety of drug that has been examined continuously since the department has been organized; consequently, a drug chart similar to that of foods could not be prepared.

Tincture of iodine has been examined for a longer period than any other drug, and since 1904 the ratio of adulteration has been brought down from 90 to 15 per cent. Since 1908 from 7 to 15 per cent of the samples contained less than the required seven grams of iodine per hundred cubic centimeters. Notwithstanding this, during the same period the average sample contained from

96 to 99 per cent and the average adulterated sample contained from 77 to 84 per cent of the required amount of iodine. During the years 1898–1904 from 81 to 84 per cent of the samples were below the standard, the average bad sample containing from 63 to 75 per cent and the average of all samples containing from 76 to 88 per cent of the required amount of iodine. The improvement in the quality of this drug appears to have been extended to the adulterated samples, caused by the presence of a less number of the highly deficient and a proportionately greater number of the slightly deficient samples. Similar conditions exist in the statistics of the other pharmacopoeial preparations listed in the chart.

The glycerine statistics are of unusual interest. During 1899 it was found that the glycerine on the market contained considerable arsenic, and as nearly all of this drug came from outside the state, notification rather than prosecution (of which latter there was but one) was resorted to for the purpose of purifying the drug. The increase in adulteration during the second year is due to the fact that the examination for arsenic in 1899 was begun in the middle of the year and the samples not examined for arsenic were reported as good, which lowered the ratio of adulteration for the year. At that time the United States Pharmacopoeia did not specify that glycerine should be free from arsenic, and the fact that the Massachusetts market was practically cleared of the arsenical preparation before the publication of the 1900 Pharmacopoeia speaks well both for the work of the department and of the co-operation of the manufacturers in the country, who changed their process of manufacture so that the pharmacopoeial glycerine was made arsenic free.

The proprietary medicine law was enacted in 1906, but was written in such a manner that except in those portions relating to cocaine it was practically useless. This law was amended in a satisfactory manner in 1907 and went into effect in 1908. For these reasons the most attention was given during 1906 and 1907 to the preparations in which cocaine might be used, and of eighty-seven samples obtained in 1906, seventy-eight were suspected of containing cocaine, in eighteen of which the drug was present.

In 1907 no collections were made of those medicines shown by the previous year's work to contain no objectional substances, and a vigorous campaign was carried on against the sale of medicine known to contain cocaine. This was continued during 1908 and 1909, the result of which is that it is now almost impossible to purchase cocaine in a drug store in this state without a prescription from a physician; and, furthermore, proprietary drugs

TABLE 60

PROPRIETARY MEDICINES

Year	Samples found Good	Number of Samples containing —					Total
		Cocaine	Morphine	Acetanilide	Alcohol	Chloroform	
1906........	69	18	..	..	..	..	87
1907........	84	87	4	..	..	..	175
1908........	165	83	4	22	9	..	283
1909........	73	2	..	4	13	..	92
1910........	43	1	..	3	8	..	55
1911........	51	..	6	4	6	..	67
1912........	44	..	..	...	13	2	59
1913........	33	..	..	..	1	..	34

containing this substance have been eliminated from the Massachusetts market. In most instances the law requiring the per cent of morphine to be labeled upon the package has been lived up to, and the dealers in headache powders have now complied with the laws requiring that the amount of acetanilide and phenacetin in such substances shall be stated upon the label of the package. The fact that the proprietary medicines are at present sold in compliance with the law does not mean that the evils of the drug habits have been eliminated. Habitual users of drugs obtain a supply in some manner, as is shown by the amount of such substances which has been found upon the persons of prisoners and submitted to this Board by the police. These are not, however, proprietary drugs, but are either the pure chemicals or are tablets containing them. It appears to be impossible for a non-user of these drugs to purchase them without a prescription in those stores the proprietors of which illegally sell such substances to their regular customers, who naturally are known to the dispensers as habitual users of drugs. The drugs sold on the streets by peddlers are of the same nature as those dispensed in certain disreputable drug stores.

Notwithstanding the fact that the traffic in hypnotic drugs is not what all would desire, the present state of affairs is an immense improvement over conditions a few years ago, when alleged catarrh powders, asthma remedies, etc., containing cocaine were frequently sold in this state, and many persons innocently acquired the drug habit by using them in good faith as medicines. If a person uses hypnotic drugs today he must first obtain the drug, no doubt illegally, with certain knowledge of the nature of the substance he is using.

PART IV

ABSTRACTS OF SCIENTIFIC ARTICLES AND REPORTS PUBLISHED IN THE REGULAR SERIES OF ANNUAL REPORTS

I. ABSTRACTS OF SCIENTIFIC ARTICLES AND REPORTS

1870

First Annual Report

Report on Slaughtering for Boston Market.

Dr. George Derby, pp. 20–37

One of the first problems to engage the attention of the State Board of Health was the nuisance caused by slaughtering animals in an insanitary manner within six miles of the State House. This report describes the conditions, suggests remedies, and presents economic arguments in favor of their adoption.

Report on the Sale of Poisons. pp. 38–41

A brief statement of the problem.

The Prevention of Disease. *Dr. George Derby*, pp. 42–57

An address delivered at a meeting of the Boston Social Science Association, December 3, 1868, before the State Board of Health was established.

1871

Second Annual Report

Poisoning by Lead Pipe used for the Conveyance of Drinking Water. pp. 22–44

A report stating the results of a study of the occurrence of lead poisoning in various cities and towns of the state. Aside from these results the report is of especial interest in that it includes an experimental study of the effect of various waters on lead by Professor William Ripley Nichols of the Massachusetts Institute of Technology (pp. 32–40).

Trichina Disease in Massachusetts. pp. 46–50

A general discussion of this disease.

Charbon in Massachusetts. *Dr. Arthur H. Nichols*, pp. 86–108

A report on the occurrence of charbon, or malignant vesicle, in the state.

The Causes of Typhoid Fever in Massachusetts. pp. 110–179

A statistical study of the occurrence of typhoid fever in the cities and towns of the state and a discussion of the various causes suggested.

It was estimated that "more than one per cent of the able-bodied adult population was rendered helpless every year from this disease for a period often extending through many months."

The report contains a summary of Pettenkofer's "soil theory" of the cause of typhoid fever, and this is contrasted with the English opinion that typhoid fever was caused by the contamination of water by animal excrement. The letters received from the physicians in different parts of the state are somewhat amusing in the light of present day knowledge. It is evident that at that time the idea of water supply pollution was taking hold of the popular mind, but it was *decomposition of organic matter, not infection*, that was being considered. That the situation was not clearly understood is evident from the following words taken from one of the closing paragraphs of the report, — "On the question of the propagation of typhoid fever by contagion there is little new to be said, and what is old is contradictory. When two such authorities concerning the fever of New England as Dr. Nathan Smith (who believed in the contagion theory) and Dr. James Jackson (who thought it was miasmic) differ in opinion on this point, we may be sure that it is one not readily settled."

The concluding paragraph, quoted from Dr. Benjamin Rush, is worth noting. He said, "To every evil the Author of Nature has kindly prepared an antidote. Pestilential fevers furnish no exception to this remark. The means of preventing them are as much under the power of human reason and industry as the means of preventing the evils of lightning or common fire. I am so satisfied of the truth of this opinion that I look for the time when our courts of law shall punish cities and villages for permitting any of the sources of bilious and malignant fevers to exist within their jurisdiction."

Letter from the *Chairman*, **Dr. Henry I. Bowditch,** concerning **Houses for the People** and the **Sewage Question.** pp. 182–244

During the summer of 1870 Dr. Bowditch resided in London. On December 10, he wrote to the board, — "I could not serve Massachusetts better than by investigating the homes of the London poor and some of the means used to improve them, together with some other topics of similar importance. The results have been of very great interest to me. I have therefore embodied them in this letter to you." This letter contained eight distinct sections having the following titles: —

1. A Night-stroll with an Inspector of the London Metropolitan Police, compared with a similar one taken in Boston.
2. Operations of Philanthropists for the Improvement of the Dwellings of the Poor in London.
3. The Improved Industrial Dwelling Company, or the Union of Philanthropy with Capital, and with Perfectly Successful Results to Both Parties.
4. The Jarrow Building Company, by which a tenant becomes a proprieter of the home he lives in.

5. Organized work among the poor, inaugurated by Miss Octavia Hill, assisted by Mr. Ruskin and others.

6. A comparison between a model lodging house, and a low tenement house in Boston.

7. Convalescent homes.

8. The sewage question in England.

In the last section Dr. Bowditch writes, "The great sanitary question throughout Great Britain is the economic removal from houses of what is deleterious to man, and the proper use, as a source of income, of what has been heretofore wholly wasted. There is no single subject that is attracting more attention in England, and which excites more heated partisanship than the vast questions looming up under the various names of 'earth-closet,' 'water-closet,' 'sewage,' 'its danger to health,' 'its widespread and fatal waste,' 'its utilization as a manure.'" These vexed questions cropped out and were bandied about from section to section of the meeting of the British Association for the Advancement of Science, presided over by the celebrated Huxley.

A visit to the two outfalls of the sewers of London into the Thames, at Barking and Crossness was described. Apparently at first prejudiced against the plan of these works, designed by the celebrated engineer, Bazolette, Dr. Bowditch felt obliged to make the following inferences: "*First*, That by some means unknown to me the excreta had become deodorized during the water carriage. *Second*, That at present there was no proof that this deodorized sewage water of London does actual harm to those dwelling near it. I therefore remembered Boston and other cities of Massachusetts with partial relief."

Correspondence concerning the **Effects of the Use of Intoxicating Liquor.** pp. 246–347

Containing the personal opinions of one hundred and sixty-four correspondents on the subject. Chiefly interesting as showing the manner in which the State Board of Health began to comply with Section 4 of the act under which it was created.

Mortality of the City of Boston in 1870. pp. 350–368

A series of statistics prepared by Dr. Frank W. Draper.

The Ventilation of School-houses. *A. C. Martin*, pp. 369–383

The author of this paper was a Boston architect. He refers to the prevailing idea that exhaled carbonic acid was the chief cause of the vitiation of the air in crowded rooms. He rejects this as insufficient and holds that "watery vapor and the animal matter given off by the lungs and the skin" are of more importance. Carbonic acid he regards as an obstructor of respiration and not a poison. "No surer or more exact test than a well-educated nose has, as yet, been discovered to measure the amount of vitiating animal matter thrown into the air." Some of these ideas are now considered as modern. Martin's ideas of school-room ventilation are interesting as an example of the use of many local inlets and outlets, the latter being located at the individual desks. Diagrams illustrative of the principle are given.

Examination of the Water of Mystic Pond. pp. 386–393

This relates chiefly to a report made by "Mr. William Ripley Nichols, Assistant Professor of General Chemistry at the Massachusetts Institute of Technology." The results have no value today, but the state of the art of water analysis at that time is shown by the tables of analyses, which gave the following results of determinations:

1. Number of cubic centimeters of permanganate to a liter.
2. Number of cubic centimeters of soap solution to 100 cubic centimeters of water.
3. Solid residue at 100° C. (Given in parts per 100,000 and also in grains per U. S. gallon.)
4. Loss on Gentle Ignition. (Similarly expressed.)
5. Chlorine. (Similarly expressed.)
6. Reactions for Nitrites. (Stated as "slight," "distinct," etc.)
7. Reaction for Sulphates. (Stated as "slight," "distinct," etc.)

The report gives a few of these determinations for the water supplies of Boston, New York, and Philadelphia.

Air and Some of Its Impurities. pp. 396–408

Examinations of air for carbonic acid were made under the direction of Professor Frank H. Storer, at the Massachusetts Institute of Technology, and at Harvard College by H. B. Hill, Assistant in Chemistry.

Mr. Charles Stodder, an accomplished microscopist of Boston, undertook to make a study of the dust in the air and contributed an interesting letter describing the failure of certain methods and the partial success of others. He used a glass surface smeared with gelatin to collect floating particles. Of especial interest is his reference to the iron particles found in the dust collected from one of the shops in the United States armory at Springfield.

Health of Minors, employed in Manufactures of Cotton, Woolen, Silk, Flax, and Jute. pp. 409–423

A compilation of statistics.

Report on the Use of Milk from Cows Affected with "Foot and Mouth Disease." *Dr. Arthur H. Nichols*, pp. 426–433

The conclusions were that the disease could be communicated to man through the agency of diseased milk, but that the disease so acquired was not to be dreaded. Cooked meat and boiled milk were not to be feared.

1872

Third Annual Report

Arsenic in Certain Green Colors. *Dr. Frank W. Draper*, pp. 18–57

A study of the supposed evil effects of the use of arsenic in certain green colors used for dyeing artificial flowers, articles of dress, confectionery, pastry ornaments, toys, wall papers. Instances of poisoning are cited both of manufacturers and users. Analyses of various substances for arsenic are given. The public is warned against green paper, green lamp-shade, and against most things green.

Milldams and other Water Obstructions.
Dr. George Derby, pp. 60–70

Looking back, this seems to us of today as a curious article. Apparently it is an argument against the storage of water on the ground that reservoirs impede run-off and hence raise the ground water level, convert meadows into swamps, while the waters become foul and give forth noisome vapors. Reservoirs thus tend to produce consumption and typho-malarial fevers.

Intemperance as Seen in the Light of Cosmic Law.
Dr. Henry I. Bowditch, pp. 71–129

This was an analysis of the correspondence on the use and abuse of intoxicating drinks throughout the globe which was presented to the legislature in 1871. Starting out with the idea that the love of stimulants is a human instinct Dr. Bowditch attempted to show the fundamental relations between intemperance and isothermal lines, race, nature of the stimulant and the culture of the grape.

In view of present day interest in the subject of alcoholic prohibition, the conclusions of Dr. Bowditch's studies are presented at some length on page 12. The letter was illustrated by a map of the world showing the distribution of intemperance.

The Adulterations and Impurities of Food. *Dr. Henry B. Hill*, Assistant in Chemistry, Harvard College, pp. 132–137

A study of the action of acid fruits upon tin cans.

Proper Provision for the Insane. *Dr. Edward Jarvis*, pp. 140–159

A general discussion of insanity, the various needs of the insane, and the proper arrangement of hospitals.

The Use and Abuse of Opium. *Dr. F. E. Oliver*, pp. 162–177

A consideration of the drug habit in Massachusetts.

Sewing Machines. *Dr. Arthur H. Nichols*, pp. 180–221

The sewing machine of Elias Howe, Jr., of Cambridge, was invented in 1846. Twenty-five years later we find a heated discussion as to the effect which the constant use of foot machines had on the health of the women operators. The article of Dr. Nichols describes various styles of machine and their relative tendency to injure health. The general conclusion was that moderate use of the sewing machine, say three or four hours a day, was without prejudical effect, but that better treadles might be used with advantage and the substitution of some other motive power was urged.

Slaughtering, Bone Boiling and Fat Melting.
Dr. George Derby, pp. 224–245

A history of the efforts of the State Board of Health to bring about a reform in these processes.

Vegetable Parasites and the Diseases caused by their growth upon man. *Dr. James C. White*, pp. 248–296

Smallpox in Massachusetts. *Dr. George Derby*, pp. 297–304

A discussion of certain defects in the laws relating to the control of this disease.

1873

Fourth Annual Report

Sewerage; Sewage; The Pollution of Streams; The Water Supply of Towns. *William Ripley Nichols*, Professor General Chemistry in the Massachusetts Institute of Technology, pp. 19–108

This is interesting as being the first comprehensive report on this subject made by the State Board of Health. On April 10, 1872, the legislature had "Ordered: — that the board of health be requested 'to consider the general subject of the disposition of the sewage of towns and cities, having in view:

" '*First*, Its utilization as a fertilizer.

" '*Second*, The sanitary effects of draining the same into the waters of the Commonwealth.

" '*Third*, The increasing joint use of water-courses for sewers, and as sources of supply for domestic use by the people of the Commonwealth.

" 'And that the said Board be requested to report to the next legislature their views, with such information as they can obtain upon the subject from our own or other lands.' "

Professor Nichols visited England to study the new developments then being made and his report describes various processes then new, but now all but forgotten. He made a study of the existing sewerage systems in Massachusetts and classified the cities and towns on the basis of completeness of system. He also considered the effect of sewage on streams, and in particular, the effect of the sewage of Worcester on the Blackstone River, and that of Lowell on the Merrimack River.

The report contains many analyses made by Professor Nichols and it is interesting to compare these determinations with those used in his previous report on Mystic Lake two years before. Here we find figures for "ammonia," "albuminoid ammonia," "phosphoric acid," "nitrogen as nitrites and nitrates," "suspended matter." Evidently the art had advanced during the interval. The report concludes with a discussion of the water supplies from the great ponds of the state.

The chief interest of this report of Professor Nichols lies in the fact that it reflects the opinions of the various sanitary authorities of that time on such general questions as the self-purification of streams, the utilization of sewage. Interesting also is the fact that many of the water analyses were made at the Massachusetts Institute of Technology by Miss Ellen H. Swallow, A.B., who afterwards became Mrs. Ellen H. Richards.

The Opportunity and Possibility of Utilizing Sewage in the City of Worcester. *Phineas Ball*, pp. 109–116

The Great Ponds of Massachusetts. *H. F. Walling*, pp. 117–132

A list of the lakes and ponds with areas and name of outlets.

Beer-shops and Prohibitory Laws. *P. Emory Aldrich*, pp. 133–144

Additional analyses of evidence as to the use and abuse of intoxicating liquors.

Character of Substances Used for Flavoring Articles of Food and Drink. *Dr. Henry K. Oliver*, pp. 145–172

A study of supposed deleterious ingredients used for flavoring and coloring.

Drainage for Health. *Henry F. French*, pp. 175–191

A discussion of building sites, cellar drainage, and sink drains.

Infant Mortality. *Dr. Edward Jarvis*, pp. 193–233

A scholarly discussion, strikingly modern in tone. It contains statistics of infant mortality in different countries and in different parts of the United States, comparing them with figures for Massachusetts. The causes of infant mortality are discussed and the statements differ very little from those so much talked about today. Emphasis is laid on the need of education of mothers, both before and after the child is born.

This is a paper well worth reading by modern social workers.

The Food of the People of Massachusetts.
Dr. George Derby, pp. 237–275

A collection of facts relating to the habits of the people of the state in the use of foods of different kinds, based on a circular letter sent to the correspondents of the board in the cities and towns. Such topics as these are touched upon: the quality of bread, variety in food, the frying of meat, the use of pastry and cakes, time devoted to meals, the use of tea and coffee, the excessive use of water, cost of labor as influencing food. Speaking of too rapid eating Dr. Derby says, "The usual or average time occupied in the process of taking food by the people of this state we think does not exceed from twelve to fifteen minutes for each meal."

The paper contains interesting allusions to the domestic conditions of the time. The wages of domestic servants were increasing, home life was being discouraged, people were taking refuge in hotels and boarding-houses, women were leaving homelife for the factory, pressure of town life was increasing. Special emphasis was laid on the quality of the bread being made, the concluding words of the article being, " When bread, the staff of life in all countries, is found to be as good in Massachusetts as in Europe, it will be a sign that the point at which we should aim has been reached."

The Adulteration of Milk.

Dr. Arthur H. Nichols and Professor James F. Babcock, pp. 277–306

An early study of a subject which for many years has given great concern to public health authorities. The subdivisions of the subject were: (*a*) The composition of milk, its variations. (*b*) Methods of examination. (*c*) Methods of adulteration. (*d*) Examination of samples of milk sold in Boston. (*e*) Legislative enactments with regard to the sale of adulterated milk. At that time Professor Babcock was Analyst to the City of Boston and the report of his analyses are of interest to food specialists.

Some of the Causes or Antecedents of Consumption.

Dr. Henry I. Bowditch, pp. 307–388

An analysis of the correspondence elicited by sending a questionnaire to many physicians showed the following opinions to be generally prevalent at that time.

Consumption is influenced by hereditary tendencies. The effect of drunkenness of parents on consumption is not strongly marked, but the effect of drunkenness in the individual is marked. Consumption is favored by overwork, by certain trades, by mental trouble. Of 210 correspondents only 100 held the disease to be contagious, but 168 believed it to be caused or promoted by a wet location, — thus supporting a theory strongly urged by Dr. Bowditch himself.

Adulterations and Impurities of Food.

H. B. Hill, Assistant in Chemistry, Harvard College, pp. 389–394

The Homes of the Poor in our Cities.

Dr. Frank W. Draper, pp. 395–441

A report based on a personal inspection of conditions in the following eight cities, — Boston, Fall River, Lawrence, Lowell, Lynn, Salem, Springfield, Worcester. It contains an analysis of the legislation on the subject up to that time and urges the establishment of local boards of health.

Butcher's Slaughtering and Melting Association. pp. 443–447

A short report to the Board by the president of the association.

1874

Fifth Annual Report

Preventive Medicine and the Physician of the Future.

Dr. Henry I. Bowditch, pp. 31–60

An excellent résumé of the state of the art in 1874. It is reprinted, with some omissions, on page 17.

On the Present Condition of Certain Rivers of Massachusetts, together with considerations touching the water supply of towns.

Prof. William Ripley Nichols, pp. 63–152

A study made in continuation of that described in the Fourth Annual Report of the State Board of Health, pp. 19–108, and describing in detail and with statements of water analysis the various rivers of Eastern Massachusetts, especially the Merrimack, Blackstone, Sudbury, Concord, Neponset, and Charles.

The report contains, on page 148, a detailed description of the methods of analyses used. The only substantial difference from those used the year before was the addition of the test for dissolved oxygen.

On page 103 is given a discussion of the then mooted question of the self-purification of streams.

At that time the Cochituate water supply of Boston was polluted on various streams and notably by Pegan Brook at Natick. Several storage dams on this stream built for the protection of the supply are described. Certain pollutions of Mystic Lake, then used as a water supply for Charlestown, Chelsea, and other places to the north of Boston were discussed.

In this report the water supplies of Lowell and Lawrence, which have long been of interest to sanitarians, come into view. Lowell at first considered a project to use sand-filter beds, but it was decided to use a "filtering-gallery," now generally called an "infiltration-gallery" instead. It is interesting to notice that in the study of this problem Nichols made determinations of iron (and alumina), hardness and dissolved oxygen, very much as a modern chemist would do. Lawrence was then constructing its new works and it was proposed to draw water directly from the river except when it was turbid. At such times it was the intention to take water from a filtering-well near the shore.

The Charles River was considered as a source of water supply by a number of communities, Dedham, West Roxbury, Brookline, Newton, Waltham, and Watertown, and there were acrimonious discussions between those who favored the river and those who favored Lake Cochituate. In 1874 Waltham alone took water from the river and Nichols discussed the quality of water from this source in his report. The soundness of his ideas throughout this and other discussions are, in the light of present day knowledge, notable.

The Brighton Abattoir. pp. 153–180

A description of the abattoir, a list of the regulations approved by the State Board of Health and a letter from the U. S. Commissioner at the Vienna Exhibition describing certain abattoirs in Europe.

The Health of the Farmers of Massachusetts.

Dr. J. F. A. Adams, pp. 181–248

A paper based largely upon correspondence with physicians. It treats of the following topics: social condition and prosperity; longevity; general health; causes of disease; prevailing diseases; then of the farmer's work, his diet, location of dwellings, cleanliness of surroundings, drinking water, sleeping apartments, mental influences.

Some Farm-Houses and Some Mistaken Ways of Living in Them.
Mrs. Thomas F. Plunkett, pp. 249–259

Cerebro-Spinal Meningitis in Massachusetts.
Dr. J. Baxter Upham, pp. 261–312

A report on the epidemic which occurred in Massachusetts in 1873, with an inquiry into the circumstances attending its origin or supposed cause. Correspondence with physicians was analyzed as to the occurrence of the disease in different places and the relation of the disease to sanitary conditions. The conclusions were largely negative.

Hospitals. *Dr. George Derby*, pp. 313–332

The object of this paper, the author states, was to show the advantage of hospitals, constructed simply, detached from each other, and of a single story.

Political Economy of Health. *Dr. Edward Jarvis*, pp. 333–390

A splendid discussion of public health based on a text quoted from the distinguished sanitary engineer, Baldwin Latham, " Health is the Capital of the Laboring man." The subject is treated from many standpoints, — statistical, financial, political, moral, physical. Answering the question " Can the government aid in Improving Human Life ? " Jarvis refers to the threefold powers of government which are exerted.

" It is mandatory, and says, thou shalt and thou shalt not."

" It is permissive, and grants privileges."

" It is advisory, instructive and encouraging."

A résumé is given of some of the more important laws relating to public health enacted in England (p. 364).

School Hygiene. *Dr. Frederick Winsor*, pp. 391–448

A general discussion based on correspondence with physicians. Then as now the crying need was for better ventilation.

Work of Local Boards of Health. *Dr. Azel Ames, Jr.*, pp. 449–486

A description of the status of the local boards of health and their work.

Use of Zinced or Galvanized Iron, for the storage and conveyance of Drinking Water. *Dr. W. E. Boardman*, pp. 487–510

An excellent résumé of the views of scientists, with a letter from Professor William Ripley Nichols. The conclusion is well stated and the opinion stands today.

" It is proved theoretically, experimentally and practically that zinc is acted upon by ordinary drinking water; that water, allowed to stand in reservoirs or drawn through pipes of zinced or galvanized iron, usually contains an appreciable amount of zinc, more or less, according to various influences; that the zinc, contained in the water, is in the form of undissolved oxide and carbonate and of dissolved salts, the exact nature of the latter not being known; that probably under no circumstances is the oxide or the carbonate an active or gradual poison, much less in the amounts in which they can occur under the conditions mentioned; that, at least with water fit for drinking purposes in other respects, the contained zinc salts in solution do not exert any deleterious effects upon the human system; finally, that, even if all the zinc in solution were in the form of the chloride, which is known to be the most active poison of the zinc salts, the amount would still be insufficient to endanger health."

1875

Sixth Annual Report

Inebriate Asylums or Hospitals. *Dr. Henry I. Bowditch*, pp. 25–53

Dr. Bowditch, after discussing the difference between vicious and morbid drunkenness, suggested a method of dealing with the problem by establishing state asylums for inebriates, and described his idea of how such asylums should be conducted. As a result of this paper the Board recommended to the legislature the establishment or endowment of one or more asylums *as a sanitary measure of the highest importance.*

The Value of Health to the State. *Dr. W. E. Boardman*, pp. 55–75

A statistical and economic study.

On the Transportation of Live-stock. *J. C. Hoadley*, pp. 77–132

A report by an engineer, prepared at the request of the Board. It discusses the subject "in its economical, sanitary and humane aspects." The first of these — "abundant food at a reasonable price" — gives the key to the situation. Although a vital subject at the time, linked as it was with the studies of the abattoirs, the details of the paper are no longer of importance.

Our Meat Supply, and Public Health.
Dr. Charles F. Folsom, pp. 133–183

An account of the various ways in which decayed or infected meat may cause disease to human beings, including a study of trichina and other parasites.

The Brighton Abattoir. *Mr. J. N. Meriam*, pp. 185–203

An account of various matters relating to the business of slaughtering cattle for the market. Regulations of the State Board of Health.

On the Composition of the Air of the Ground-Atmosphere.
Prof. William Ripley Nichols, pp. 205–224

This investigation was made, no doubt, because of the prominence at that time of the theories of Pettenkofer, which had to do with the sanitary significance of ground water and ground air. Nichols collected samples of ground air by an interesting method (p. 214) at various places in the Back Bay, where the city "consisted largely of made land." These were tested for CO_2, sulphuretted hydrogen, and ammonia. The CO_2 results were quantitative and are given in the paper. They ranged from about 7 to 45 parts per 10,000 just below the surface to 25 to 200 parts at depths of 10 or 12 feet. The quantities were higher in summer than in winter. No sulphuretted hydrogen was found. Nichols, with his keen scientific mind, expresses his opinion that no very useful conclusions can be drawn from the CO_2 tests. He practically gave the ground air of the Back Bay district a clean bill of health. In an appendix to his report (p. 221) he describes experiments made by Professor Fleck in Dresden to show the variations in the CO_2 of ground air above a decomposing body. The data given are interesting.

Ventilation of Railroad Cars. *Dr. Theodore W. Fisher and Professor William Ripley Nichols*, pp. 225–240

A report of analyses of air in cars, especially smoking cars. The CO_2 found varied from 10 to 37 parts per 10,000. References to previous studies by various writers are given.

Cremation and Burial. · *Dr. J. F. A. Adams*, pp. 241–325

An elaborate discussion of the relative advantages of the two methods, largely historical and with many references to other writings. His conclusion was that cremation is an innovation not demanded in this country on sanitary grounds.

1876

Seventh Annual Report

The greater portion of this report is devoted to the subjects of stream pollution, drainage, sewage disposal and water supply. It may be regarded as one of the great classic reports of the Board.

Rivers Pollution. *James P. Kirkwood, C.E.*, pp. 21–154

In 1875 (Chapter 192) the legislature had passed an act providing for an investigation of the question of the use of running streams as common sewers in its relation to the public health. Mr. Kirkwood, of Brooklyn, N. Y., then an eminent authority was appointed by the Board to make a systematic examination of certain of the river-basins of the state. His report is divided into several parts.

Part I (p. 21) is a summary of the then prevalent ideas concerning the relation between the use of unclean water supplies and disease, notably cholera. Illustrations are taken from the water supplies of London.

Part II (p. 37), which comprises the body of the report, is a statistical study of the various drainage areas studied, with accounts of the various trade wastes encountered. The following index to these topics will assist the reader in obtaining an idea of the scope of the investigation and be a convenience in finding the data in the report:

Woolen manufacture (p. 37), cotton manufacture (pp. 42 and 45), bleach-works (p. 45), linen and jute manufacture (p. 46), silk manufacture (p. 49), paper manufacture (p. 50), metal manufacture (p. 60).

On page 69 is given an account of the effect of various poisons in water on fish life:

Blackstone River, p. 73.
Neponset River, p. 89.
Charles River, p. 97.
Chicopee River, p. 109.
Taunton River, p. 123.

Part III (p. 144), contains the general conclusions and recommendations.

Tables of Analyses. *Professor William Ripley Nichols*, pp. 155–174

Many samples of water were analyzed by Professor Nichols in connection with Kirkwood's investigation. The methods used were practically the same as had been used for several years previous.

Water Supply, Drainage and Sewerage of the State, from the Sanitary Point of View. *Dr. Frederick Winsor*, pp. 175–275

A report of the sources of water supply and the place of sewage disposal for many of the cities and towns of the state, based upon the answer to eleven questions sent out by the author in a circular letter and answered by one hundred and eighty-eight cities and towns. It contains many points of information in regard to the water supplies of the state as they were at that time.

On pages 180–191 is given a discussion of the methods of excrement removal used in England and elsewhere, with sketch of privies and arrangements of parts.

The tables relating to water supplies begin on page 193, and those on sewer outlets on page 202.

Three principles stated on page 218 give a good illustration of current ideas as to the danger of water pollution. In brief they were as follows:

First. Chemical analysis is not alone sufficient to detect impurities in water for an incredibly small amount of the poison of typhoid fever or cholera is sufficient to set up specific morbid actions.

Second. A water supply not enough polluted to actually cause disease or be detected by the chemist may yet gradually and insidiously lower the vigor and cause persons who may subsequently drink polluted water to succumb.

Third. Where sewers must inevitably discharge into a body of water used for drinking, it should be strictly forbidden to discharge any excrement into the sewers.

On page 231, et seq. are given detailed accounts of certain water supplies and sewerage works in various cities, as follows: Boston

(p. 232), Haverhill (p. 248), Lynn (p. 249), Salem (p. 257), South Braintree (p. 261), Winchester (p. 262), Worcester (p. 264).

Well waters are discussed on page 268.

The new water supply of Springfield obtained from Ludlow Reservoir is referred to on p. 271 and mention is made of the occurrence of Anabaena (then erroneously called Nostoc) for which this supply has long been famous.

The ice supply of Pittsfield is described on p. 274.

The Disposal of Sewage. *Dr. C. F. Folsom*, pp. 276–401

This is a comprehensive discussion of current sewage disposal practice in Europe in 1875. A list of the principal topics treated will indicate its wide scope.

	pp.
The effect of filth on health	279
The influence of sewer gas on health	281
Water contaminated by sewage	283
Experience in England, a list of sanitary measures, with dates	285
The sewage question in England	289
Substitutes for the water-carriage system	299
Experience in France	302
Experience in Germany	307
Experience in Holland (" Liernur system ")	311
Experience in other countries	322
Processes for purifying sewage	323
Irrigation (a very interesting description)	334
Method of disposing of sewage in various European cities, with maps and estimates of cost	347

Summary and Recommendations. A report signed by the *State Board of Health*, and by *James P. Kirkwood, Frederick Winsor, and William Ripley Nichols*, pp. 402–408

The recommendations were as follows:

I. That no city or town shall be allowed to discharge sewage into any water-course or pond without first purifying it according to the best process at present known, and which consists in irrigation; provided, that this regulation do not apply to the discharge from sewers already built, unless water supplies be thereby polluted; and provided, also, that any intended discharge of sewage can be shown to be at such a point or points that no nuisance will arise from it.

II. That no sewage of any kind, whether purified or not, be allowed to enter any pond or stream used for domestic purposes.

III. That each water-basin should be regarded by itself in the preparation of plans of sewage and water supplies.

IV. That accurate topographical surveys be always made of all towns before introducing water supplies or sewers.

V. That steps should be taken, by special legislation, based upon investigations and recommendations of experts, to meet cases of serious annoyance arising from defective arrangements for the disposal of sewage.

VI. That irrigation be adopted, at first experimentally, in those places where some process of purification of sewage is necessary; and that cities and towns be authorized by law to take such land as may be necessary for that purpose.

VII. That every city or town of over four thousand inhabitants be required by law to appoint a board of health, the members of which shall be required not to hold any other offices in the government of their city or town.

Sanitary Hints. *Dr. Henry I. Bowditch*, pp. 409–422

Some experiences with typhoid-fever epidemics with some suggested practical remedies.

Defects in House-Drainage and Their Remedies.

Edward S. Philbrick, C.E., pp. 423–464

Some of the criticisms made in this article apply today, but for the most part the fixtures described long ago went out of use. The article is well written and well illustrated, but its value is chiefly historical.

Report on an Outbreak of Intestinal Disorder Attributable to the Contamination of Drinking Water by Means of Impure Ice.

Dr. Arthur H. Nichols, pp. 465–474

An outbreak of disease, often referred to as having been caused by decomposing organic matter, frozen into the ice, — a theory no longer tenable.

Report on the Registration of Prevalent Diseases.

Dr. Frank W. Draper, pp. 474–492

A suggested plan for getting weekly reports of prevalent diseases to be compiled and published by a "Bureau of Health Correspondence." The article contains charts showing variations in the occurrence of various diseases.

Health of Boston in 1875. *Dr. F. E. Oliver*, pp. 493–506

A statement as to the prevalence of certain diseases.

The Surface-drainage of the Metropolitan District.

Dr. C. W. Folsom, pp. 507–512

A description of certain fresh-water marshes and salt-water marshes.

The Health of Lowell, 1875. *Dr. F. Nickerson*, pp. 515–524

A statement as to the prevalence of certain contagious diseases.

1877

Eighth Annual Report

The Pollution of Streams, Disposal of Sewage, etc.

Dr. C. F. Folsom, with Chemical Examinations by *Professor William Ripley Nichols*, pp. 19–79

This paper recounts the results of a sanitary survey, with map, made by Mr. E. K. Clark, C.E., of the Nashua River Basin. Included in it (p. 48) is a report by Professor Nichols giving the results of analyses of water samples collected at various places. On page 68 there is a brief statement of the pollution of the Merrimack River. Then follows, on page 73, the text of an act passed in England the year before and known as the Rivers Pollution Prevention Act, 1876.

The Disposal of Sewage. *Dr. Charles F. Folsom*, pp. 80–113

This report alludes to the experiments made at the insane asylums at Concord, N. H., Augusta, Me., and Worcester, Mass., and the women's prison at Sherborn, and to recent experiences in England. On page 88 are given the opinions of experts and on page 90 the latest English government statistics. Then follow references to German (p. 104) and French (p. 105) experiences.

Effects of Bad Drainage on Health.

Dr. Charles F. Folsom, pp. 113–136

Interest in this paper lies in the fact that it makes mention of the controversies then arising in England between Wanklyn, Frankland and others. Professor Wanklyn held that the contagium of the water-borne diseases was of an albuminoid character and could be removed by filtration. Professor Frankland belongs to the "Purist" school, and condemned the use of river waters to which sewage had access, going so far as to recommend that the Thames supply of London be abandoned on the ground that even filtration would not sufficiently remove the "animal and other offensive matters." In this controversy both sides were partly right and partly wrong. The paper refers also to another controversy in Germany, Virchow holding that the level of the ground water did not always bear a relation to the occurrence of typhoid fever, and Pettenkofer holding to his old theory that "the chief agency in the spread of typhoid fever and cholera was the decomposition of organic matter in the soil from variations in the level of the ground water, allowing the virus to escape into the air."

On page 118 we find mention of *bacteria* and the controversy as to whether the germs of disease may arise *de novo* from filth.

Then follow several accounts of outbreaks of typhoid fever and their probable cause. One at Fort Cumberland was thought to be due to "sewage contaminated air," one at Uppingham to badly laid drains, and one at Eagley caused by watered milk. On page 124 is an account of the celebrated typhoid-fever epidemic at Lausen, Switzerland in 1872, with a statement as to the theory that it was caused by a "germ."

Under the caption "Prevention of Filth Diseases" the need of adequate sewerage is pointed out and on page 130 are given the regulations adopted at Frankfort, where W. Lindley was Chief Engineer. Dr. Buchanan's recommendations as to the use of the running trap, or house trap, are given on page 133.

Sewerage, its Advantages and Disadvantages, Construction and Maintenance. *E. S. Chesborough, C.E.*, pp. 137–167

A general paper by the celebrated engineer of Chicago who designed some of the earliest great sewerage systems in the United States. It treats the subject from the engineering standpoint, and is not of much interest to present day readers.

The Sanitary Condition of Lynn. *Dr. J. G. Pinkham*, pp. 169–230

A sanitary survey, apparently quite complete and containing one unique feature, — a table of death-rates by streets.

Registration of Deaths and Diseases.
Dr. Charles F. Folsom, pp. 231–271

A study of the accuracy of the returns in Massachusetts.

On page 258 is a history of the registration of deaths in Massachusetts and a statement as to the faults in existing law. On page 262 some amusing causes of death are given as "death caused by five doctors," "delicate from birth," "collocinphantum," "direars," "artry lung busted," etc.

The Growth of Children. *Dr. H. P. Bowditch*, Professor of Physiology, Harvard Medical School. pp. 273–323

An elaborate and very important statistical study of the height and weight of the school children of Boston, classified by age, sex, nationality, and occupation of parents. The data are given both by tables and diagrams and are very valuable for purposes of comparison with more recent studies. Comparisons at the time were made with European studies by Quetelet and others. This paper has long been regarded as a classic.

Disease of the Mind. *Dr. Charles F. Folsom*, pp. 325–433

An extended treatise of the general subject under ten headings as follows: 1. Early treatment of the Insane. 2. Pinel's reform and European progress. 3. English progress and Conolly. 4. American progress. 5. Modern methods of Less Restraint. 6. Responsibility for crime and definitions of insanity. 7. Massachusetts statistics and asylums accommodation. 8. Supervision by the state. 9. Certain asylum needs. 10. Medical education.

1878

Ninth Annual Report

Drainage and Health; Sewerage; and the Pollution of Streams, report by the Board. pp. 1–80

The first sixty-six pages of this report give the results of a study of the stream pollutions of the Hoosac and Housatonic rivers by Mr. E. K. Clark, C.E., and Professor William Ripley Nichols.

As a result of a three-years study of stream pollution the Board recommended the passage of a bill establishing a Rivers Pollution Commission. The reasons for this are given on page 66, and the proposed law on page 73. This was entitled "A bill to prevent the pollution of streams and for other purposes." On page 77 will be found certain other recommendations of the board in regard to privies, cesspools, earth closets and sewerage systems.

Cottage Hospitals. *Dr. J. F. A. Adams*, pp. 81–95

A paper advocating the cottage hospital and showing sketches and floor-plans.

Dangers from Color Blindness. *Dr. B. Joy Jeffries*, pp. 97–136

A good discussion of the subject emphasizing the dangers to the community from the employment of color blind persons in certain positions, especially on railroads, where a discernment of color is necessary. Contains a long bibliography.

The Filtration of Potable Water.
Professor William Ripley Nichols, pp. 137–226

This is one of the early American classics on the subject of filtration written by a master mind before the days of bacteriology. A portion of the report is reprinted on page 26, in order that the student of today may see the ideas of the leading expert on the chemistry of water more than thirty-five years ago.

The report is divided into three parts, treating respectively: I. Artificial filtration on a large scale (p. 141); II. Natural filtration (p. 175); III. Household filtration.

The discussion of sand filtration was naturally based largely on English experience, but interesting references are made to the early American works at Hudson and Poughkeepsie, Columbus and Toledo, Springfield and Lowell. We find in this report also one of the first important discussions of the algae problem in reservoirs. Filter experiments made at Springfield in 1877, using the cement-lined pipes then common, are mentioned and analyses given.

Much of the material in this paper was afterwards published in his well known volume " Water Supply," published in 1883, but still read by students.

Sanitation of Public Schools. *Dr. D. F. Lincoln*, pp. 227–252

This paper concerns itself with the site, construction, sewerage, drainage and ventilation of schoolhouses. Like many other papers of that period it was based on data obtained from circular letters. The replies received from persons outside of Boston, scattered through nearly one hundred cities and towns, and from the Boston school authorities, represented about one-sixth of the school population of the state, and serve to give a good idea of the conditions existing at that date. Then, as now, the ventilation problem was one attracting attention.

Scarlet Fever. *Dr. A. H. Johnson*, pp. 253–327

Statistics of the disease, sources and methods of contagion, the influence of insanitary surroundings are described and the following conclusions drawn: " The contagion is particulate, capable of exceedingly minute subdivision, has a very light specific gravity, is very tenacious, is not volatile." Evidently the author accepted some of the newer ideas in regard to the germ theory then beginning to gain ground. Lastly, follow methods of disinfection, and the function of hospitals in controlling scarlet-fever.

Report on the Sanitary Condition of Cambridge.
Dr. Edward R. Cogswell, pp. 329–374

A fairly complete survey of the sanitary conditions in 1878, taking up the natural conditions of the city, make-up of the population, certain artificial conditions (water supply, sewerage, low lands, house drainage, etc.), vital statistics, prevailing diseases, and comparisons of health of different districts. These matters are of considerable local interest, especially the analyses of the Fresh Pond water which go back to 1872.

1879

Tenth Annual Report

An Asylum, or "Hospital Home." *Dr. T. S. Clouston*, pp. 1–32

A detailed description of the general principles of hospital construction, with suggested plans.

The Growth of Children. *Dr. H. P. Bowditch*, pp. 33–62

A continuation of the report on the same subject published in 1877 (8th An. Report, pp. 273–323). This second paper discusses the relation between growth of children in Boston schools and occupation of parents.

A description is given of the anthropometrical methods used.

Physical Education and Hygiene in Amherst College.
Professor Edward Hitchcock, pp. 63–72

An account of the manner in which the physical condition of the students was being looked after.

Coal-Gas from Heating Apparatus. *Dr. Frederick Winsor*, pp. 73–84

Dangers from poisoning by carbonic oxide due to escape of coal-gas.

Common Defects in House-Drains.
Mr. Eliot C. Clarke, C.E., pp. 85–109

A very interesting description of some of the old sewers. Profusely illustrated with sketches.

Evidence in Case of The City of Cambridge *vs.* **Niles Brothers** before State Board of Health. pp. 111–227

This case resulted from a complaint made by the City of Cambridge that the establishment of a proposed slaughterhouse by Niles Brothers on the catchment area of Fresh Pond would impair the quality of the public water supply of that city.

The testimony and the arguments (pp. 208 and 220) give an interesting picture of the conception of the day as to what constitutes the pollution of a water supply.

The case was not closed this year and references to it are given in subsequent reports of the Board.

A Contribution to the Study of Ventilation. *Dr. Edward S. Wood,* Professor of Chemistry, Harvard Medical School, pp. 231–248

Results of observations of temperature, humidity, air currents, etc., at the Boston City Hospital. Also tests for carbonic acid. Diagrams showing air currents at the flow level and at heights of 3, 6, 9, 12, 15 and 18 feet above the floor around the hospital beds. Apparently a very careful study of the subject.

1879

Eleventh Report. For Six Months ending June 30, 1879

No scientific papers were published in this report.

General Index. *Dr. Francis H. Brown,* pp. 45–184

A complete alphabetical index of volumes I to XI inclusive.

1879 Supplement

Supplement to the First Annual Report of the State Board of Health, Lunacy and Charity

Pollution of the Westfield and Merrimack Rivers. *Dr. Charles F. Folsom,* pp. 1–18

A sanitary survey made in continuation of the investigation begun by Mr. J. P. Kirkwood in 1875.

Pollution of a Brook by Sulphuric Acid. *Professor William Ripley Nichols,* pp. 19–21

An account of an accidental discharge of sulphuric acid into a tributary of Mystic Pond, by reason of a fire in chemical works.

Trichinae in Relation to the Public Health. *Dr. F. S. Billings,* pp. 23–54

A description of the organism, its method of entering the body, dangers from swine, and methods of prevention are all described.

Adulteration of Some Staple Groceries. *Mrs. Ellen H. Richards,* Instructor in Chemistry, Woman's Laboratory, Massachusetts Institute of Technology, pp. 55–65

A general report as to the adulteration of staple groceries. Contains few analyses.

The Water Supply of Cambridge. *Dr. Edward S. Woods,* pp. 67–94

An important report on the local pollution of the catchment area of Fresh Pond. One of the water analyses quoted dates back to 1853 (p. 85). Many analyses given for years 1875–79.

Observations on Fresh Pond, Cambridge. *Professor William Ripley Nichols,* pp. 95–107

" A contribution to the knowledge of stored waters," containing a diagram showing seasonal fluctuations in temperature of water and water analyses, — an early study of stagnation.

Examination of Mystic River, with Remarks on Frankland's Method of Water Analyses. *Professor William Ripley Nichols*, pp. 111–120

This is an interesting discussion of methods of water analysis. Few students of today know of the controversies of Frankland and Wanklyn as to the respective merits of the "carbon-nitrogen ratio," and the "albuminoid and free ammonia method." In this controversy Nichols sided with Wanklyn.

Algae Observed in Storage Basin No. 3 of the Boston Water Supply in 1879. *Alphonse Ftely*, Resident Engineer, Boston Water Works, pp. 121–128

A study of water temperatures and algae growths in Basin No. 3, with reference to a small experimental sand filter. Diagram given.

On Some Impurities of Drinking Water Caused by Vegetable Growths. *Professor W. G. Farlow*, Harvard University, pp. 129–152

The first report relating to algae made to the Board of Health, which contains botanical descriptions and illustrations of blue-green algae and other forms.

A portion of this article is reprinted on another page (p. 39).

The Effect on Health of Certain Algae in the Mystic Water Supply. pp. 153–160

A series of replies from physicians as to the use of Mystic Water. No present value.

The Drainage of Summer Hotels and Country Boarding Houses. *Mr. Ernest W. Bowditch, C.E.*, pp. 161–198

An interesting discussion of the pollution of country wells, with many diagrams. Very little present value.

Suggestions on Sewerage. *Mr. Eliot C. Clarke, C.E.*, pp. 199–238

A discussion of the engineering principles involved in sewer construction, starting with soil borings and float experiments and concluding with descriptions of sewers, sewer sections, etc. A valuable paper for present day students to consult, as many reasons for failures are given.

1880 Supplement

Supplement to the Second Annual Report of the State Board of Health, Lunacy and Charity

The Pollution of the Deerfield and Millers Rivers. *Mr. W. E. Hoyt, C.E.*, pp. 1–21

A continuation of the sanitary surveys of the waters of the state.

The Separate System of Sewerage. *Mr. Eliot C. Clarke, C.E.*, pp. 23–44

An excellent résumé of the principles of the separate system of sewerage, then coming into notice, with simple illustrations.

Intermittent Fever in Massachusetts.
Dr. J. F. A. Adams, pp. 45–108

Reference is made to Dr. Oliver Wendell Holmes' article published in 1836, and an account given of the recurrence of the disease (Malaria) in New England. The true medium of the spread of the disease was then unknown, and various theories, all erroneous, were being discussed.

School-house Sanitation. *Mr. Ernest C. Bowditch, C.E.*, pp. 109–147

A sanitary survey of a number of schools, some of them broader in scope than the buildings themselves, involving studies of environment, the preparation of sanitary maps, etc.

Epidemic of Cholera Morbus in Adams, in June, 1880.
Dr. J. F. A. Adams, pp. 149–163

Supposed to be caused by the public water supply.

Sanitary Condition of Holyoke. *E. W. Bowditch, C.E.*, pp. 167–176

Interesting chiefly for the diagrams showing the relative sanitary conditions in the different wards in the city.

Neglect of Vaccination. *Dr. Z. B. Adams*, pp. 177–194

A discussion of the value of vaccination and a plan for making it more generally applicable.

1881

Third Annual Report of the State Board of Health, Lunacy and Charity

(No supplement to this report was issued this year, but merely a special sanitary appendix, which contained the following papers).

Circular from the Health Department of the State Board of Health, Lunacy and Charity on Drainage, etc. pp. 107–116

A circular relating to cesspools and drains. Of no present value.

The Worcester Sewage and the Blackstone River. *Dr. Charles F. Folsom, Joseph P. Davis, C.E., Dr. Henry P. Walcott*, pp. 117–133

A report of a committee containing a comparison of various possible methods of sewage treatment and recommending intermittent downward filtration upon an area so large that the land may be used for growing crops.

Project for the Purification of the Sewage of Worcester.
George E. Waring, Jr., pp. 134–146

Colonel Waring, acting for the town of Millbury, which is on the river below Worcester, presented a report recommending a separate system of sewers, screening, subsidence, aëration, a flow through ten miles of ditches at a low velocity and application to one hundred and twenty-six acres of wooded swamp land. Estimates of cost were made by Phineas Ball, S. C. Heald, and Amos Pike.

Report upon Metropolitan Drainage.
E. S. Chesborough, C.E., Dr. Henry P. Walcott, Dr. Charles F. Folsom, A. W. Boardman, C.E., and Dr. Azel Ames, Jr., pp. 147–159

An important document, being the report of a legislative committee which laid the foundations for the present metropolitan system of sewers.

The conclusion of the report was as follows: That a metropolitan district system be recommended, which we believe should include the entire territory naturally draining into Boston inner harbor; a system of intercepting sewers and branches to be supplemented, where found advisable, by irrigation or intermittent downward filtration works; and a Board of Commissioners to plan, carry out, and manage the works, and to make the apportionment of taxes necessary to pay for the same, subject to the supervision of the Governor and Council. We believe that the system recommended would preserve, so far as is practicable by general sewerage, the purity of the water supply of the cities included in this district.

1882 Supplement

Supplement to the Fourth Annual Report of the State Board of Health, Lunacy and Charity

Adulteration of Food. *Professor S. P. Sharples*, pp. 1–86

An extensive treatment of the methods, chemical and microscopical, used to detect adulterations in many kinds of food, with a bibliography. A valuable paper for students of food analysis, but of no present interest to the general reader.

Our Eyes and Our Industries. *Dr. B. Joy Jeffries*, pp. 87–117

A general discussion emphasizing the dangers of eye-strain and defective vision, and urging that greater attention be given to the care of the eyes.

Leprosy as Related to Public Health.
Dr. Samuel W. Abbott, pp. 119–139

A general discussion.

Reports of the Water Boards, Commissioners, and Companies of Massachusetts. pp. 141–223

A compilation of water works statistics upon a uniform basis in accordance with an act of legislature passed in 1879 requiring triennial returns. The questionnaire used is given on page 146, a summary of the statistics on page 212.

The Sewerage of Nahant. pp. 227–248

A plan for a sewerage system. It contains sketches of various devices used for cleaning sewers, such as mirrors, hinged rakes, etc.

1883 Supplement

Supplement to the Fifth Annual Report of the State Board of Health, Lunacy and Charity

Tubular Wells and Wells in General as a Source of Water Supply for Domestic Purposes. *J. C. Hoadley, C.E.*, pp. 1–36

A paper describing the geology and hydraulics of underground waters, with an account of experiments made at Malden, Mass., on the lines of flow and the circles of influence around a driven well. References are also made to the well supply of Berlin.

The Sanitary Condition of Somerville. *Dr. John F. Couch.*

An account of the sanitary conditions of Somerville as found by the local board of health.

Trichinosis. pp. 177–189

A summary of recent investigations of the subject.

Certain Questions Relative to the Sewerage and Sanitary Condition of Nantucket. pp. 191–209

Containing a report by Ernest C. Bowditch, C.E.

Arsenic as a Domestic Poison.
Professor Edward S. Wood, pp. 211–267

An extended study of the prevalence of arsenic in articles intended for domestic use, the form in which it is present, its danger to health and measures of prevention. In particular a study was made of wall paper, actual samples of which are to be found in the report. An important contribution to a subject, not now considered to be of great moment.

1884 Supplement

Supplement to the Sixth Annual Report of the State Board of Health, Lunacy and Charity

Sanitary Conditions of School Buildings in Massachusetts.
Dr. D. F. Lincoln, pp. 1–94

Results of a detailed study of school buildings in twenty-five cities and towns, illustrated by twenty-two plans.

The Relation of Illuminating Gas to Public Health.
Dr. Samuel W. Abbott, pp. 247–274

This paper treats of the composition of illuminating gas, the dangerous character of carbonic oxide, and remedies for the prevention of accidents. There are several tables showing the numbers of deaths from illuminating gas in different cities.

A Study of the Relative Poisonous Effects of Coal and Water Gas.
Professor William T. Sedgwick and Professor William Ripley Nichols, pp. 275–313

An important contribution to the subject embodying the results of experiments upon animals. Parts of this paper are reprinted on page 47.

Epidemic Cholera. *Dr. Samuel W. Abbott*, pp. 315–340

A statistical study of the occurrence of cholera in Massachusetts from 1847 to 1884, and an account of the epidemic in Boston in 1849. Reference is made to Koch's discovery of the comma-bacillus, the cholera germ in July, 1884. This is one of the earliest references to the modern germ theory of disease to be found in the reports of the Board.

Rules are given for the prevention of the disease.

Disinfection. pp. 341–354

Reprint of a report on the subject made by a committee of the American Public Health Association.

Sanitary Relations of Taunton. *Dr. E. V. Jones*, pp. 335–369

A brief sanitary survey. Unimportant.

1885 Supplement

Supplement to the Seventh Annual Report of the State Board of Health, Lunacy and Charity

Malaria in Eastern Massachusetts. *Dr. Z. B. Adams*, pp. 1–25

Description of an epidemic of malaria in Framingham in 1885, and a discussion of prevailing ideas as to the cause of the disease. A map is given showing standing water and its relation to the occurrence of the disease.

An interesting article in the light of modern knowledge on the subject.

Disposal of Sewage at the Massachusetts Reformatory, at Concord. *William Wheeler, C.E.*, pp. 193–208

Description of the project proposed, which included tankage, sludge pits, and broad irrigation.

Case of Lead Poisoning. *Dr. Frederick W. Jones*, pp. 209–213

A case at South Ashburnham said to be due to use of water delivered through lead pipe.

Reports of the Water Boards, Commissioners, and Companies of Massachusetts. pp. 215–282

Third triennial report of statistics of Water Works.

General Index of the Health Supplements to the Annual Reports of the State Board of Health, Lunacy and Charity. pp. 283–348

General Index of Chapters and Other Material Relative to Public Health Contained in the Seven Annual Reports of the Board. pp. 349–357

1886

Eighteenth Annual Report

Transmission of Infectious Diseases through the Medium of Rags.
Dr. Charles F. Withington, pp. 1–69

The following section headings will give an idea of the scope of this paper: 1. Introductory. 2. Commercial and Industrial. 3. History of Sanitary Regulations. 4. The Recorded Evidence as to the carrying of Disease by Rags. 5. Personal Investigations.

The author concluded that a few diseases, such as smallpox, could be conveyed by rags, that on the whole, not many diseases were thus spread, that domestic rags were more dangerous than foreign rags, and that in any event seasonal precautions should be taken.

Manual for the Use of Boards of Health of Massachusetts.
pp. 233–322

Contains a codified list of the statutes relating to the Public Health and the Decisions of the Supreme Court of Massachusetts relating to the same.

Rules and Regulations Relative to the Inspection of Food and Analysis of Food and Drugs. pp. 323–327

1887

Nineteenth Annual Report

Sewage Disposal at Medfield, Mass.
Frederick Brooks, C.E., pp. 97–110

Treatment of trade wastes at a straw factory by application to land.

Report on Oleomargarine. pp. 197–289

A general view of the subject, inspection of establishments where oleomargarine was being made, protection afforded by laws, national, state, and local.

The Healthfulness of Oleomargarine as an Article of Food.
Dr. Elliott G. Brackett, pp. 248–279

A comprehensive discussion of the scientific aspects of the subject. The general conclusions were favorable to the use of oleomargarine as food, but as a food distinct from butter and made recognizable.

The Ventilation of Schoolrooms Heated by Stoves.
Dr. J. D. Pinkham, pp. 313–361

Contains diagrams of many schoolrooms in Lynn, and results of ventilation tests. The latter included temperature, humidity, and carbonic acid determinations made at different hours through the day. The results are shown by diagrams.

1888

Twentieth Annual Report

Trichinae in Swine. *Professor E. L. Mark* of Harvard University, pp. 111–134

A paper describing the results of a study of the cause of infection of swine with Trichinae. It is of interest in that the most probable causes are said to be uncooked garbage containing swine flesh and rats. Of two the former is regarded as the more important.

The Sale and Use of Opium in Massachusetts. *Dr. B. H. Hartwell,* pp. 135–158

A report of an investigation undertaken in compliance with a legislative act passed in 1888 after there had been an exposé of opium joints in Boston. Data are given for the imports of opium, together with the opinions of many physicians as to the use of the drug, and the forms in which it appears.

The Number and Distribution of Micro-organisms in the Air of the Boston City Hospital. *Greenleaf R. Tucker,* pp. 159–229

This was one of the earliest bacteriological investigations published by the State Board of Health. It is interesting not only for the results obtained, but from the use of the "aërobioscope," devised in conjunction with Professor William T. Sedgwick.

An abstract of this report is given on page 65.

Returns of Water Boards and Water Companies of Massachusetts. pp. 301–311

A summary of statistics in continuation of previous reports.

1889

Twenty-first Annual Report

Report of Investigations of the State Board of Health upon the Pollution of Ice Supplies. pp. 143–223

This investigation was made in compliance with a legislative act (Chap. 84 of the Resolves of 1888). It was a comprehensive study of the subject, with the latest and best analytical methods used. The tables of water and ice analyses (pp. 155–223) are given in a form which is still used and in addition to the determinations made several years before we now find statements as to turbidity and sediment, a numerical statement of color, and quantitative studies of algae, fungi, animal forms and bacteria.

This report, except the tables, is printed in full on pages 77–85.

Intermittent Fever in Massachusetts. *Dr. C. H. Cook,* pp. 245–284

A study of the occurrence of malaria in the state, based on the replies to circulars received from the physicians of the state.

Physique of Women in Massachusetts.

Professor H. P. Bowditch, pp. 285–304

A continuation of the author's investigation on the growth of children. Among the data collected were records of height and weight, rates of sitting height to total height (average = 53 per cent), stretch of arms in per cent of total height (average = 100.54 per cent), etc.

This paper is especially valuable for the statistical methods used. The "percentile grades" are employed to illustrate certain facts.

The Influenza Epidemic of 1889–90.

Dr. Samuel W. Abbott, pp. 305–383

This paper contains a history of the disease and the prevailing opinions as to its cause, as well as a statistical study of the epidemic in Massachusetts.

Apparently it started in Russia in October, 1889. In November, it was prevalent in Berlin, Vienna and Paris; in December, in London. It appeared in New York about December 20, and in Massachusetts soon afterwards. It was a very severe epidemic, the death-rate for the state from this cause being estimated (1889–90) as 120 per 100,000. About 25 per cent of the population of the state was attacked (there were 850,000 cases). Bronchitis and pneumonia followed in the train of "la grippe." The conclusion was that while aërial transmission may have been a factor a more important factor was "human intercourse." This today would be called "contact."

The paper is of great value, but is too long to be reproduced.

An Inquiry Relative to the Conditions which Attended an Unusually High Rate of Mortality in Lawrence in 1889, with Special Reference to Diphtheria. *Dr. Samuel W. Abbott*, pp. 387–415

The chief interest in this paper today lies in the mortality statistics of the city, from 1848 to 1889, given on page 395, and the remarks appended to the table. Apparently the death-rates as given in the Registration Reports were computed on the basis of census populations, no estimates being made for the populations in the intermediate years. A table of corrected figures is therefore given. The paper should be consulted by students of water filtration in connection with the possible influence of filtration on the general death-rate. Lawrence, like other cities of the state, suffered from influenza in 1889, which was just before the water filter was installed.

Reference is made to the various insanitary conditions existing in the city.

1890

Twenty-second Annual Report

Suggestions as to the Selection of Sources of Water Supply.

Frederic P. Stearns, pp. 333–371

This paper relates especially to the quantity of water to be obtained from catchment areas under various circumstances. It covers both surface waters and ground waters. It outlines the general principles used in balancing rainfall, stream-flow, storage, evaporation, and such factors and because of its importance is reprinted in part on page 106.

The topics discussed are as follows: Quantity of Surface Water (p. 336), Quantity of Ground Water (p. 352), Quality of Surface Water (p. 364), Quality of Ground Water (p. 366).

The Growth of Children, Studied by Galton's Method of Percentile Grades. *Dr. H. P. Bowditch*, pp. 477–522

This is an application of a new statistical method to the data of the growth of children obtained by the author in 1877.

A portion of the paper, without the tables and with only a few of the many diagrams, is given on page 119.

Typhoid Fever in its Relation to Water Supplies.
Hiram F. Mills, C.E., pp. 523–543

Historically this is an important paper as it shows the relation between the occurrence of typhoid fever and polluted water. It relates the events that led up to the improvements of the water supplies of Lowell and Lawrence.

An abstract of this paper is given on page 131.

1890

Part I of Report on Water Supply and Sewerage

The Chemical Examination of Waters and the Interpretation of Analyses. *Dr. Thomas M. Drown*, Chemist of the Board, pp. 516–578

The first section of this paper describes the methods of water analyses under the following heads: Collection of samples (p. 519), Free and albuminoid ammonia (p. 523), Organic Nitrogen (p. 526), Nitrogen as Nitrites (p. 527), Nitrogen as Nitrates (p. 528), Chlorine (p. 528), Residue on Evaporation and Loss on Ignition (p. 529), Hardness (p. 531), Odor (p. 531), Color (p. 531), Turbidity and Sediment (p. 532).

In the second section the principles of the interpretation of water analyses are discussed, first in a general way and then as related to each determination. The general principles are set forth at length. The paper should be consulted for these details, but a more condensed report, published in the 1892 report, is given in full on page 218.

The topics in the remainder of the paper were these:—Normal and polluted surface waters (p. 539), chlorine (p. 542), albuminoid ammonia (p. 545), free ammonia (p. 550), nitrogen as nitrites and nitrates (p. 556), residue on evaporation (p. 564), turbidity and sediment (p. 566), color (p. 566), odor (p. 567), ground waters (p. 569).

Report upon the Organisms, Excepting the Bacteria, Found in the Waters of the State, July, 1887 to June, 1889.

G. H. Parker, Biologist, pp. 579–620

This paper is interesting historically as being the first attempt to show by quantitative methods the relation between microscopic organisms and odors in drinking waters. The methods of enumeration were crude, but the general conclusions were nevertheless sound. The following topics were discussed: Methods of examination (p. 583), The relation of organisms and odors in Natural Waters (p. 583), Organisms found in the Water supplied to Boston, Charlestown and Cambridge (p. 587), Seasonal Distribution of Organisms (p. 597), Distribution of Organisms in Waters variously situated (p. 601), Purification of Water rendered Impure by Organic Growths (p. 609), Growth of Sponges in Water Supplies (p. 614).

Summary of Water Supply Statistics, also Records of Rainfall, Flow of Streams, and Temperatures of Air and Water.

Frederic P. Stearns, C.E., pp. 621–676

The first portion of this report comprises statistics of rainfall, etc., in connection of previous records. On page 660 temperatures of the water in various reservoirs are given, on page 663 there is a comparison of air and water temperatures at different seasons, and on page 665 a detailed study of the temperatures of the water in Jamaica Pond at different depths. On page 671 there is a section on the temperature of ground waters and on page 673 a record of the temperature of the water as delivered to consumers.

A Classification of the Drinking Waters of the State. pp. 677–716

This is a most important paper: it shows the application of Dr. Drown's principles of the interpretation of chemical analyses to the water supplies of the state.

The use of the normal chlorine map is described. (This part of the report is reprinted on page 139.)

The surface waters of the state are grouped first according to the excess of chlorine above the normal and second according to the albuminoid ammonia. The relation between these substances and the other items of the analyses to the known conditions as to the pollution of the watersheds is then shown.

The ground waters are then considered and grouped not only according to excess of chlorine, but to the excess of total nitrogen above a certain average quantity (namely 0.221 parts per million) found in the unpolluted ground waters. The ratio between the chlorine excess and the nitrogen excess is also computed.

The paper is one which may very profitably be consulted by students of water analysis. Unfortunately it is too long to be reproduced in the present volume.

Discussion of Special Topics Relating to the Quality of Public Water Supplies. *Frederic P. Stearns and Dr. Thomas M. Drown,* pp. 717–782

This paper is virtually a study of the storage of water and the influence of storage on quality. The influence of storage in open reservoirs on surface water is discussed on page 720, and that on ground waters on page 725. Then follows a section on the storage of ground waters in open reservoirs and tanks.

On page 734 the effect of long storage in large reservoirs or ponds is treated, color and organic matter receiving particular attention.

The section on the effect of storage upon the taste and odor of surface waters is reprinted on page 144.

On page 749 begins a discussion of deep ponds, with an elaborate account of stagnation phenomena. The conditions in Jamaica Pond were described and illustrated by tables and diagrams.

Interesting characters of certain water supplies of the state are given on page 767, *et seq.* and finally on page 773, there is a section on the filtration of water in filter galleries and an account of troubles with Crenothrix.

The Pollution and Self-Purification of Streams. *Frederic P. Stearns*, pp. 783–802

The first part of this paper is printed on page 156.

The second part relates to the changes in the condition of certain rivers, such as the Blackstone and Merrimack above and below some of the more important points of pollution.

Index. pp. 803–857

Attention is called to this as an unusually complete index.

1890

Part II of Report on Water Supply and Sewerage

Filtration of Sewage and Water. *Hiram F. Mills, C.E.*, pp. 1–704

Without question this is the most important paper on the purification of sewage and water ever published in the United States. It describes the original investigations made at the Lawrence Experimental Station. On account of its length a part only is reprinted (p. 172).

After describing the experimental plant and the object of the work (p. 5) an account of the methods of recording the analyses and interpreting the results is given. Then follows an elaborate discussion of the results obtained from the various tanks, with elaborate tables. As an example a partial index is given of the headings which relate to one tank, i. e., Filter Tank No. 1, started January 10, 1888, and still in operation (1915).

Physical characteristics	pp. 14
First application of sewage	15
Beginning of nitrification	18
Progress of sewage through sand indicated by chlorine	18
Effect of frost upon the effluent	21
First effects of nitrification	22
General results of filtration through the first winter	22
Purification by nitrification continued	23
Effect of increased quantity	23
Condition of the surface	24
Regimen essential to success	25
Nitrification in winter	27
Increased nitrification in the spring	29
More complete nitrification the second year	29
Relation of suspended matter to matter in solution	34
Mineral constituents of sewage and effluents	37
Comparison of winter result with that of year	38
Comparison of results of two years	39
Storing of nitrogenous matter in sand	40
Removal of stored nitrogen by nitrification	43
Quality of effluent at different hours of the day	45
Microscopical examinations of effluent	47
Bacteria in effluent	51
Proof that bacteria came down through the sand of this tank	56
The greatest number of bacteria came through with the sewage first applied after an intermission	57
General conclusions in regard to management	58
Bacteria found in sand at different depths	59

More than five hundred pages of the report are devoted to similar records of the other tanks, and to the tables and diagrams.

On page 577 is a summary of the results reprinted in part on page 173.

The experiments on the intermittent filtration of water are described on pages 601–665. These are of less interest than the experiments on sewage purification.

On pages 666–669 is an account of experiments on purification of sewage by chemical precipitation by Allen Hazen, Chemist in charge.

Pages 670–704 contain a record of additional results of filtration of sewage and water obtained in 1890.

Rainfall and evaporation records are given on pages 702–704.

A Report of the Chemical Work of the Lawrence Experiment Station, Including Methods of Analysis and Some Investigations of the Process of Nitrification.

Dr. Thomas M. Drown and Allen Hazen, pp. 705–734

Critical studies of the methods of determining nitrogen in its various forms, total residue and loss on ignition, chlorine, oxygen consumed, dissolved oxygen, alkalinity are given.

Then follows (p. 724) a study of nitrogen in filters, nitrification and the factors which influence it. The following is a résumé of the results.

In the foregoing comparisons and experiment, showing the effect of the storage of surface and ground waters in distributing reservoirs and tanks, we find that surface waters may be so stored without deteriorating in quality; and at one place (Lawrence) there is a marked improvement in the quality of the water, owing to the storage and subsequent passage through pipes to the consumers. The state does not contain any good examples of surface waters stored in covered reservoirs; but it seems probable that, under such conditions, water containing many algae might become worse owing to their death when deprived of light.

With ground waters the case is entirely different, as the water at the source is free from organisms, and it only needs to be kept so in order to be delivered to the consumer in satisfactory condition. The comparisons show that the ground water does not deteriorate when the light is excluded;[1] but that it does when exposed to the light, except in some instances where the water is stored in iron tanks which receive only a limited amount of light. It seems hardly safe, however, in view of the unfavorable effect of storing ground water in the high-service tank at Brookline, to rely upon these apparent exceptions to the rule; and it is better in all cases to keep a ground water in the dark.

Report of Experiments upon the Chemical Precipitation of Sewage.
Allen Hazen, pp. 735–791

This paper gives the results of a series of carefully prepared experiments. A part of the paper is printed on page 188.

A Report of the Biological Work of the Lawrence Experiment Station.
Professor William T. Sedgwick, pp. 793–862

This report comprised the following sections:

Micro-organisms pp. 796
Methods of microscopical analysis 799
New methods (Sedgwick-Rafter Method) 803
Methods of bacteriological analysis 811
The microscopical organisms in sewage 815
The bacterial organisms in sewage 819
Certain species of bacteria in sewage (Jordan) 821
Biological phenomena observed in the intermittent filtration of sewage 845
Variations in bacterial composition of certain effluents after an application of sewage 849
The passage of bacteria through certain sand filters 850
Effect of application of bouillon, peptone, salt, sugar, ammonium chloride, and sulphuric acid upon the bacterial discharge from the filters 855

[1] These statements are not true of imperfectly filtered surface waters, as they are frequently affected by growth of Crenothrix which thrives better in the dark than in the light.

Micro-organisms in the filtration of water and in the chemical purification of sewage pp. 859
Biological aspects of the theory of intermittent filtration 859

Investigations upon Nitrogen and the Nitrifying Organism.
Edwin O. Jordan and Mrs. Ellen H. Richards, pp. 863–881

An important bacteriological study incident to the main work at Lawrence.

Index. pp. 885–910

Attention is called to the complete index.

1891

Twenty-third Annual Report

Examination of Spring Waters. pp. 351–369

A report upon the quality of the spring waters publicly sold in the state. Each spring is described. Analyses are given and the springs are grouped according to the excess of chlorine above the normal.

On the Amount of Dissolved Oxygen Contained in Waters of Ponds and Reservoirs at Different Depths.
Dr. Thomas M. Drown, pp. 371–381

A study of stagnation in Jamaica Pond, Lake Cochituate and elsewhere. The data are valuable.

The Effect of the Aëration of Natural Waters.
Dr. Thomas M. Drown, pp. 383–394

A series of laboratory experiments from which the following conclusions were drawn:

1. The oxidation of organic matter in water is not hastened by vigorous agitation with air or by air under pressure.

2. The aëration of water may serve a useful purpose, by preventing stagnation, by preventing the excessive growth of algae, by removing from water disagreeable gases, and by the oxidation of iron in solution.

The Microscopical Examination of Water.
Gary N. Calkins, pp. 395–421

A description of the Sedgwick-Rafter method with a discussion of sources of error.

The Differentiation of the Bacillus of Typhoid Fever.
George W. Fuller, pp. 635–644

A bacteriological investigation from which the following conclusions, important at the time, were drawn:

1. After prolonged investigation, it has been found that it is possible to separate the bacillus of typhoid fever from all other bacteria hitherto encountered in the water of the Merrimack River.

2. The potato method of differentiation is for this organism of no diagnostic value.

3. The three tests which have been found to be highly characteristic of the bacillus of typhoid fever are (after non-liquefaction): (1) non-coagulation of milk; (2) non-formation, or formation of a very slight amount, of acid in milk; (3) production of a turbidity, without gas, in the Smith test.

On Uroglena. *Gary N. Calkins*, pp. 645–657

A carefully made and valuable study of an organism that has caused much trouble in Massachusetts water supply. The article is illustrated with three beautifully colored plates.

On the Geographical Distribution of Certain Causes of Death in Massachusetts. *Dr. Samuel W. Abbott*, pp. 757–874

An elaborate and very thorough study of the distribution of measles, scarlet fever, diphtheria, smallpox, typhoid fever, cholera infantum, phthisis and pneumonia.

The following important topics are considered:

1. Population of the state, its distribution and density by counties (pp. 765 and 769).
2. Vital statistics of the state (p. 768).
3. General death-rates of counties, cities, and towns (p. 771).
4. Statistics of measles (p. 780).
5. " " scarlet fever (p. 789).
6. " " diphtheria and croup (p. 798).
7. " " smallpox (p. 81c).
8. " " typhoid fever (p. 819).
9. " " cholera infantum (p. 83c).
10. " " consumption (p. 844).
11. " " pneumonia (p. 855).
12. Conclusions (p. 866).

The influence of the following conditions were considered:

1. Natural Conditions. — Such as the conditions of climate (temperature, rainfall, humidity, prevailing winds), elevation above sea level, distance from sea, character of the soil (dryness of moisture).

2. Artificial Conditions. — Density of the population, purity of water supply, efficiency of sewerage system and sewage disposal, sufficiency and purity of food supply, and especially of milk, protection from accidents, management and prevention of infectious diseases, freedom of intercommunication, especially among children, efficiency of municipal sanitation.

3. Character of the Population. — Race and nationality, distribution by sexes and ages, occupation, education, social condition as to poverty or wealth, habits, size of families, etc.

The paper is illustrated by maps. The tables are given in details.

It may be well taken as a model for students to follow in studying vital statistics.

1892

Twenty-fourth Annual Report

The Interpretation of Water Analyses.
Dr. Thomas M. Drown, pp. 317–330

This is one of the classic papers on the subject. It is printed in full on page 218, *et seq.*

On the Amount of Dissolved Oxygen Contained in the Water of Ponds and Reservoirs at Different Depths in Winter, Under the Ice. *Dr. Thomas M. Drown*, pp. 331–342

A continuation of the study of stagnation begun the previous year. The data are valuable.

On the Mineral Contents of Some Natural Waters in Massachusetts.
Dr. Thomas M. Drown, pp. 343–351

Analyses are given for various ground waters and waters naturally filtered. The data are valuable.

A Study of Odors Observed in the Drinking Waters of Massachusetts.
Gary N. Calkins, pp. 353–379

A statistical study of the causes of the odors of the drinking waters of the state, with special reference to the effect of microscopic organisms. The following conclusions were drawn:

We have now arrived at certain definite theories concerning the causes of odors in drinking waters, namely, that they may be produced by the putrefactive decomposition of the body plasm through the agency of bacteria; by the excretion of certain products of growth, or by the liberation of products by the physical disintegration of the body or breaking down of the enclosing cell walls. These three causes give rise to three classes of odors, as follows: (1) odors of chemical or putrefactive decomposition, (2) odors of growth and (3) odors of physical disintegration.

In regard to the specific cause of an odor of growth or disintegration, all evidence seems to point to the importance of oil globules, it being assumed that these are odorous, as are the odor-giving oils of some of the higher plants. In Uroglena, Bursaria and Cryptomonas we notice a difference in the quality of the odor, just as we do in the case of the violet, rose and heliotrope.

The paper is illustrated by a colored plate.

The Seasonal Distribution of Microscopical Organisms in Surface Waters. *Gary N. Calkins*, pp. 381–390

A discussion of the subject illustrated by diagrams.

Some Physical Properties of Sands and Gravels, with Special Reference to Their Use in Filtration. *Allen Hazen*, pp. 539–556

This paper is printed in full on page 232.

Report upon Artificial Ice. pp. 589–598

A study of the chemistry of the artificial freezing of water, from which the following conclusions were drawn:

1. Artificial processes of freezing concentrate the impurities of the water in the inner core or the portion last frozen.
2. The impurities are reduced to their lowest terms by the use of distilled water (condensed steam) for the manufacture of ice.
3. The number of bacteria in artificial ice is insignificant, under the prevailing methods of manufacture.
4. The amount of zinc found in the samples of melted artificial ice under observation is insufficient to injure the health of persons using such ice.

Investigation of Recent Epidemics of Typhoid Fever in Massachusetts. *Professor William T. Sedgwick*, pp. 665–704

This is an elaborate report of the famous typhoid fever epidemics which occurred in the Merrimack valley in 1890–91. Lowell and Lawrence were the principal cities concerned. The length of the paper and its frequent mention in the modern literature of sanitation preclude its publication in full in this volume. The following topics illustrate the breadth of the investigation:

The Lowell epidemic in 1890–91 pp. 668
Five systems of water supply in Lowell 671
Conditions to be fulfilled by any water-infection theory of the epidemic 678
Discovery of the probable cause of the epidemic 679
The canal-water theory 685
The milk supply of Lowell 687
Results of the investigation 688
The Lawrence epidemic in 1890–91 692
Typhoid fever in the cities of the Merrimack valley during five years, 1888–93 694
An outbreak of typhoid fever in Lowell, Lawrence, and Newburyport in 1892–93 701

An Investigation of an Outbreak of Typhoid Fever in Chicopee Falls apparently due to Infected Water Supply.
George V. McLauthlin, pp. 705–714

An interesting study of a small typhoid outbreak by a brilliant young scientist made shortly before his untimely death.

An Investigation of an Epidemic of Typhoid Fever in the City of Springfield in July and August, 1892, due to Infected Milk.
Professor William T. Sedgwick and Dr. Walter H. Chapin, pp. 715–725

An important report, — one of the earliest investigations of a "milk epidemic."

An Investigation of an Epidemic of Typhoid Fever in Somerville, due to Infected Milk. *Professor William T. Sedgwick*, pp. 726–731

An important example of a well studied "milk epidemic."

Investigations of Epidemics of Typhoid Fever in Bondsville, Provincetown, and Millville, apparently due to Secondary Infection. *Professor William T. Sedgwick*, pp. 732–742

An interesting study of a phase of the subject new at the time.

1893

Twenty-fifth Annual Report

On the Amount and Character of the Organic Matter in Soils and its Bearing on the Storage of Water in Reservoirs. *Dr. Thomas M. Drown*, pp. 383–398

This study was made in anticipation of the construction of the great storage reservoir above Clinton. Its object was to determine whether the organic matter in the soil was likely to injure the quality of the water, and if so the extent to which it should be removed. After drying the loss on ignition, the carbon, nitrogen, albuminoid ammonia, free ammonia, and oxygen consumed were determined. Extraction experiments were also made. The methods are described and the results given in a series of tables. The general conclusions were as follows:

"It may be said that the effect of the organic matter in these various soils on the water in contact with them is simply a question of its amount, and that its origin and composition seem to be without marked influence. The watershed from which the samples were taken is very sparsely populated, and the organic matter in all cases is mainly of vegetable origin. It is probable, therefore, that we need only concern ourselves with the amount of organic matter in a soil of this character in determining the necessity of its removal, and as a provisional standard we may perhaps fix 1.5 to 2 per cent of organic matter as determined by the loss on ignition of the sample dried at 100° C., as the permissible limit of organic matter that may be allowed to remain on the bottom and sides of a reservoir."

The Filter of the Water Supply of the City of Lawrence and its Results. *Hiram F. Mills, C.E.*, pp. 543–560

This was the first scientifically designed filter in the United States. In several respects it was unique and not all of the ideas have been followed in later works. It was an open filter of the slow sand type, and was put in operation September 20, 1893.

This paper describes the filter and contains a plan of it. It also gives typhoid statistics for Lawrence before and after the filter was started. The concluding paragraph is interesting, as it shows the confidence resulting from the experimental work and this first installation.

The study of this problem and its solution have established with more of certainty than ever before three important points in sanitary science:

1. The insufficiency of the self-purification of streams.
2. The ready conveyance of typhoid fever down a stream by sewage-polluted drinking water.
3. The practicability of protecting a community against an infected drinking water supply by natural sand filtration.

Chemical Precipitation of Sewage at the World's Columbian Exposition, Chicago, 1893. *Allen Hazen*, pp. 595–624

Mr. Hazen, having been granted a leave of absence from the Lawrence Experiment Station went to Chicago and made the investigation here described.

The sewage of the exposition grounds amounted to about 2.5 million gallons per day. As a protection of the lake shore, as an object lesson to visitors and as a scientific experiment the sewage was treated chemically in large iron tanks. The chemicals used were copperas, lime, alum and ferric sulphate. It was found that copperas and lime produced a sludge more easily pressed than that resulting from the use of alum.

The paper gives the analytical data, the cost and efficiency of the processes used.

Isolation Hospitals for Infectious Diseases.
Dr. Samuel W. Abbott, pp. 689–737

This paper was written in response to a demand for information in regard to the advantages of isolation hospitals and the best methods of arranging them. An appendix contains data relating to European practice.

1894

Twenty-sixth Annual Report

The Composition of the Water of Deep Wells in Boston and Vicinity.
Dr. Thomas M. Drown, pp. 421–431

A paper giving the chemical analyses of samples of deep well waters, some of them more than one thousand feet deep.

The Bacterial Contents of Certain Ground Waters Including Deep Wells.
Professor William T. Sedgwick and S. C. Prescott, pp. 433–443

Contains chemical analyses and bacterial counts of well waters.

Physical and Chemical Properties of Sands with Special Reference to the Filtration of Water. *H. W. Clark*, pp. 701–710

The studies here described were made in continuation of those of Allen Hazen (24th report, p. 539). The conclusions were that calculations of rates of flow and losses of head should be made after the sand had been compacted. Values of the coefficient c are given for different conditions.

Reports upon Experiments in Feeding Hogs at a State Institution where Trichinosis among the Swine had been Unusually Prevalent. *Professor E. L. Mark*, pp. 757–762

A short paper showing the effect of feeding uncooked swine flesh to hogs.

On an Epidemic of Typhoid Fever in Marlborough apparently due to Infected Skimmed Milk.
Professor William T. Sedgwick, pp. 763–774

An important epidemiological study, showing a method of transmission of this disease hitherto unsuspected, namely, the use of infected skimmed milk.

1895

Twenty-seventh Annual Report

The Hardness of Water and the Methods by which it is Determined.
Mrs. Ellen H. Richards, pp. 433–442

A description of Clark's "Soap Method," and Hehner's "Acid Method," with tables of the hardness of some Massachusetts waters as determined by both methods.

Methods Employed at the Lawrence Experiment Station for the Quantitative Determination of Bacteria in Sewage and Water.
George W. Fuller and William R. Copeland, pp. 583–598

The topics treated are:

1. Collection and storage of samples.
2. Preparation of culture media.
3. Sterilization and storage of culture media.
4. Technique of plating.
5. Technique of counting colonies of bacterial on plates.
6. Effect of length of period of cultivation and of temperature at which cultivation takes place.
7. Comparison of the relative values of gelatine and glycerine agar for quantitative bacterial work.
8. Roll cultures in four-liter bottles.

Report upon the Production and Use of Antitoxin. pp. 687–708

A series of circulars describing the advantages of the use of antitoxin and the extent to what it was being used in the state. A laboratory had been established in October, 1894 in charge of Dr. J. L. Goodale, but as the work became more extended Dr. Theobald Smith was appointed pathologist in charge of the department.

1896

Twenty-eighth Annual Report

A Comparative Study of the Toxin Production of Diphtheria Bacilli.
Dr. Theobald Smith and Ernest L. Walker, pp. 647–658

This paper is given in full on page 274, *et seq.*

Comparative Study of Forty-two Cultures of Diphtheria Bacilli and of Four Cultures of Pseudo-Diphtheria Bacilli from Different Localities in Massachusetts.

Dr. Theobald Smith and Ernest L. Walker, pp. 659–672

A very careful bacteriological study of the cultural characteristics and their toxin-producing power. The toxin-producing power of bacilli persisting in the throat after recovery was also studied.

The Vital Statistics of Massachusetts, 1856–95, — a Forty-Years' Summary. *Dr. Samuel W. Abbott*, pp. 711–829

A very valuable paper prepared in Dr. Abbott's customary thorough manner. The headings of the paper will assist the reader in finding the facts reported.

On the accuracy of the material collected for publication in the Massachusetts registration reports pp. 714
Population of the state 716
Interstate and international vital statistics 722
Marriages 724
Fecundity of marriage 731
Births (still-births, illegitimacy) 733
Deaths 742
Infant mortality 752
Cause of deaths 757
Summary of special causes of death 772
Typhoid fever 779
Consumption 785
Cancer 802
Childbirth 804
The balance of mortality 812
The returns of medical examiners 817
Vital statistics of cities, 1894 and 1895 821

1897

Twenty-ninth Annual Report

(No special articles were published in this report.)

1898

Thirtieth Annual Report

An Investigation of the Action of Water upon Lead, Tin, and Zinc.

H. W. Clark, pp. 539–585

This is a detailed report of an investigation extending over two years to learn the nature and extent of the action of various waters on lead-pipe and the relation between this action and lead poisoning.

Many analyses are given showing the relation between the presence of lead and the color of the water, chlorine, hardness, nitrogen in its various states and oxygen consumed. Experiments were also made with waters containing various chemical substances. On page 565 the relation is shown between lead and carbonic acid and dissolved oxygen. This was the most important feature of the paper. On page 577, methods are described for the determination of lead, tin, zinc, and copper. This portion of the paper was prepared with the assistance of Mr. F. B. Forbes.

The Vital Statistics of Massachusetts for 1897, with a Life Table Based upon the Experience of the Five-year Period, 1893–97.
Dr. Samuel W. Abbott, pp. 797–827

The important part of this paper is the life table, which is reprinted in full on page 300, *et seq*.

1899

Thirty-first Annual Report

The Occurrence of Iron in Ground Water and Experiments upon Methods of Removal. *H. W. Clark*, pp. 535–553

The tables of water analyses in this paper are especially valuable from the fact that they give for many ground water supplies the carbonic acid and dissolved oxygen.

On pages 539–553 are given the results of experiments made at Provincetown, Watertown, Marblehead, and Reading.

The different treatments required to remove iron present in the forms of carbonate and sulphate are well shown. Aëration, filtration through sand, coke and iron strips, and chemical treatment with potassium permanganate and lime were the methods tested.

1900

Thirty-second Annual Report

Continuation of an Investigation on the Action of Water upon Metallic or Metal-lined Service Pipes, and Methods for the Separation and Determination of Metals in Water.
H. W. Clark and F. B. Forbes, pp. 485–506

This paper contains the results of determinations of lead, zinc, copper and tin in water flowing through pipes in ordinary use and after standing in the pipes.

On pages 498–506 are given the results of studies made to determine the accuracy of the methods of analyses, with suggestions as to how certain errors may be avoided.

An Investigation in Regard to the Retention of Bacteria in Ice, when the Ice is Formed under Different Conditions.
H. W. Clark, pp. 507–524

This is a valuable contribution to the study of the freezing of water.

Experiments were made by freezing sewage and sewage diluted with water in tanks. Many samples of ice from the Merrimack River were analyzed chemically and bacteriologically, as well as samples of ice from various ponds.

A summary of the results is given on page 521. It was found that in the still freezing of water practically all impurities are excluded from the ice, but that the freezing of river waters does not always offer adequate safety of the ice and the same is true of snow ice, or ice formed by the freezing of water which has flowed over the ice sheet.

Studies of the Efficiency of Water Filters in Removing Different Species. *Stephen de M. Gage*, pp. 525–535

A study of the removal of B. coli and B. typhi by sand filters. It was concluded that B. coli was the more hardy of the two organisms.

Examination of Spring Waters. pp. 537–585

A continuation of the examination made in 1891. Ninety-nine springs were examined. Descriptions and analyses are given for each one. They are grouped according to excess of chlorine. Great fluctuations were found in the numbers of bacteria.

Consumption of Water in Cities and Towns in Massachusetts. pp. 587–616

An important tabulation by cities and towns of these facts: Year; population; average daily consumption; daily consumption per capita; number of services; per cent of metered services; length of distributing pipes. The influence upon consumption of the following factors was studied: Age of works, introduction of sewers, introduction of meters, extent of manufacturing hot and cold weather. Fluctuations in consumption are also considered.

Statistics of Cancer in Massachusetts. *Dr. W. F. Whitney*, pp. 731–753

Statistics are tabulated by sex and ages for each five-year period from 1850 to 1895 for Massachusetts, and in somewhat less complete form, for other states.

1901

Thirty-third Annual Report

Report on the Experimental Filtration of the Water Supply of Springfield at Ludlow, Mass., from December 21, 1900 to January 31, 1902. *H. W. Clark*, pp. 323–369

Ludlow Reservoir water had been notorious for its summer growths of Anabaena. These experiments were undertaken to ascertain whether it was feasible to filter the water and, if so, how. The following topics were discussed:

Condition of the water during the experiments pp. 325
Filtration of the reservoir water 334
Refiltration of reservoir water 346
Aëration, dissolved oxygen 351
Experiments with canal water 354

The following is a summary of the work as given by Mr. Clark.

Studying the general results of the investigations made upon the feasibility of sand filtration of the Ludlow canal water, we find that all three filters were entirely successful in removing the organisms present in the water applied. The odor of the effluents of all three filters was generally very slight, and at times the effluents were entirely odorless, although during the last week in July, after the break in the canal bank by the side of Belchertown Reservoir and the consequent flow from this reservoir into the canal of water containing Anabaena, the effluent of each filter had the odor of this organism. Double filtration, however, would probably remove this odor as successfully as it did in the case of the reservoir water.

The removal of color and organic matter, while not equal at all times of the year to that obtained in the filtration of reservoir water, was very good, and as great as usually expected with sand filtration of surface waters resembling this canal water. The small amount of suspended matter in the canal water passed to these filters is shown by the few scrapings of the surface needed during the period of operation.

A Study of the Stability of the Effluents of Sewage Filters of Coarse Materials, Including Investigations upon Putrefaction and Secondary Decomposition. *H. W. Clark*, pp. 371–393

Bottles of sewage effluents were kept for many days and analyzed at frequent intervals, these analyses being quite complete. The data are given in detail. The results are critically discussed and summarized on pages 389–393.

Bacteriological Studies with Special Reference to the Determination of B. coli. *Stephen de M. Gage*, pp. 395–420

This report includes the following studies:

1. Changes in the methods for the detection of B. coli in water pp. 398
2. Review of routine B. coli studies 400
3. Methods for the differentiation of bacteria 407
4. Proposed classification of bacteria 415
5. Description of species 419

1902

Thirty-fourth Annual Report

On the Value of Tests for Bacteria of Specific Types as an Index of Pollution. *H. W. Clark and Stephen de M. Gage*, pp. 243–281

Contains summaries of tests for B. coli in the Merrimack River and Lawrence water supply, with comparisons of results in summer and winter; effect of storage on B. coli; tests for B. coli in ground waters. Summaries of B. coli tests in sea water and shellfish are given. There is also a discussion of the significance of B. coli and other bacteria and a comparison of B. coli and B. typhosus as affected by cold, freezing, heat and sunlight. The general conclusion was that the two organisms behave very much alike under adverse conditions of living.

1903

Thirty-fifth Annual Report

(There were no special articles in this report.)

1904

Thirty-sixth Annual Report

(There were no special articles in this report.)

1905

Thirty-seventh Annual Report

Materials Used for Service Pipes in Massachusetts. pp. 195–205

A statistical summary of the materials used for service pipes, i. e., wrought iron, galvanized iron, cement-lined, lead, lead-lined, and tin-lined, the number of services in each case being given.

Experiments upon the Removal of Organisms from the Waters of Ponds and Reservoirs by the Use of Copper Sulphate.

X. H. Goodnough, pp. 207–287

The experiments were made at the Arlington Reservoir, the Belchertown Reservoir, the Lexington Reservoir, the Quincy Reservoir, Jamaica Pond, Crystal Lake in Newton, and Massapoag Lake in Sharon.

The success of the copper treatment of water containing certain blue-green algae and protozoa is shown; its failure in the case of other organism is pointed out. Caution is urged in regard to this method of treatment on account of the danger to fish and the poisonous character of the chemical.

Investigations in Regard to the Use of Copper and Copper Sulphate.

H. W. Clark, pp. 289–338

The experiments described are of considerable interest. Among the topics treated are: Description of Method of Determining Copper, Copper Existing Naturally in Massachusetts Waters, Destruction of Algae by Copper Sulphate, Absorption of Copper Sulphate by Organic Matter, Copper and Copper Sulphate as a Bacteriacide, Experiments with Metallic Copper, Comparison of Copper Salts with other Salts.

Examination of Sewer Outlets and of Tidal Waters and Flats from which Shellfish are Taken for Food.

X. H. Goodnough, pp. 411–426

This is an interesting study of the pollution of the waters and flats of Boston harbor by the sewage of Boston and vicinity discharged at Moon Island, Deer Island, and Paddocks Island. Maps are given showing results of chemical analyses (free and albuminoid ammonia) at various places and at different depths. Another map shows the bacteriological findings.

The conclusions, being of especial interest to the people of Boston, are printed in full on page 322.

Studies at the Lawrence Experiment Station on the Pollution of Shellfish. *H. W. Clark*, pp. 427–457

The following topics were treated: Studies of Clams; Examination of the various portions of Shellfish for the Detection of Infection; Studies of Digestion, Sterilization by Heat; Studies of Oysters; Destruction of Bacteria in Oysters by Cooking; Studies of the Joppa Clam Flats at Newburyport; Viability of B. coli in Salt and Fresh Waters.

Inspection of Dairies. *Dr. Charles Harrington*, pp. 517–526

This report, except the tables, is printed in full on page 333, *et seq.*

A Description of the New Antitoxin and Vaccine Laboratory, together with a Ten Years' Retrospect of the Production and Distribution of Diphtheria Antitoxin. *Dr. Theobald Smith*, pp. 527–546

The first part of the paper is a detailed description of the laboratory, located on the grounds of the Bussey Institute of Harvard University, near the Forest Hills Station, illustrated with plans and photographs.

There follows an account of the work of the department during the first ten years of its existence. The topics specially amplified relate to diphtheria antitoxin, tetanus antitoxin, and vaccine lymph. The latter, in particular, is referred to in detail.

1906

Thirty-eighth Annual Report

Significance of the Numbers of Bacteria in Water and Sewage Developing at Different Temperatures. *Stephen de M. Gage*, pp. 325–349

Comparisons are made between bacterial counts at 20°, 30°, 40° and 50° C. Ratios between these counts are found for different waters, some polluted and some not polluted. Ratios between bacteria and B. coli are given for the Merrimack River. The influence of Temperature, Oxygen and Dilution upon the Bacterial Contents of the Merrimack River are considered. The bacterial counts at different temperatures are used to show the efficiency of water filters. Acid-producing bacteria are compared with B. coli. The results of incubation tests are given.

A Comparison of Methods for the Determination of the Alkalinity of Ash. *Hermann C. Lythgoe*, pp. 411–414

A brief statement of Method.

Report on the Sanitary Condition of Factories, Workshops, and Other Establishments. *Dr. Charles Harrington*, pp. 449–619

An important report, being an account of the first work done by the Board in accordance with the legislative act of 1905. It describes in detail various industries from the sanitary standpoint. The textile industries, the boot and shoe industry, machinery, the chemical industries, and slaughtering come in for long descriptions.

1907

Thirty-ninth Annual Report

Report upon the Chemical Examination of Drawn and Undrawn Poultry Kept in Cold Storage. *Dr. William F. Boos*, pp. 263–282

A chemical investigation of the subject of ptomaines, Bacillus botulinus, as well as a practical study of the subject. The results of many experiments are given in detail. The general conclusions were as follows:

1. In cold storage itself no chemical changes occur. This is shown by:

(*a*) The absence, after nine months and more of cold storage, in both drawn and undrawn cold-storage fowl of ptomaines and decomposition products in general, except such as are formed by bacteria and autolytic changes occurring before the birds are placed in cold storage and after they are thawed.

(*b*) The negative results of animal inoculations with extracts obtained from the two kinds of poultry.

2. When fowl are taken out of cold storage and exposed to a temperature of 68° F., the conditions of exposure being the same, the undrawn birds show better keeping qualities.

3. When freshly killed fowl are exposed at 68° F. under conditions constant for all the birds exposed, the birds drawn according to the method described above show perfect keeping qualities, while the undrawn fowl undergo a rapid process of decomposition. Under these conditions the ordinarily drawn birds show fair keeping qualities, although they are not free from bacterial decomposition.

It may be concluded, therefore, from these results that it is best to draw fowl in a different manner from that usually followed, before they are placed in cold storage. After removal from cold storage, the fowl should never be contaminated by soaking in water, but should thaw in the air. Ordinary drawing is worse by far than no drawing at all.

Report upon the Bacteriological Examination of Drawn and Undrawn Poultry. *Herbert R. Brown*, pp. 285–336

A detailed bacteriological study. The following conclusions were drawn:

1. Poultry kept at temperatures ranging from + 5° to − 14° F. undergo no decomposition as a result of bacterial activity.

2. Freezing destroys the red and some of the white blood corpuscles.

3. Freezing temperatures as low as − 14° F. destroy a large percentage of the bacteria present, but do not affect the more resistant ones.

4. When the tissues are thawed, they become moistened by the melting ice crystals, and in this condition bacterial growth is facilitated and decomposition of the tissues and contents of the cells is promoted.

5. In the drawn chickens placed in cold storage aërobic conditions prevailed throughout the pleuroperitoneal cavities. The undrawn chickens showed much smaller numbers of bacteria in the pleuroperitoneal cavities. On account of the closed cavity, partial anaërobic conditions prevailed in these birds.

In decomposing meats, putrefactive aërobic bacteria may possibly produce the primary stages and prepare the way for anaërobes which possibly control the intermediate stages of decomposition. By the combined action of both, decay is brought about, but it is probably finished by aërobic bacteria.

From these facts it appears that, given the aërobic conditions and the larger numbers of bacteria growing on the moist surfaces and tissues of a thawed drawn chicken, decomposition will proceed at a more rapid rate than with an undrawn one containing fewer bacteria existing under partial anaërobic conditions.

6. In freshly killed, unfrozen drawn chickens, the surfaces and tissues become dry within a very short time, and, although aërobic conditions prevail, the bacteria cannot grow because of lack of moisture.

7. In freshly killed, unfrozen and undrawn chickens, on account of the closed pleuroperitoneal cavities there is no drying of the tissues and surfaces, and facultative aërobic and anaërobic bacteria from the intestines rapidly cause decomposition.

8. By the removal of the viscera without the spilling of the contents of the alimentary tract decomposition can be prevented absolutely. The operation requires about two minutes.

9. Briefly stated, decomposition depends largely upon the presence of moisture in the tissues, for moisture is absolutely essential to bacterial growth. In freshly killed birds, ordinarily or properly drawn, the surfaces quickly become dry. In cold-storage birds, no matter how they are drawn, the tissues will be moist, because of the melting of the crystals of ice. If properly drawn, there would be but few bacteria present capable of causing decomposition.

The Infantile Mortality of Boston, June 1–November 30, 1907.
Dr. Donald Gregg, pp. 401–413

A study of the deaths of infants distributed by wards, by season, by feeding, etc.

Report upon the Growth of Pathogenic Bacteria in Milk.
Herbert R. Brown, pp. 415–437

A study of the growth of B. typhosus, the paratyphoid bacillus, the hog-cholera bacillus, the bacillus of dysentery, the diphtheria bacillus, etc., under different conditions. The following conclusions were drawn:

1. *Bacillus typhosus*, paratyphoid, hog cholera, *bacillus dysenteriae* (Shiga) and *bacillus diphtheriae* can all grow in milk, but the last grows the poorest of the five when placed under the optimum conditions of temperature.

2. All species grow less luxuriantly at room temperature than at 36° C.

3. Exposure to low temperatures (5.6° to 6.7° C.) causes no appreciable destruction of bacteria during the first forty-eight hours, and there may even be some multiplication of the more vigorous individuals of all five species. Continued exposure for three weeks causes a rapid destruction of the individual bacteria most susceptible to the low temperature.

4. *Bacillus typhosus* produces an acid reaction in milk early in its development. The milk remains normal in appearance.

5. Bacillus hog cholera and the paratyphoid bacillus produce an initial rise in acidity, which is followed by alkali production as an end product. The milk assumes a primary opalescent appearance, which later on is changed to a translucence due to alkaline reaction and probable peptonization of the proteids present.

6. *Bacillus dysenteriae* produces a slight initial rise in acidity, which is followed by a return to a slightly alkaline reaction. The milk remains normal in appearance.

7. Exposure of *baçillus typhosus* to − 1.1°, − 12.2°, 17.8° and 21.1° C. for fourteen days did not kill all the bacteria of any one tube, for growth always ensued when the culture was placed in favorable environment.

1908

Fortieth Annual Report

A Review of Twenty-One Years Experiments upon the Purification of Sewage at the Lawrence Experiment Station.

H. W. Clark and Stephen de M. Gage, pp. 251–538

A most important paper. The subject matter is indexed under the head of the Lawrence Experiment Station in the third volume. A part of this Review is reprinted on page 341.

1909

Forty-first Annual Report

Disposal and Purification of Factory Wastes or Manufacturing Sewage.

H. W. Clark, pp. 339–403

An important paper giving the result of much experimental work. The subject matter is indexed under the head of the Lawrence Experiment Station.

The Collection and Disposal of Municipal Refuse.

X. H. Goodnough, pp. 405–421

An important paper which treats of the following topics: Classification of municipal refuse (p. 407), sources, separation, methods of collection (p. 408), quantity of refuse (p. 410), methods of disposal (p. 412), cremation (p. 419).

A Study of Some of the Spore-bearing Anaërobic Bacteria in Market Milk. *Herbert R. Brown*, pp. 632–667

An extended bacteriological study of samples of milk purchased from small stores in Boston and vicinity. The methods used are first described (pp. 633–643), and then are given descriptions of seventeen different organisms studied. On page 666 is given a long list of references.

1910

Forty-second Annual Report

Studies of the Relative Corrosion of Metal Pipes by Waters, especially before and after Purification. Review of Literature on Corrosion.
H. W. Clark and Stephen de M. Gage, pp. 287–310

The results of a series of experiments relating principally to "rusty water troubles." The effect of hot and cold water is discussed (p. 291), and that of dissolved oxygen on page 292. A review of the literature is given on page 295. Theories of corrosion are discussed on page 299, and methods of prevention on page 307.

1911

Forty-third Annual Report

Experiments upon the Disinfection of Sewage and Effluents from Sewage Filters.
H. W. Clark and Stephen de M. Gage, pp. 339–364

This paper is indexed under the head of the Lawrence Experiment Station.

1912

Forty-fourth Annual Report

Studies of Fish Life and Water Pollution.
H. W. Clark and George O. Adams, pp. 336–345

The results of experiments to show the effect on small fish of sewage, diluted sewage, and various sewage effluents. The effect of dissolved oxygen, nitrates, iron, etc., is referred to (p. 341). The consumption of oxygen by fish life (p. 342), the solution and diffusion of oxygen in water (p. 343) and the liberation of oxygen by algae (p. 344) are studied.

A Study of the Efficiency of Certain Methods for the Sanitary Control of Swimming Pools.
H. W. Clark and Stephen de M. Gage, pp. 346–367

A general study of various swimming pools, notably those at Andover and Lawrence (p. 351), Worcester (p. 365), and Cambridge (p. 366). Bacterial counts and B. coli results are given.

A Study of the Hygienic Condition of the Air in Textile Mills with Reference to the Influence of Artificial Humidification.
H. W. Clark and Stephen de M. Gage, pp. 659–692

The following topics were considered: Influence of the condition of the air upon health and comfort (p. 662), respiratory diseases in textile cities (p. 664), factors influencing the health of textile operatives

(p. 667), artificial humidification (p. 670), air in spinning and weaving rooms (p. 676), air in picker and carding rooms (p. 681), air in other wool manufacturing processes (p. 684), effect of humidifiers on bacteria and molds (p. 688).

Fecal Contamination of Roller Towels.

Henry N. Jones, pp. 549–552

A brief statement giving results of tests for B. coli, Staphylococci and other organisms.

The Occurrence of Infantile Paralysis in Massachusetts.

Dr. Mark W. Richardson, pp. 555–561

Certain facts and observations of an unusual nature in the experience of Massachusetts with infantile paralysis are here set forth, together with a discussion of their possible significance. This article is published in full on pages 350–365, and with it an article by Dr. M. J. Rosenau and one by Dr. John F. Anderson and Dr. Wade H. Frost on the agency of *stomoxys calcitrans* in the spread of infantile paralysis.

1913

Forty-fifth Annual Report

Further Experiments on Poliomyelitis.

Dr. M. J. Rosenau, pp. 535–557

Experiments with the stable-fly described in detail.

Experiments to Determine Paralyzed Domestic Animals and those Associated with Cases of Infantile Paralysis may Transmit that Disease. *Dr. Carl Ten Broeck*, pp. 558–577

The experiments are described in detail, the results showed that " in no case do the monkeys inoculated from any of these animals show any signs of a paralysis or symptoms which would indicate that they were infected with poliomyelitis."

A Study of an Epidemic of Infantile Paralysis Occurring in the Southern Connecticut Valley during the Year 1912.

Dr. James V. W. Boyd, pp. 578–601

An epidemiological study. Refers to paralysis among birds and horses. The cases are classified in various ways.

1914

Forty-sixth Annual Report

Disposal of Sewage in the South Metropolitan Sewerage District, including report of the Chief Engineer.

X. H. Goodnough, pp. 361–400

This report relates chiefly to an extension of the system so as to include the sewage of Wellesley and Needham, but various data are given for other places in the Charles River Valley.

The Suppression of Tuberculosis, an Address to the State Inspectors of Health of Massachusetts. *Hiram F. Mills*, pp. 701–722

A valuable statistical summary, with map, showing the decrease in tuberculosis between 1908 and 1912 in different parts of the state.

The Protection and Maintenance of the Public Health during and subsequent to a Great Conflagration. *Dr. William C. Hanson*, pp. 739–743

An account of the measures taken to safeguard the public health at the time of the Salem Fire.

The Early Diagnosis of Lead Poisoning. *Dr. Harry Linenthal*, pp. 743–749

A critical study of thirteen cases of lead poisoning.

II. ABSTRACTS OF SPECIAL REPORTS

1889

Sewerage of the Mystic and Charles River Valleys

Report of the State Board of Health upon the Sewerage of the Mystic and Charles River Valleys.

Dr. Henry P. Walcott, Chairman, January, 1889, pp. 1–36

In 1887 the legislature had asked the Board to report on the general drainage and sewerage of the Mystic and Charles River Valleys, including the best method of disposal. This comprehensive study resulted. Abstracts of the report are printed at some length on pages 86–105. The general scheme here recommended was adopted and is now in use under the name of the North Metropolitan Sewerage System. The portions of the report not reprinted included additional experiments on the flow of water and sewage through peat and detailed statements relating to the cities and towns to be included in the district. The report contains maps and profiles.

Report of Consulting Engineer. *Joseph P. Davis*, pp. 37–40

A general report approving the project recommended.

Report of the Engineer. *Howard A. Carson, C.E.*, pp. 41–84

Contains the results of the surveys and estimates of cost.

Report upon Disposal by Chemical Precipitation.

Charles H. Swan, C.E., pp. 112–120

The best location for works of this type was on the estuary of the Mystic River. Detailed estimates of cost were given.

Report of the Chief Engineer. *Frederic P. Stearns*, pp. 85–111

This report covered the following points: The capacity of the Boston Main Drainage Works (p. 85), Operation of the Main Drainage Works with reference to the Outlet (p. 97), Methods of providing sewerage systems for each city and town within the district (p. 99), Independent systems for cities and towns (p. 106), Estimates of cost (p. 110).

Report on Absorption of Water upon Saugus Marshes.

Frederick Brooks, C.E., page 121

Detailed descriptions of the experiments referred to in the main report. Interesting as showing the impossibility of using peat for sewage filtration.

1894

Improvement of Charles River

Report of the Joint Board Consisting of the Metropolitan Park Commission and the State Board of Health upon the Improvement of the Charles River from the Waltham Line to the Charles River Bridge.

Dr. Henry P. Walcott, Chairman, April, 1894, pp. i-xxii

This report because of the importance of the subject to the people of Boston and the Metropolitan District is printed in full, with a few details omitted, on pages 249–259.

The project of the Charles River Basin had been considered in 1891. There were many advocates and opponents. This report carried great weight and led to the immediate undertaking of the project.

Report of the Engineer. *Frederic P. Stearns*, pp. 1–32

The following topics which were considered indicate the comprehensiveness of the investigation upon which the report was founded:

Present condition of the river (p. 1), sanitary examination (pp. 6 and 14), methods of improvement (p. 9), proposed dam (p. 12), effect upon navigation (p. 17), effect upon the harbor (p. 18), effect upon sewerage systems (p. 23), effect upon ground water in filled lands (p. 26), effect upon marshes (p. 28), relation to storm water (p. 28), possible shoaling (p. 30), and cost (p. 30).

Report of the Landscape Architects.

Messrs. Olmstead and Eliot, pp. 33–43

A general discussion followed by statements concerning three sections of the project. The Fresh Water Section, from the Waltham line to the Watertown Bridge, the Marsh Section, from the Watertown Bridge to Cottage Farm, and the Basin Section, from Cottage Farm to the Craigie Bridge.

Appendix 1. Freshet Flow of the Charles River.
Appendix 2. Charles River Bridge.
Appendix 3. Ground water in filled lands.

1895

Metropolitan Water Supply

Report of the State Board of Health upon a Metropolitan Water Supply. *Dr. Henry P. Walcott*, pp. 9–21

This report is reprinted in full on page 260, *et seq.*

Report of the Consulting Engineer. *Joseph P. Davis, C.E.*, pp. 34–36

A short report approving the plan recommended by the Board.

Report of the Chief Engineer. *Frederic P. Stearns*, pp. 1–148

A comprehensive report giving the results of the investigations made and a description of the works recommended for a Metropolitan supply of water. The Metropolitan District was taken to be the cities and towns within ten miles of the State House.

The following were the main subjects considered:

1. Statistics and estimates relating to the water supply of the Metropolitan District as a whole. pp. 3

2. A statement of the present condition of the water supply of each of the cities and towns in the district, prefaced by some remarks regarding sources of water supply in general. 14

3. An outline of the plan recommended for taking an additional water supply from the Nashua River. 67

4. A financial statement with regard to the existing water works of the district. 80

5. A statement with regard to each city and town in the district, as to whether it should obtain its water supply independently or as a part of the district. 85

6. A statement regarding sources investigated but not recommended. 103

7. A detailed description of the works recommended, both for bringing water to the Metropolitan District, and for distributing it to the cities and towns within the district, including estimates of cost. 125

As is now well known, the Nashua River was selected as the source of the Metropolitan Supply. Among the sources studied but not recommended were the Merrimack River (p. 103), Lake Winnipisogee (p. 108), Charles River (p. 111), Shawsheen River (p. 113), Ipswich River (p. 114), Assawompsett Pond (p. 115), and Sebago Lake (p. 117).

Sources available for future additions to the Nashua River supply were: Tributaries of the Assabet River (p. 117), Ware River (p. 118), Swift River (p. 120), Deerfield River (p. 121), Westfield River (p. 122), Squannacook River (p. 122).

The report is illustrated with maps and general plans, including sections of the main dam and dykes at the Wachusett Reservoir.

A very important report.

Appendix No. 1

Growth of Population in the Boston Metropolitan District.
pp. 151–156

A statistical study of the populations of the cities and towns within the Metropolitan District, with a graphical estimate of future population.

Appendix No. 2

Present and Future Consumption of Water in the Metropolitan District. *Dexter Brackett, C.E.*, pp. 157–175

A detailed study of the water consumptions in Boston and suburban cities and towns. Contains average per capita consumptions, quantities used for domestic purposes, mechanical trade and manufacturing uses, public uses, and waste; also fluctuations in consumption. Estimates were given for the probable future consumptions.

Appendix No. 3

Improvement of the Quality of the Sudbury River Water by the Drainage of the Swamps upon the Watershed.

Desmond FitzGerald, pp. 176–187

Contains records of colors of various waters in the small feeders of the Sudbury River, with estimates of the probable improvements resulting from swamp drainage.

Appendix No. 4

On the Amount and Character of Organic Matter in Soils and its Bearing on the Storage of Water in Reservoirs.

Dr. Thomas M. Drown, pp. 188–201

Reprinted from the Annual Report of the State Board of Health for 1893.

Appendix No. 5

Chemical Analyses of Water from the Sources Investigated.

Made under the direction of *Dr. Thomas M. Drown*, pp. 202–216

Appendix No. 6

Water Supply of Different Qualities for Different Purposes.

Dexter Brackett, C.E., pp. 217–221

A study of a possible dual supply, — a spring or ground water supply for domestic uses, and a supply of water of inferior quality, not suitable for drinking, for mechanical, manufacturing, and other purposes.

Appendix No. 7

Sanitary Examination of Nashua River Watershed.

Chester W. Smith, pp. 222–223

A sanitary survey with results expressed in tabular form.

1896

Improvement of Upper Charles River

Report of the Joint Board Consisting of the Metropolitan Park Commission and the State Board of Health upon the Improvement of Charles River from the Line between Watertown and Waltham to Mother Brook, May, 1896.

Dr. Henry P. Walcott, Chairman, pp. 1–10

This work was practically a continuation of the work of a similar joint board in 1894. It covered that portion of the river above that formerly considered, and recommended a control of the water level, arrangements for the transfer of boats past the dams, the acquisition of land for parks, along the stream, and public control of the area secured.

Report of the Landscape Architects.
Messrs. Olmstead and Eliot, pp. 11–20

Contains data of an engineering character.

Intermittent Fever in the Charles River Valley.
Dr. John Jenks Thomas

The care of low lands and swamps is emphasized as a necessary measure, but no mention at this date was made of the mosquito in connection with malaria.

1897

Improvement of Neponset River

Report of the State Board of Health upon the Sanitary Condition and Improvement of the Neponset Meadows.
Dr. Henry P. Walcott, pp. 5–10

This investigation was undertaken in accordance with a legislative act (Chap. 83 of the Resolves of 1895). Drainage of the meadows was recommended, largely in order to protect the region against malaria, but with an incidental increase in the usefulness of the land. This report is printed in full on page 293.

Engineer's Report. *X. H. Goodnough*, pp. 1–27

The general conditions are first described, the sanitary condition of the river, its pollution by manufacturing waste; next the condition of the meadows (p. 14) and the feasibility of improving them (p. 17). The plan is described on page 20, and estimates of cost given. Finally the probable effect of the work upon the meadows.

Report of the Chemist. *H. W. Clark*, pp. 28–33

A chemical investigation of the pollution and a study of the possibility of purifying the manufacturing wastes. Filtration experiments were made.

1898

Cerebro-spinal Meningitis.
Dr. W. T. Councilman, Dr. F. B. Mallory and Dr. J. H. Wright, page 178

This report covers the general nature and history of the disease, its epidemic occurrence in Massachusetts, and detailed medical descriptions of many cases. The bacteriology of the disease is also discussed.

The paper is illustrated with colored plates.

1898

Restoration of Green Harbor

Report of the Joint Board Consisting of the Harbor and Land Commissioners and the State Board of Health upon the Restoration of Green Harbor in the Town of Marshfield, Mass., January, 1898.

Dr. Henry P. Walcott, Chairman, pp. 1–24

The report of an investigation made to determine the advisability of removing a dike so that the tidal waters might overflow certain marsh lands in the town of Marshfield and restore the harbor of Green Harbor. Estimates of the relative amounts of damages and betterments were considered. It was concluded inadvisable to remove the dike. The report contains some interesting local historical statements and a statement as to the effect of applying salt water to a fresh water marsh.

Appendix No. 1

Report of the Engineers.

Frank W. Hodgdon and X. H. Goodnough, pp. 29–60

The report contains the engineering data required for the investigation, a study of the saltness of the water above the dike, the effect of reflooding the meadows with salt water and suggestions for improving the harbor without removing the dike.

Appendix No. 2

Report of the Engineer. *Frank W. Hodgdon*, pp. 61–63

On the cost of removing the dike and of improving the harbor without removing the dike.

Appendix No. 3

Report of the Chemist. *H. W. Clark*, pp. 64–67

Contains the results of analyses of soils from the marshes and dike lands and experiments upon sections of soil.

1898

Sewerage of Salem and Peabody. (*House No.* 1301.)

Report of the State Board of Health upon the Sewerage of the City of Salem and the Town of Peabody.

Dr. Henry H. Walcott, Chairman, pp. 3–16

Made in accordance with the Resolves of 1895 and 1896.

The existing nuisances caused by the discharge of sewage about Salem, the condition of the North River and the shores and flats have warranted the recommendation for improvement and change. Disposal by discharge into the sea is recommended.

The report contains a description of various experiments and investigations made to determine the most suitable point of outlet. A description of the proposed sewerage system and its design, together with cost data, are given.

Engineer's Report. *George A. Kimball*, pp. 19–48

This report describes the complete situation, the topography, population and estimated increase, water supply, present sewerage facilities, industries, nuisances caused by the sewage and quantity of sewage in both places. The various methods of disposal available about Salem are enumerated and the disposal by dilution in sea water is recommended.

Detailed accounts of the float experiments are given in order to find the proper location for the outfall sewer and in conclusion recommendations relating to the entire system, trunk sewer, pumping station, and estimates of cost are given.

1900

Discharge of Sewage into Boston Harbor

Report of the State Board of Health upon the General Subject of the Discharge of Sewage into Boston Harbor. pp. 5–7

This special report was prepared in accordance with an act of the legislature (Chap. 65 of the Resolves of 1899). It was written by Dr. Henry P. Walcott, Chairman of the Board. It is printed in full on page 317, *et seq.*

Engineer's Report. *X. H. Goodnough*, pp. 10–87

This report contains the fundamental data upon which the report of the Board was based. It describes briefly the existing works, their capacity and the necessity for relieving the Boston Main Drainage System (p. 20). The proposed method of relief, namely the construction of the South Metropolitan System, is then described in detail. Certain areas are recommended for inclusion in this district and other areas were excluded because local disposal was more advantageous. These latter areas were in the upper parts of the Charles and Neponset drainage areas. On page 64 are given estimates of population and quantities of sewage, and on page 69 a description of the proposed harbor outlet for the high-level sewer. Finally, mention is made of the relief needed in Braintree, Weymouth and Hingham. An appendix gives populations of sewer districts from 1850 with estimates to 1940.

1901

Sanitary Condition of Sudbury and Concord Rivers

Report of the State Board of Health upon the Sanitary Condition of the Sudbury and Concord Rivers.
Dr. Henry P. Walcott, Chairman, pp. 1–9

The results of a sanitary survey of the river are here given. The recommendation was that certain pollutions be excluded, but that the efficacy of lowering the river's bed be left for future study.

Report of the Chief Engineer. *X. H. Goodnough*, pp. 10–37

The statistics of pollution are given, with water analyses and statements as to the conditions of the rivers.

Report upon the Disposal of Manufactural Wastes from the Mills at Saxonville, Mass. *H. W. Clark, Chemist,* pp. 38–46

The wastes considered are from the processes of wool-scouring, washing yarn and dyeing. Various experiments were made.

Sanitary Conditions in the Towns Bordering the Sudbury and Concord Rivers. *Dr. Frank L. Morse, Medical Inspector,* pp. 47–55

Malaria in Concord. *Dr. Theodore Chamberlain,* pp. 56–57

1904

Investigation of the Business of Undertaking and Embalming. pp. 1–4

The business is being satisfactorily carried on under the supervision of local health authorities.

1904

Dumping of Garbage and Rubbish in the Harbors and along the Sea Coast of Massachusetts Bay. (*Senate, No.* 277.)

The Report of the State Board of Health upon the Dumping of Garbage and Rubbish into the Harbors and along the Sea Coast of Massachusetts Bay. *Dr. Henry P. Walcott, Chairman,* pp. 3–5

This report considers the general subject of dumping of refuse into the sea and along the shores. From observations made in the harbors of several cities there is believed to be little objection to the practice of dumping at sea providing it is done at a sufficient distance from the shore. Very little garbage or other putrescible matter is disposed of along shores — chiefly ashes, house dirt, street sweepings and rubbish. The enclosing of such dumping areas by walls is recommended.

Report of the Chief Engineer. *X. H. Goodnough,* pp. 6–25

This report treats of the disposal of refuse matters in the City of Boston, Lynn, and Hull and the dumping of such materials into the harbor and along the shores. Observations were made relative to dumping from scows and disposal along shores.

Appendix. pp. 26–27

Results of observations of dumping of Boston Refuse scows in Boston Harbor, also the dumping of Hull garbage. Appended is a map showing location of dumping grounds.

1906

Mystic River and Alewife Brook. (*Senate, No.* 363.)

The Report of the State Board of Health on the Purification of Mystic River, Alewife Brook and the Adjacent Water Courses, Ponds and Drainage Areas. *Dr. Henry P. Walcott, Chairman,* pp. 2–18

The report states that the Mystic River, Alewife Brook and their tributaries are most seriously polluted by sewage and manufacturing wastes. The drainage areas are largely swampy low lands suitable for breeding mosquitoes and giving rise to the malaria existing in the valley.

The construction of a dam on the Mystic River at Craddock's Bridge, equipped with tide gates; the deepening and widening of channels; and the exclusion of storm sewage was recommended.

1907

Water Supply of Lynn. (Senate, No. 239.)

An Act Relative to Increasing and Improving the Water Supply of the City of Lynn (Approved, June 21, 1906). page 3

A Report by the State Board of Health and the Water Board of the City of Lynn Relative to the Increase and Improvement of the Water Supply of the City of Lynn.
Dr. Henry P. Walcott, Chairman, pp. 4–5

A joint report by the State Board of Health and the Water Board of the City of Lynn. It consists of a description of the present supply and the conditions which make a new supply necessary. Possible methods for the improvement and increase of the supply are given. Sand filtration is recommended as a means of purification.

Report of Engineers. *X. H. Goodnough, Chief Engineer,* State Board of Health and *George I. Leland, City Engineer* of Lynn. pp. 7–26

This joint report outlines the present system of water supply and the existing conditions and character of the present polluted sources.

Plans for an additional supply from several unpolluted sources are given together with details of the required works and the estimated costs. Sand filters were recommended. Maps are included in the report.

1908

Sanitary Condition of the Merrimack River

Report of the State Board of Health upon the Sanitary Condition of the Merrimack River. *Dr. Henry P. Walcott, Chairman,* pp. 1–4

A special study made at the request of the legislature (Chap. 114 of the Resolves of 1908). It was concluded that while the condition of the stream was not injurious to the public health, more complete regulation of the pollution, especially pollution by trade wastes, was desirable. Particular mention is made of the possible recovery of wool grease.

Report of the Chief Engineer. *X. H. Goodnough,* pp. 6–36

The details of the investigation are given in this report, as follows: Description of the river (p. 7), sources of pollution (p. 8), manufacturing wastes (p. 13), stream flows (p. 18), comparisons with other rivers (pp. 16, 22), analyses of the water at various points (pp. 22 and 37), sewer outlets (p. 28), summary (p. 34).

1908

Pollution of Boston Harbor by the Discharge of Sewage at Moon Island. (*Senate, No.* 65.)

Report of the State Board of Health on the Pollution of Boston Harbor by the Discharge of Sewage at Moon Island.

Dr. Henry P. Walcott, Chairman, pp. 2–5

An investigation as to the extent to which the water of the Boston Harbor was polluted by the discharge of sewage at Moon Island. Bacterial and chemical examinations showed that the waters of the inner harbor were more polluted than the waters of the outer harbor, except in the immediate vicinity of the sewer outfall. The results indicated that the pollution of the inner harbor was not due to the discharge of sewage at Moon Island or at the other main outlets.

1909

Green Harbor

Report of the Joint Board Consisting of the Harbor and Land Commissioners and the State Board of Health upon the Improvement of Green Harbor, in the Town of Marshfield, Mass.

Dr. Henry P. Walcott, Chairman, pp. 1–15

A further study of the problem reported on by a similar joint board in 1898, but with substantially no change in opinion.

Report of the Engineers.

Frank W. Hodgdon and X. H. Goodnough, pp. 6–21

Contains the engineering data, including estimates of cost.

1909

Lake Quannapowitt. (*Senate, No.* 208.)

Report of the State Board of Health upon the Flooding of Lands Bordering Lake Quannapowitt and its Tributaries, and the High-water Elevation of the Lake.

Dr. Henry P. Walcott, Chairman, pp. 2–10

A report by the State Board of Health investigating the condition of lands adjacent to Lake Quannapowitt in the vicinity of Wakefield and Reading, due to inadequate drainage. The drainage of the low lands in question by the removal of the dam at Vernon Street on the Saugus River, and the construction of drainage channels of sufficient size are recommended by the Board. No legal high-water mark for the lake has ever been established.

1909

Sewage Disposal for Worcester Insane Hospital. (*House, No.* 197.)

Report of a Commission to Investigate the Advisability of Establishing a System for the Disposal of Sewage from the Worcester Insane Hospital in the City of Worcester.
Dr. Henry P. Walcott, Chairman, pp. 2–10

This is a report of a Joint Commission composed of members from the State Board of Health and the Board of Health of the City of Worcester. It consists of a brief statement of the past and present conditions and the method of sewage disposal practiced, leading up to the recommendation that hospital sewage be discharged into the sewerage system of the City of Worcester.

1911

Water Supply of Salem, Beverly, and Peabody and the Use of the Ipswich River

Preliminary Report of the State Board of Health. pp. 1–21

Final Report of the State Board of Health. pp. 22–37

A consideration of the water supply needs of these communities and the way in which Ipswich River may be used to furnish a supply.

1913

Sanitary Condition of the Merrimack River. (*House, No.* 2050.)

Report of the State Board of Health upon the Sanitary Condition of the Merrimack River. *Dr. Henry P. Walcott, Chairman*, pp. 3–6

This report is the result of investigations into the sanitary condition of the bed, banks, and waters of the Merrimack River, and of streams tributary or adjacent thereto in cities and towns bordering upon the river. Recommendations for the improvement of the sanitary condition of the river and the removal of objectionable conditions therefrom are given.

Report of the Engineer and Chemist. *X. H. Goodnough and H. W. Clark*, pp. 7–45

This report details the general condition of the river along its course, particularly at Lawrence, Haverhill, and Lowell, aided by charts showing the averages of monthly analyses of samples taken at these points. The causes of the excessive pollution below the City of Lawrence are the sewage from several cities and towns, manufacturing wastes from the process of wool scouring and wastes from other concerns. The wool scouring wastes are very objectionable and their effect upon the river condition furnishes the basis for the recommendations as to the further treatment of wool scouring wastes. Objectionable conditions caused by the discharge of sewage near the banks of the river and plans by which objectionable conditions can be removed from the river at Lowell, Lawrence, and Haverhill are designated. Suitable maps of explanation are included as well as analyses of waters at various points in the river.

An important contribution to the subject of the disposal of wool scouring wastes.

1913

Danvers River and its Estuaries. (*House, No.* 2201.)

Report of the State Board of Health upon an Investigation of the Danvers and its Estuaries.

Dr. Henry P. Walcott, Chairman, pp. 1–6

An investigation made in accordance with (Chap. 84, Resolves of 1912), to ascertain whether it would be feasible and safe to construct a dam at Beverly Bridge and what changes in methods of sewage disposal of cities and towns in the watershed would be necessary to maintain a sufficient degree of purity in the basin.

The report includes a sanitary survey of the Danvers River, its tributaries and of towns within the watershed, together with an account of the objectionable conditions contributing to the serious pollution now prevailing therein. Remedies are suggested for the elimination of the gross pollution and for the general improvement of the river and basin. It was thought advisable to construct a half-tide dam allowing free flow of the tide into and out of the basin, and to make certain improvements in sewage and waste disposal methods.

Report of the Engineer. *X. H. Goodnough,* pp. 7–27

In this report are given in detail a complete description of the Danvers River and its tributaries, the existing conditions of sewerage, methods of sewage disposal employed within the watershed and existing conditions giving rise to the serious pollution of the river and basin. Measures necessary for the prevention of the present objectionable pollution are stated, and the practicability of improving the sanitary condition of the river by means of a dam at Beverly Bridge is discussed. The impracticability of a fresh water basin was shown.

Chemical Examinations of Water. pp. 30–32

1913

Dorchester Bay. (*House, No.* 1840.)

Report of the Joint Board on an Investigation as to the Advisability and Cost of Improving the Shores of Dorchester Bay.

Dr. Henry P. Walcott, Chairman, pp. 1–3

This report, which was made jointly by the State Board of Health and the Directors of the Port of Boston, treats of the nuisances caused along the shores of Dorchester Bay mainly by the dumping of large quantities of refuse of various kinds, but in part by the discharge of sewage at times of storms from sewer overflows along the shore. Filling in a portion of the bay was advised as a remedy for the existing nuisance and moreover it would add twenty-five acres of land to the area already filled at the upper end of the bay.

Report of the Engineers.

Frank W. Hodgdon and X. H. Goodnough, pp. 4–9

This report details the principal causes of nuisances and the practicable means of remedying the existing conditions; with estimates of cost, maps, etc.

1914

The Addition of the Town of Reading to the North Metropolitan Sewerage District. (House, No. 6.)

A Joint Report by the Metropolitan Water and Sewerage Board and the State Board of Health Relative to the Addition of the Town of Reading to the North Metropolitan Sewerage District.

Dr. Henry P. Walcott, Chairman for the Joint Board, pp. 1–3

A report of an investigation of the conditions affecting the disposal of the sewage of the town of Reading, the expediency and cost of disposing of the sewage of the town into the North Metropolitan Sewerage System. It was recommended that the town of Reading should be made a part of the North Metropolitan Sewerage District.

An Act to Provide for the Addition of the Town of Reading to the North Metropolitan Sewerage District. pp. 4–6

A proposed act.

Report of the Chief Engineers.

Messrs. Frederick D. Smith and X. H. Goodnough, pp. 4–11

A report by the chief engineers of the two boards giving details and estimates.

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