FRONTISPIECE
drawn by
MABEL KEYES BABCOCK

PANORAMA OF A STREAM'S POLLUTION.

INSTRUCTOR IN
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CONSERVATION BY SANITATION

AIR AND WATER SUPPLY
DISPOSAL OF WASTE

[INCLUDING A LABORATORY GUIDE
FOR SANITARY ENGINEERS]

BY

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TO

G. M. H. AND I. F. H.

A remark of appreciation accidentally coming to my ears many years ago gave me courage at a critical moment in a difficult path.

A daily companionship of twenty years sustained often weary hands. The translation of crude and hasty suggestions into effective action is the greatest satisfaction in life.

FOREWORD

THE SPIRIT IN WHICH THE PROBLEMS OF MODERN CIVILIZATION, ESPECIALLY THOSE IN RELATION TO AIR SUPPLY AND VENTILATION AND WATER SUPPLY AND WASTE DISPOSAL, ARE TO BE APPROACHED AND SOLVED

THE sanitary engineer has a treble duty for the next few years of civic awakening. Having the knowledge, he must be a *leader* in developing works and plants for state and municipal improvement, at the same time he is an *expert* in their employ. But he must be more; as a health officer he must be a *teacher* of the people to show them why all these things are to be. The slowness with which practicable betterments have been adopted among the rank and file is, partly at least, due to the separation of functions, of specialization, and partly to the exclusiveness of agents in the work.

The individualism of the nineteenth century extended to the domain of hygiene. The physician looked after the interest of his patient, not of his patient's neighbors, and the mass of the people went their own individual way without giving him a chance until the mischief was done. The advocates of Preventive Medicine, among whom were some of the most eminent physicians, found stony fields for the seed they wished to sow. The engineer had to plow this field, lift out the stones, and prepare the ground. The application of sanitary principles used for the benefit of the people with the same energy and business sense as has been used for the profit of the individual, will soon prove that sanitation will *pay* as well as railroads and machine shops.

Sanitation cannot be fully developed until capital employs the expert in both engineering and sanitation to plan for the masses of people who have not the means either financial or practical to live under such conditions as make for their own happiness and the State's wealth. Hence the new era we are entering upon demands a new training, a fresh point of view. It may be that fortunes will not come so readily to the engineer as they have come to the business promoter, but there will be honorable and well-paid employment. It is open to the sanitary engineering expert to do a service never before acceptable. Therefore this side of the professional training should be kept in mind. Knowledge vital to the health of the people should be made as accessible as possible at as little expense and trouble to them as may be.

Here the paths of medical tradition and modern sanitation diverge. In spite of the early recognition of Preventive Medicine and State responsibility, that branch has not until now flourished in medical education. It is a question how far tradition hampers it in its future progress, but no tradition or precedent hampers sanitary engineering. As its name implies, it is all the wealth of engineering knowledge applied to sanitary measures. There must be added the idea of making available this knowledge as quickly and completely as possible, even if some of the application is premature. It is better to believe that all dirt is dangerous rather than to hold it of no consequence how thick the dirt lies. The engineer always uses a factor of safety.

It was better to disinfect needlessly than to suffer longer the unchecked spread of disease. So much of the past work done under the impulse of half knowledge or even under misapprehension of causes has been of value educationally that it cannot be regretted.

It should not be counted against the sanitarian that he cried fire when there was only smoke and sometimes even only dust with no danger of fire. It caused a looking after danger spots, and was much better than the old medical practice, which usually locked the stable door too late.

Let the education of the people go on through mistakes, through excess of zeal, if it must, but go on all the time it must. As experience accumulates, wiser means will be found. Let the sanitary engineer seize his opportunity to lead in the application of all knowledge to the betterment of living conditions. Let him not forget the need of teaching the people the value of his services to the community as a teacher as well as an expert.

PREFACE

THE experience of twenty years since the first class of sanitary engineers was graduated in 1890 has led to the compilation of these pages from the notes prepared annually for each succeeding class. The work of arousing the intelligent humanitarian is done. The economist and the sociologist are to be confirmed in their awakening interest, but *too popular* movements are to be deprecated in the beginning of any science.

Sanitation has broadened to a substantial base and there is room for a treatment of the subject from several sides. This volume is primarily a laboratory guide, with résumés of the principles given in the lecture course which accompanies the laboratory, made at the same time readable, it is hoped, to the engineer and health officer who may not have had as full laboratory training. It is not a complete guide for the untrained practitioner; it assumes familiarity with both the bacteriological and the chemical laboratory and access to an engineering library. It is stimulating rather than complete. As one of the youngest divisions of engineering, the subject is barely fledged, not full-fledged by any means. The school course has been loaded with details not agreeing with the bewildering surroundings of the actual plant. The student recently graduated is apt to become confused in his work or abnormally confident in his newly acquired information.

If the engineer can leave school with enthusiasm for his work, with a vocabulary and list of references of recent date he will make his way. If he has a sense of background behind him, a knowledge that these subjects have a past history and will have a future even after he has done with them, he will be in a temper to do good work for his time, not too confident on the one hand and not too pessimistic on the other to be of use. It is this attitude of moderated enthusiasm that we hope to foster.

The thanks of the author are due to the classes who have been the subjects of experimental notes; to Miss Mabel Babcock for her spirited interpretation of a sketch of American unsanitary habits; to Miss Lillian Jameson for careful proof reading; and especially to Mr. Royce W. Gilbert, who has criticized step by step with great judgment and insight, and without whose aid the volume could not have been prepared.

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CONSERVATION BY SANITATION

CHAPTER I

AIR: A NEGLECTED RESOURCE

COMFORT, DUTY, PROFIT. MODERN NEEDS DUE TO TIGHTER HOUSES, MORE FOOD AND CLOSER LIVING

MAN has learned very slowly the condition of his own safe living. Of the three essentials, air, food, water, the air he breathes and is surrounded by, being invisible, is the least known of all.

Before the time of Galen, B.C. 200, air was supposed to be carried in the body by the arteries. It was about 1553 before Servetus in his search for the connection between the breath of life and the soul discovered the circulation of air through the lungs and that the bright color of arterial blood was taken on there. He was burned at the stake for his unholy work.

In 1668 the real office of air was discovered by Mayow but was lost sight of for many years.

Respiratory exchange and its physical and physiological relation is of only recent scientific proof, and even now cannot be fully explained.

It is not to be wondered at that to most persons the word *air* means very little. They are so used to taking air like other cosmical phenomena, "as it comes," that they are not conscious of the effect of different qualities of air upon their brains and bodies. It is only when they themselves are smitten with the more spectacular forms of disease caused by bad air, such as tuberculosis, and when a physician in whom they have confidence assures them that their only chance for life is to live out of doors, that they begin to realize that the indoor air they have been taking must have been bad.

To account for the effects of outdoor air, one theory after another has been propounded — such as ozone, aromatic essence from certain trees, dryness, dampness, rarity, density, freedom from earth exhalations, etc. It is one of the great advances of modern science to have discovered that just simple ordinary outdoor air is a most valuable health resource; that a balcony on a city street is a thousand times better than a room in a house closed for fear of drafts, curtained for fear of fading the furniture, and lighted by a lamp.

The long delay in discovering that it was the mosquito and not the night air that brought malaria, caused the habit of closed windows in the country; the fear of burglars was added in the towns; and the cities grew up with the habits of the country; added to the small and smaller living spaces, until thousands of men, women, and children smothered in the products of their own breathing.

It is not too much to claim that only the application of the laws of physics and mechanics have proved the various early medical empirical theories insufficient.

It is free air, air in motion, that is needed. Motion is an essential factor in life. The still animal is dead matter. Living water is flowing water. Fresh air is air in motion; if the sun shines on it, so much the better. Confined air has an effect like wrapping up in cotton wool. On the other hand, moving air carries away with it the elements of discomfort — heat, moisture, CO_2, odors; and, if from the right quarter, brings to us ozone, oxygen, freshness, dryness, and general stimulation.

The engineer and the architect have been expected to provide all these advantages without cost because "air is free"; they have only to draw their plans as they should be drawn, provide ducts, etc. Result: failure in a large number of cases.

The time has arrived when the engineer and the architect must work together to uphold their professions.

The pioneer held food, which was only to be had by the sweat of his brow, the most costly of his needs. Water required a little effort, either daily to bring it from the stream or spring, or once for all to pipe it to the house and barn, or to dig a well to serve his own and his grandchildren's needs. Air was *free* — in winter it was an enemy, even, to be kept out of the dwelling. Mankind's primitive habits linger long in the unconscious cerebration of the race.

A distinguished engineer wrote only a few years since: "Food is costly, air is free. If man had to work . . . for air as he does for food, he would value it."

Under the latest conditions of crowded modern living, taking account of space, fuel, etc., it is estimated that to supply a family with fresh air costs the householder about one-fourth as much as food, only he does not find it set down in his bill for rent (air space) or for fuel (air moving power, circulation). Air does not circulate in pipes in rooms as does water, but through the whole space; is not an item for which he pays when paying his car fare, or when he buys his theater tickets. Baseball grounds have no roofs and the air circulates freely; this, perhaps, gives that game considerable advantage over the theater.

The cost of the present-day schoolhouse is enhanced 10 to 15 per cent by the cost of the air supply, screened, washed, and circulated; cooled or heated, as the season demands. The city taxes contain hidden under other names charges for clean air, oil or water for streets — cleaners, smoke consumers, special ordinances on nuisances, etc.

Clean "fresh" air at a comfortable temperature is not free to a single city taxpayer. It is hardly attainable at any price to the lodger, the tenement dweller, the factory worker.

The best that the law can do is to see that the confined air is not vitiated to an immediately dangerous extent.

Contaminated air, affecting as it does the body processes, metabolism, acts as a slow poison first by reducing the body's resistance and thus allowing its various enemies to secure a foothold. It is generally understood to-day by investigators that no one or several substances found in " bad air " act as an external poison, but that the danger lies in the interference with the normal body metabolism. Thus no one would think of calling heat a poison, and yet it affects the mechanism which regulates body temperature, the most important constant of living tissue. Humidity acts indirectly in preventing that loss of heat which regulates body temperature. It has been estimated that 22.9 per cent of the loss of body heat is by water evaporated. This loss is increased by exercise twice or even three times, — from 935 grams H_2O in twenty-four hours to 2848 grams when working.

Man cannot control the temperature of outside air, the amount of water it contains, or its pressure; to some extent the amount of impurity it contains may be controlled. Oiled streets and dustless pavements may be insisted on. The city should carry out its duty towards its citizens in the matter of clean air by keeping its streets free from dust and dirt — such as the grit from abrasions of the surface, ground-up droppings, iron dust from wheels and carts, bacteria from dried sputum, etc. — which would otherwise be lifted by the wind.

For example, the State might be visualized as immersed in a great sea. Here and there a city is sending up great clouds of dust, smoke, and foreign gases which may be likened to city sewage rising from points at the bottom of the clear sea. Between these great sources of pollution run connecting roads, boulevards, railways, each sending out all along its sinuous course dense currents of waste and contaminated air. Along these lines of pollution appear houses and factories, often emitting foul air themselves and completely surrounded by dense clouds of air sewage, only appearing to the view as sudden gusts blow the mass away. This sort of visualization will lead to the conclusion that even outside air is bad in the vicinity of cities. It is, but it is better for the most part than indoor air. A man living all his life in the open is said to be able to smell the bad air of a city the moment he steps inside its gates.

We who live and smother in our own and our neighbors' exhalations grow accustomed to the stench.

Out of doors in the daytime is not, however, for the workers of the world. Only the so-called leisure classes and workers in certain occupations, as agriculture, can enjoy that privilege. The work of the world is carried on indoors. Most people, whatsoever their occupation, can, however, with little trouble manage to approximately sleep out of doors. Almost any room having windows on two sides can be kept full of outside air at most seasons of the year. Just as windows wide open from top to bottom will convert an ordinary schoolroom into a model out-of-door school for the anæmic children of our big cities, so wide-open windows may, *if properly arranged*, convert an ordinary bedchamber into an out-of-door camp for the tuberculous.

The difference between indoor and outdoor air is in small additions, chiefly odors and heat, and in stagnation or "closeness" so that the layer of air next the skin is not changed rapidly enough for comfort. Overheating is the most common difference, and this makes the presence of products of respiration harmful. The Eskimo in his snow hut has the best absorbent in the melting ice.

General discussion for improving the air in enclosed spaces:

(1) Comfort: people will pay for it quicker, perhaps, than for sanitation. Example — theaters.

(2) Duty of cities, to supply better air in the schoolhouses because of effect on future citizens in the development of the race.

(3) Profit: solid cash for owners of factories, etc., in increased capacities of workers. No humanitarian dream of duty, but a business proposition of increased income.

This education of the people to the necessary cost in money (neither time nor strength can supply the want in case of air and water) of sanitary living is one of the duties, as well as privileges, of the sanitary engineer in his sociological relations and is the reason for this brief discussion in this place.

CHAPTER II

STANDARDS OF AIR SUPPLY

CURVE OF COMFORT

AIR in motion is necessary. When man put a flat roof over his head and windows in the lower part of his room he began his downward career in health. Warm air rises into a cooler medium, and common sources of bad air give also warm air. Man's breath yields carbon dioxide, heat, and moisture; man's body adds heat, moisture, and odors. Lighting and heating, cooking, sweeping, dusting, even walking on the floor, especially if carpeted, each adds its quota. The resulting gaseous mixture would readily escape if an opening was left, but as it cools by contact with cold walls it sinks to envelop the occupants, deaden their senses, and force back into the body the refuse which freely moving air would carry away. Such at least is the engineer's working theory of house ventilation to-day.

Satisfactory ventilation is the result of the action of several variables, chief of which are *humidity*, *temperature*, and *carbon dioxide*. Dust, escaping gas, other products of combustion than CO_2, disagreeable odors from persons, clothing, etc., unsealed sewer traps, — all become more or less important factors at times. Many of these factors may be eliminated by cleanliness, and the engineer should insist that this extra demand upon the apparatus should be removed.

Removal of carpets and upholstered furniture from public halls, or at least their cleansing by vacuum air-sweeping apparatus; floors and walls nonabsorbent and easily cleaned; air ducts smooth and freed from dust by sweeping; electric lighting; absolutely tight joints in sewer and gas pipes, if insisted upon, would render the life of the ventilating expert more tolerable. The noxiousness of confined air is caused not only by accumulated CO_2 but also by heat, by excessive humidity, by unpleasant odors, especially from the sebaceous, sudoriferous, and intestinal secretions.

In the absence of a better indicator, 10 parts in 10,000 CO_2 may mark the change to discomfort, because accompanied by the other factors.

Processes of cooking and cleaning, and the appliances of heating and lighting, escape of ferrosilicon, unburned gases (CO,H, hydrocarbons), steam, each gives an increment of danger.

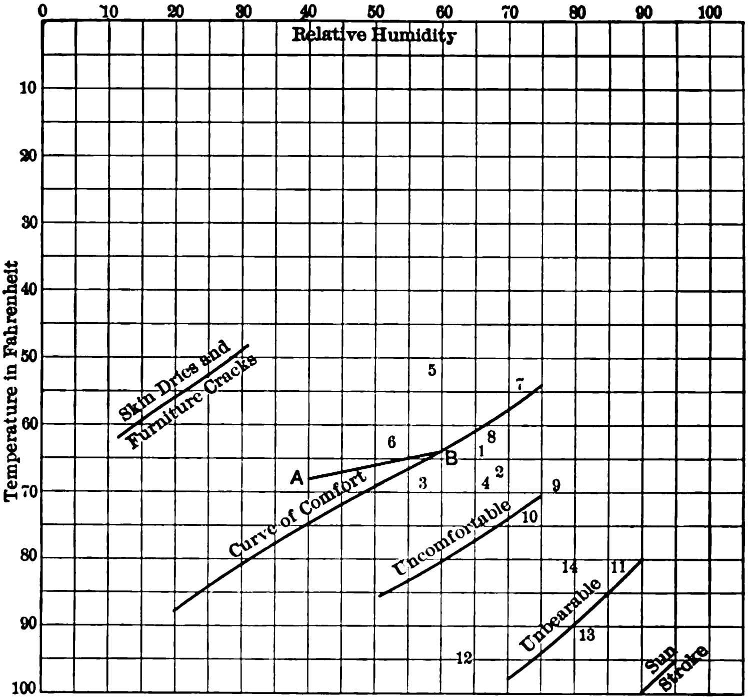
The air of occupied spaces contains a greater or less amount of dust of both organic and inorganic nature. The organic particles may be either living or dead. Before methods of bacterial determination were perfected this organic matter was figured largely in chemical examinations of air.

Because it was constantly present and because some explanation of the effect of "crowd poison" was demanded, a resort was had to the theory of the presence, in expired air, of volatile organic substances poisonous in their nature.

Ransome in 1870 (*Jour. Anatomy and Physiology*) and Ufflemann in 1888 (*Archiv. f. Hygiene*) used the reduction of potassium permanganate to show the presence of organic matter (0.2 gram in twenty-four hours). Remsen in 1880 (Bulletin of the U. S. National Board of Health) used pumice stone as absorbent and Chapman's suggestion of distillation with alkaline permanganate and estimation of the produced ammonia. In the Massachusetts Institute of Technology Laboratory of Sanitary Chemistry, 1884 to 1887, many experiments culminated in the conclusion (Marion Talbot, *Technology Quarterly*, 1887) that the source of the organic matter in the air of rooms was the invisible dust suspended in the air and not in matter given out by healthy persons.

Seegen and Nowack, 1879 (Pflüger's Archiv., Bd. XIX), found expired air poisonous to small animals. Brown-Sequard and d'Arsonval, 1887–1888 (*Comptes Rendus*), found the aqueous washings of expired air poisonous to animals when injected into the blood, and although they recognized the presence of ammoniacal salts, they suspected the presence of alkaloidal substances similar to leucomaines and ptomaines. They held that expired air participated largely in the production of pulmonary tuberculosis, and this opinion stimulated investigations, so that for a period of ten years much work was done alternately pro and con.

The Curve of Comfort



Mean annual temperature and humidity of health resorts:

1 Algiers
2 Alexandria
3 Cairo
4 Bermuda
5 Arequipa
6 Luxor–winter
7 Los Angeles
8 Madeira

Unfavorable to white man's residence:

9 New Orleans
10 Havana
11 Malay Archipelago
12 Persia
13 India
14 Singapore

A-B Most comfortable for indoor workers (Hill).

Emanuel Formanek, Prag (*Archiv. f. Hygiene*, 1900), reviewed the previous work, made experiments with modern appliances, and since then observers have accepted his conclusions, i.e., that the healthy lung or skin does not give off poisonous volatile organic compounds; that ammoniacal salts are poisonous to small animals and have been the cause of some otherwise conclusive deaths under experiment.

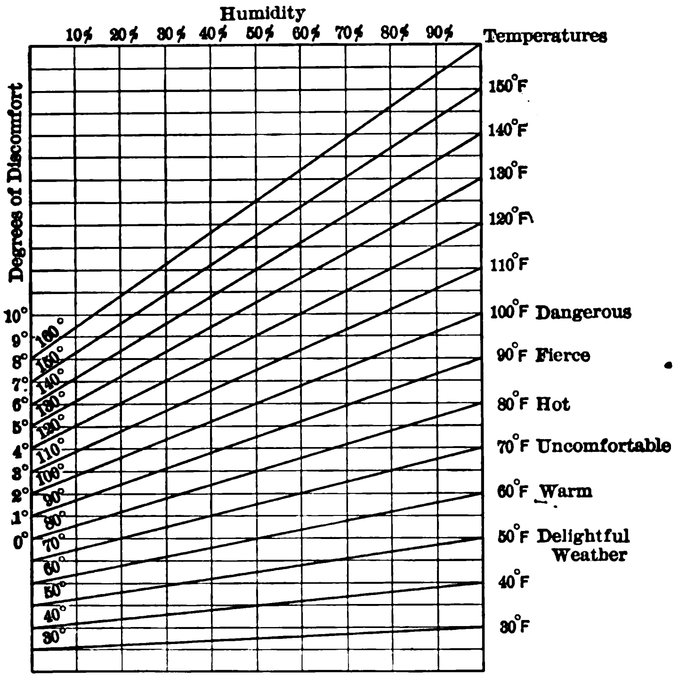


Chart to Show "Degrees of Discomfort"
By Mark R. Lamb in *Mining and Scientific Press*, Aug. 27, 1910.

Experience of twenty-five years with various plans of artificial ventilation of closed space leads to a certain standard of air content which permits efficiency of workers and thinkers. This standard must take account of the psychic factors mentioned. The chief of these is a sensation of comfort, or rather the absence of anything which may suggest discomfort.

To illustrate the conditions which seem to meet the requirements of the majority, the Curve of Comfort based on such records as are available has been plotted as a beginning of what may prove a rational working hypothesis for architects and engineers. This curve, as will be seen from the references, shows the opinion of experts as to favorable and unfavorable climatic conditions.

The favorable conditions of the air for workers are 64° to 68° F. and 40 to 60 per cent of saturation (humidity). At 60° F. 70 per cent relative humidity is bearable. At 80° to 86° F. there should be as little humidity as possible. At 86° F. 60 to 70 per cent humidity is distinctly unfavorable. "A temperature equal to or greater than that of the body cannot be tolerated if the air be saturated with moisture." (Leonard Hill, "Recent Advances in Physiology and Biochemistry," p. 270.) This is a condition favorable to heat apoplexy. (See chart.)

Extremes of heat are better borne when the air is in motion than when it is still. Extremes of cold, on the other hand, are better borne when the air is still.

Roughly, every increase of 27° F. doubles the amount of water vapor the air can hold in proportion to its weight.

According to Macfie ("Air and Health," p. 97), dry air quickens metabolism, both through its cooling and its drying capacity; damp air slows it with a consequent depression or accumulation of toxins. Water vapor is a far better conductor of heat than dry air, and thus air saturated with vapor at 35° F. is raw and chill. (Hill, p. 258.)

With a temperature only 60° F. and humidity 80 per cent, 12 parts per 10,000 CO_2 is common in English practice, while the reverse, the temperature at 80° F. and humidity 60 per cent, only 6 parts CO_2 is common in American practice. Both fall in the *unfavorable* zone.

It is not suggested that audience halls or living rooms can equal the world's playgrounds in healthful conditions, but surely a nearer approach might be made to the curve of comfort if house dwellers and architects would insist on better management of details.

CHAPTER III

WHOLESOME AIR SUPPLY

THE SANITARY INSPECTOR. TESTING APPARATUS AND RECORDING INSTRUMENTS

IN the near future each city will need an engineer with sufficient training to inspect the conditions of its public buildings, its model dwellings, as to both air supply and waste disposal.

The supply of water is now more nearly regulated; the pressure in the city main forces the water out when the faucet is opened. But the existence of an air duct is not sufficient unless there is like pressure behind it. If there is, a draft is caused as objectionable to most persons as would be the stream of water from the faucet.

Because waste water runs by its own weight from the lowest point, and because carbon dioxide is heavier than air, the popular fallacy is almost ineradicable that waste air will go out of the bottom of the room if it has the chance. These two notions the engineer has to combat. When he circulates sufficient air through a closed, crowded space, *drafts* is the cry. When he opens up sufficient ducts, *cost* is the louder cry. As Professor Woodbridge puts it, " Your money or your life! "

The sanitary engineer will find certain means of obtaining good air in use. He will be called upon to inspect them to see how far they are answering their purpose and, if not satisfactory, how to improve their working. This is a more difficult task than constructing from the ground, and it is more difficult to persuade an owner to pay for modifying or undoing that for which he thinks he has already paid exorbitantly.

The whole matter of ventilation — change of air in enclosed spaces — is very simple in theory. There are two principles to be carried out scientifically:

(1) *Natural ventilation.* Contrary to common opinion, foul air coming from human bodies or lights *always rises* and strives to get out at the highest point, and if a sufficiently large and warmed outlet is furnished so as to keep the air warm until it gets to the roof there will be no trouble. Fresh air will come in from the bottom and sides of the room and should come through many small openings. The one essential is a *hot* air shaft of sufficient capacity to take all the foul air and hot enough to keep up a good current. The failure comes in expecting a cold air shaft to "draw."

(2) *Forced ventilation,* or compelling the air to go where it should whether it wants to or not. This is accomplished in three ways:

(*a*) By a fire at the bottom of a tall chimney drawing up air with great force; open fireplaces.

(*b*) By the so-called Smead or similar system, where the fire is in the basement and openings at the bottom of the rooms permit air to pass by devious ways into the sufficiently hot air shaft. (I never saw one of these which did what it was expected to do.)

(*c*) By mechanical or fan ventilation, which is now *successfully* applied to factories, schools, theaters, etc., only when the persons in control of the apparatus are intelligent enough to run it properly.

The so-called *plenum system* furnishes an admirable circulation of air in a building with smooth ducts, washed air, oblong rooms of no great size, with tight windows, and occupied by relatively few people. The slight pressure outward prevents cold indrafts from the window casings, prevents ingress of dust and outside odors. The heat and humidity may be perfectly regulated. Altogether an apparently ideal system so far as machinery is concerned.

The writer has had the experience of working in the first building put up with this ideal in mind and of meeting the human obstacles to its perfect success. It is safe to say that to the average person an open window means fresh air, a closed one, especially a fastened one, means oppressive air. To be told that one must not open the windows is to condemn any system. Again, when indoors, the least feeling of moving air means "catching cold," and the velocity required to change the air rapidly enough for a large number of persons in a limited space is intolerable to a majority of those who enjoy ten times the breeze in an automobile. The engineer has to reckon with these psychic obsessions as very real obstacles to his work.

The ideal modern system of mechanical ventilation is a combination of push and pull. A plenum inlet and an exhaust fan to the outlet. This obviates the high velocity at inlet which is essential if all the power for the movement of the air is located at that point.

By a combination of natural up-draft aided by mechanical suction instead of using force developed by heat, the *exhaust fan* is installed, for lavatories, laboratories, and many factories with noxious gases.

In a building used by many persons for many purposes coming and going, the regulation of the currents of air so that they shall go in the desired direction and not in the opposite, requires the constant attention of an intelligent and informed janitor.

With any aided natural system, the window leakage may reach 30 per cent. Tests of air leakage around windows were reported by Mr. H. W. Whitten at the recent meeting of the American Society of Heating and Ventilating Engineers. He has found that with a wind pressure equal to 0.1 inch of water outside a window having a $\frac{3}{32}$-inch clearance between window frame and sash, 105 cubic feet of air were driven per hour through each lineal foot of such clearance space, while with a $\frac{1}{16}$-inch clearance the leakage was 184.8 cubic feet per hour. With other windows, equipped with good metal weather strips and subjected to the same pressure, the leakage amounted to no more than 12 cubic feet per lineal foot per hour. In tests made with a pressure of $\frac{1}{2}$ inch of water, which corresponds to a wind velocity of 24 miles per hour, leakages were noted of 19 cubic feet for $\frac{3}{32}$-inch clearance, 402 cubic feet for $\frac{1}{16}$-in. clearance, and 45.6 cubic feet for the sash with the weather strips. With a pressure double that used in the latter case, equivalent to a wind velocity of 48 miles per hour, the leakages were 432 cubic feet, 591.6 cubic feet, and 69 cubic feet.

Parker and Kenwood state that "with less than 250 cubic feet of air space per head, no ventilation can be satisfactory which is not aided by mechanical force."

While the pure sanitarian may declare, as has been already quoted, that it is a question of money for ventilation or for funeral expenses, the sanitary engineer is forced to consider waste of fuel in his testing of efficiency. As a rule he can save his consulting fees in showing the steam engineer how and when to economize heat in a public building using mechanical ventilation.

To apply force when and where it will do the most good, to shut off both heat and power when their use will be waste, — all this means a study of the particular space in relation to the particular needs of the occupants. No general directions can be given to suit all cases. The result to be reached is the comfort of the intelligent majority, since that is on the whole the best criterion we have. It is at the same time true that unintelligent persons may think they prefer dirty air as they put up with dirty water, dirty food, dirty clothes.

The processes of testing and the use of recording instruments will be discussed in Laboratory Notes.

Much has appeared in the public press in relation to ozone as an air purifier. The pleasant results from various aromatic oils used as sprays have been attributed to the revivifying effect of ozone. Its direct use has been tried with some success. More prolonged scientific investigation is needed before the reason for an apparent "freshening" of the air when treated with ozone is fully understood. The introduction of ozone unaccompanied by chlorine, nitrites, or other objectionable gases can only be beneficial in moderate quantity.

The most noticeable increment of the air of an occupied room — odor — may be steadily given off from saturated walls, furniture and clothing, and be so small in quantity as to be detected only by the sense of smell.

The carbon dioxide in amounts less than twenty parts may be negative in effect within the curve of comfort.

The perspiring skin feels drafts which chill by carrying away moisture. The pernicious habit of keeping on outside clothing in audience rooms is responsible for much of the engineer's troubles. Overclothing is induced by the need of protection while waiting for cars on street corners or in passing from overheated, close workrooms to the chill air of a severe and variable climate.

Fashion must decree an extra wrap instead of heavy clothing.

It is only the closest combination of scientific laws of the movement of gases with experience of the elements of interference with these movements, material and human, that can devise a workable means of giving to people good air in a suitable space and giving it in spite of opposition and hindrance.

Such is the mental condition of most people that furnishing them fresh air is like giving a child a nauseous dose of medicine, he has to be *made* to take it. He is sure he does not need it. Just as no man is willing to admit that his food is wrong, so no man will admit that he does not know fresh air when he meets it.

It is only by some great crusade like the present campaign against tuberculosis that a whole nation is aroused and put in a mental condition to learn a few necessary facts. A few of these the engineer should be conversant with and as a scientific man he will hold opinions as working hypotheses until further investigation.

WATER SUPPLIES

THE NATION'S MOST VALUABLE ASSET

WITHOUT WHICH ALL VEGETABLE AND ANIMAL LIFE WOULD CEASE

CHAPTER IV

WATER SUPPLIES

A. Development from Ancient Times. B. The Modern Waterworks. C. The Indicated Future

A. ANCIENT WATERWORKS

Aside from any question of pure water, water as water is an absolute essential to life. From the beginning of the world up to a very few generations ago this economic value of water as water controlled the history of water supply, and the history of water supply in turn controlled the history of the race. Wherever there was an abundance of water, there civilization flourished; wherever it was lacking, there civilization and eventually life itself vanished. It is an established fact that the amount of water available to man in any given section is one of the best indexes of the development of that section. When the difficulty of procuring water increased, culture waned. This has been the history of Asia and Africa and of sections of our own country.

Water is a prime necessity for human life, not only as regards the few liters we drink with our food but also for the animal whose skin we wear, whose flesh we eat, and for the vegetable crops we depend upon.

In the nomad state man's wanderings were limited by the existence of flowing or dug wells. Abundant flow was frequently celebrated as a holy shrine, and the man who found hitherto unsuspected water was regarded as a benefactor.

Settlements have always been on flowing streams from the garden of Eden down. Water was necessary as a carrier and cleansing agent in greater quantities than could ordinarily be obtained from wells and springs. The latter, it is true, furnished most of the early drinking supplies, due to the natural æsthetic aversion of the people to drinking their own waste, an aversion which we appear to be somewhat outgrowing to-day. The river was the natural laundry and the natural place of disposal of waste material.

Even down to the nineteenth century people looked upon water supply as a question of economy and convenience. They used it for irrigating crops and for washing but drank tea or some other beverage of a more or less bactericidal nature. Occasionally they visited some holy shrine and there partook of well or spring waters so grossly polluted in most instances as to make it appear that the shrines must have had some miraculous properties in order to enable their visitors to return home alive.

The first water filters were porous earthen jars devised for *cooling* the water, although the observations of a few early wise men may have been enough to connect cause and effect without allowing the common people to suspect reasons.

It was not, however, until communities of considerable size grew up in wet climates like London that serious attention began to be paid to quality of water supply. In the tropical and arid lands the periods of drought dried and cleaned the earth and vegetation purified it so that the sickness which usually accompanied the first rain passed for the effect of climatic seasons.

The Roman supplies were provided for æsthetic reasons rather than sanitary in the modern sense of the word, and were abundant only for the few.

The great plagues of the sixteenth, seventeenth, and eighteenth centuries gradually brought public attention to the conclusion that dirt and waste had something to do with sickness.

In certain instances where water was plentiful at one season and scarce at others early engineers in India, Ceylon, and other Eastern countries built large tanks or reservoirs for the storage of water to be used for irrigation. Remains of these great works are still visible and attest the engineering skill of these first engineers in the history of the world. As a rule, however, these works were all constructed with a view to uses other than drinking.

Great canals and tunnels were constructed by the Assyrians and Persians, yet no large supply of water was furnished the people. In Judea, where waterways were extremely scarce, the wells and springs of a district were held of great value on account of the necessity of water for the herds of cattle and sheep. Possibly this habit of placing value on clear water, which was essential to the herds, led to the great works of the supply of the city of Jerusalem, commonly attributed to Solomon.

"At various times since the days of King Solomon efforts have been made to secure a water supply on which the city could depend. About 7½ miles to the southwest of the city of Jerusalem on the carriage road to Hebron, are three reservoirs, known as Solomon's Pools, built at different elevations so that the water might flow progressively through them. These were constructed in the bed of a valley, across which heavy walls were thrown and cemented. They were filled during the rainy season with water from the surrounding hills, and this was augmented by the inflow of a small spring a little higher in the valley, known as the 'Sealed Fountain,' and some other small springs. From these pools a masonry aqueduct was built, which, winding around the hillsides, carried the water to the temple in Jerusalem."[1] The entire course appears to be on the surface of the ground, or only slightly buried. The watercourse itself is constructed of earthenware pipes about 15 inches in diameter. These are well joined and are, in turn, enclosed in hollowed marble slabs; the entire aqueduct is then enclosed in concrete, well protected with stones and earth. At one point this conduit necessitated a tunnel 300 feet long through solid rock.

"In the sixteenth century of our era the Mohammedans remodeled this aqueduct by replacing the open trough with pottery pipes, portions of which are still in use. In the second

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[1] Engineering Record, August 13, 1910.

century the Romans had begun to carry into execution an ambitious scheme, which they seemingly were never able to finish. Their source of supply was Ain Arroub, a large fountain which is also on the road to Hebron and about twice as far from Jerusalem as the Pools of Solomon, whose water was led into the middle of Solomon's Pools, and also Bir ed-Derej in Wadi el-Biyar, whose waters were led through a large conduit, through channels cut in the rock, and through a tunnel to a point above the Pools of Solomon. These waters were led to the city by two aqueducts, the lower one carrying the water accumulated in all the pools, and the upper one conveying the waters of the Sealed Fountain and of the Bir ed-Derej. The latter descends into the valley and then rises again, running through stone siphon pipes. These were made of solid blocks of stone about 3 feet square and 2 feet thick, pierced by a hole 15 inches in diameter, and cemented together. Each one was made with a shoulder on one side and a flange on the other by which they fitted into one another. Part of this work is still to be seen."[1]

Joseph's Well. The most remarkable well probably ever made by man is Joseph's well at Cairo. This great well is excavated in the form of a rectangle 24 feet by 18 to a depth of 165 feet through solid rock, at which depth it is enlarged to a large chamber containing a basin or reservoir to receive the water raised from below. On one side of this chamber another shaft is continued 130 feet lower, making the total depth 287 feet. This deeper shaft is 15 by 9 feet, and through it the water is raised into the basin by means of pumps propelled by horses. The manner in which these animals are enabled to descend into the chamber is one of the most interesting features of the well. A spiral passageway is cut through the rock, it winds around the exterior of the well, with so slight a grade that the animals may walk up and down. The pumps consist of endless chains or ropes to which are fastened earthenware jars.

Rome. The ancient Roman supplies have been so often de-

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[1] Engineering Record, August 13, 1910.

scribed that any lengthy description is unnecessary. At the height of Roman power they consisted of nine aqueducts bringing water from rivers, lakes, and springs. Of these aqueducts those constructed by Frontinus are perhaps the best known, as well as the greatest pieces of work. The Annio Novus is a little over 62 miles in length, about 48 miles being under ground and nearly ten miles carried on arches at times reaching an elevation of 109 feet above the surface of the ground. The best water was conveyed by the Aqua Marcius. This, at the time of Claudius, was reserved for drinking purposes alone. The Roman judgment of the quality of water was based upon the following simple definition: "A wholesome water must be clear and transparent; must have no odor; must leave no sediment in the bottom of the vessel on standing; and must not coat the bottom or sides of a vessel upon heating."

The arrangement of the distribution channels inside the city walls is of considerable interest. The various aqueducts entered the city at different elevations; therefore each was made to serve that section of the city whose elevation was most nearly that of the neighboring aqueduct. Nearly all of the distribution was by means of lead pipes leading from the aqueduct to community reservoirs. From these reservoirs, in turn, lead pipes ran to the private houses served. In each house so served was a private reservoir of lead from which the water was distributed to the various baths and fountains of the house. In the community reservoir at the entrance of each house pipe was placed a metal orifice to measure the flow of water. This orifice was duplicated at the end of the pipe of the private reservoir, thus providing a check on the quantity of water used. These orifices were originally of lead, but the wily householder soon discovered that he could expand the leaden orifices and so obtain a greater flow of water at the same rental. They were therefore changed for bronze tubes delivering a definite amount. The repair work of the Romans was carried on in a very businesslike manner. In order not to interrupt the supply longer than was absolutely necessary all the materials and the workmen required for repairing an aqueduct were gathered together at the point where such repairs were needed before the supply was cut off.

The Roman works in certain of the cities of Gaul were almost as extensive as those of Rome itself. Leaden pipes have been pulled up by the anchors of vessels from the bottom of the river Rhone, showing that the Romans used such means of crossing rivers.

Aqueduct at Lyons. The old Roman city of Lyons is well provided with magnificent palaces and temples and baths, the latter requiring a large quantity of water which was transported by means of great aqueducts built during the reign of Augustus Tiberius Claudius. The most ancient was erected by Marcus Antoninus. The higher part of the city was supplied by a second aqueduct taking water from the Loire. Underneath this aqueduct was constructed a third to supply with water the palace of the Emperor Claudius. Numerous other minor aqueducts were built in the same age for private supplies or for supplies for the baths. The aqueduct of Claudius was really built of concrete, cement of lime being used together with fine gravel and water. This concrete was lined with square blocks of stone. The aqueduct channel itself was 3 feet broad and 6 feet deep. The aqueduct roughly followed the contour of the country in order to preserve the level. Several siphons of easy curvature were incorporated in the structure. The aqueduct at the bottom of the curve terminated in a reservoir near the valley of the river Garonne. From this reservoir the water was conveyed across the valley in pipes and delivered to another reservoir at the top of the opposite hill at a lower level; hence the water was conveyed by the aqueduct of Chaponost. This aqueduct ran underground for some distance, crossing a bridge composed of ninety arches and terminating in a third reservoir from which it passed through pipes, crossed the river Baunan and entered a fourth reservoir at St. Foi. From here the water flowed by a canal and tunnel to a fifth reservoir. It was then carried through pipes to a sixth reservoir near the walls of the city. The entire aqueduct is about 33 miles in length and has a descent of 360 feet.

In Spain too are many remains of splendid aqueducts of Roman origin. At Segovia is one over 2000 feet in length and 94 feet high supported by 159 arches. It is in good part still standing after 1600 years. Grenada has an example of Arabian munificence in the supply of the famed Alhambra. The square of cistern consisting of numerous reservoirs, is kept constantly supplied with water by aqueduct some 3 miles in length. One of these cisterns or tanks is 102 feet long and 56 feet wide. The cisterns are covered and provide with ventilators. The fountains and baths of the palace were supplied with a great volume of water from these cisterns.

Constantinople also has remains of aqueducts of Roman construction. Under the Greek Emperors Rome was supplied with water by means of aqueducts and large reservoirs. Ever since the days of these emperors the Turks have carefully preserved their streams and water supplies. Numerous private supplies of ancient date are scattered throughout Turkey. These early supplies of Roman origin have been carefully extended and amplified by the Turks themselves, and it is stated that in 1831 the city of Constantinople was supplied with 15,000,000 gallons of water a day through aqueducts averaging 12 miles in length. As no suitable pipes were known to them in the earlier days, they adopted a very ingenious scheme of preserving the level of their pipe lines. At various points along the line of supply artificial elevations in the form of pyramids were constructed. These pyramids really consisted of balancing reservoirs, so equalizing the pressure of the cistern that it is nowhere great enough to burst earthenware pipes.

The Supply of London. The earliest known supply in the city of London, aside from the then clear and limpid Thames, was a system of wells and rivulets throughout the city. Stowe in the "Survey of London," 1663, states, however, that even in his time these rivulets at some parts were too dry or became too filthy for use. There was, however, a large number of private springs and wells for those inhabitants near the Thames. The river of course provided a convenient source of supply as well as a public laundry. The first bill providing a supply of water was prepared by Henry III in 1236. It granted certain citizens the right to convey water from the town of Tyburne into the city by means of lead pipes. This first conduit was succeeded by eleven others. In 1568 a conduit of Thames water was laid within the city. From this the public obtained their water, which they carried to their homes in buckets and barrels. Succeeding the conduits was a system introduced by a Dutch engineer named Peter Morys, who in 1652 utilized one of the arches of London bridge as a support for a great water wheel which in turn pumped a supply of water into the city. He was given a lease of the arch for 500 years. The works afterwards covered arches of the bridge and were held in the Morys family until 1701, when they were sold to Richard Soams for £38,000. This gentleman organized a company which remained in existence until 1831, when the old bridge was destroyed. Queen Elizabeth granted to the citizens of London power "to cut and convey a river" from any part of Hertfordshire in Middlesex to the city of London, with a limitation of ten years for the performance thereof. In the third year of James I, act of Parliament confirmed what was afterwards the New River scheme, and the Mayor and citizens were empowered to bring water from the springs of Chadwell and Amwell in the County of Hertfordshire. The city considered this too great an enterprise. In 1606, however, Sir Hugh Myddelton undertook the construction at his own expense. Shares in the New River Company were incorporated by Laws Patent in 1619. This New River conduit was the greatest of all conduits, and the New River Company still supplies water by it to the reservoirs in London.

Paris. The Romans brought a considerable supply of water to the city of Paris in an aqueduct at Arcueil, probably somewhat similar to those of other Roman cities. It had, however, nearly disappeared at the time of Henry IV (1609), and the inhabitants of the city depended upon the water of the Seine and of their wells. When he ordered an investigation of the sources and condition of this ancient aqueduct, it was reported that it was in such a state of disrepair that it would be less expensive to entirely rebuild. Accordingly, an aqueduct was built which emptied into the reservoir at the observatory. Water carriers and carts distributed the water to the citizens. In spite of the recognized ability of the early French engineers, this system of water carriage and the private wells remained the only source of supply to the people until a Fleming named John Lintbaer obtained permission and installed two undershot water wheels similar to those installed in London, for the purpose of pumping the Seine water to the level of the Pont Neuf, whence it was distributed in lead pipes. Later, in 1778, these water wheels were replaced by steam engines. In 1802, when Napoleon was First Consul, an eminent engineer suggested that water be brought from the river Ourcq, a distance of about sixty miles. Napoleon took up the suggestion with great enthusiasm, and the work of building an open canal which would receive on its course the waters of some five or six small streams was pushed to completion. This gave Paris a supply of which the Parisians of that period were exceedingly proud.

South America. In America, the first provisions for artificial water supply were those of the ancient Incas in Peru. Many great aqueducts were built to carry water from the base of the mountains to the cities. That of the city of Tezcoco is perhaps the greatest work, being about 16 miles in length and carrying a stone channel 18 by 24 inches. The Incas had no knowledge of arch construction and were therefore obliged to carry their aqueducts along the surface of the ground and yet maintain the proper elevation. To do this required expert engineering skill, considering no instruments of metal were used, in order to determine the best course along the mountain sides and through the valleys. The water supply provided many magnificent fountains in the cities, some of which were still flowing in the early part of the nineteenth century, though their underground sources were then unknown.

The Spaniards were responsible for the destruction of these great works in Peru and Mexico. In Mexico some excuse for this vandalism may be found in the tradition that some of the water-carrying pipes were built of pure gold, but the destruction of the great stone aqueduct can never be forgiven.

B. THE MODERN WATERWORKS

The twentieth century begins a new era in waterworks, of which three examples are given of three types. Excellent descriptions of these completed works are available, and the student will find other examples in current literature.

Albany has a slow sand-filtered river water, nature's method, amplified and speeded up. Boston collects several smaller streams from clean soil stores in clean reservoirs, exposes to nature's disinfectant, sunlight, and prevents contamination as far as possible. Cincinnati, the type of modern engineering work on a large-scale treatment of unfit water by the most scientific means, gives an impressive lesson on the use of mechanical appliances for daily needs.

Standards past and present will be described in a later chapter. Here it suffices to bear in mind the chemical, biological, and engineering difficulties to be overcome in providing a modern city with its modern needs and modern standards with a ***sufficient*** supply of a *safe* and *satisfactory* water.

The quantity demanded is the most serious handicap. For instance, in the careful preliminary survey of the possible sources of future supply of the Boston Metropolitan area, Special Report, 1895, the plan outlined was to furnish at the accepted estimates for increase of population a per capita supply sufficient for one hundred years.

Within ten years the works were called on for about the fifty-year limit. It is evident that in all cities the great waste of water must be checked unless the larger places face the disasters of the ancient sites. Modern science may encourage an economy like that at Bright Angels, Canyon of the Colorado, where the purified sewage is utilized for the steam plant.

ALBANY

The Albany water supply, up to the year 1899, was pumped unfiltered from the Hudson River. In 1896, after an epidemic of typhoid in which the death rate was 162 in a population of 100,000, and an average death rate of 77 per 100,000 for the last twelve years, the Board of Health offered the following resolution:

"*Resolved,* That the Board of Health communicate to the Board of Water Commissioners its convictions based on evidence regarding the health of the city which has come into its possession in the course of its special work and duties; that the present public water supply is a source of sickness and unfit for prolonged domestic use, and that it urges upon the Board of Water Commissioners the necessity of either purifying the water now supplied by means of oxidizing or nitrifying filters or of procuring it from a purer source."[1]

In 1899 the slow sand filter was installed. The chief source of supply is still the Hudson River.

The intake of the Albany filters is a simple concrete structure in the form of a box having an open top covered with rails 6 inches apart, and connected below, through a 36-inch pipe, with a well in the pumping station. Before going to the pumps the water passes through a screen with bars 2 inches apart, so arranged as to be raked readily.

Meter for Raw Water. Upon leaving the pumping station the water passes through a 36-inch Venturi meter having a throat area two-ninths of the area of the pipe. The meter records the quantity of water pumped, and is also arranged to show on gauges in the pumping station the rate of pumping.

Aeration. After leaving the meter, the water passes to the sedimentation basin through eleven outlets. These consist of

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[1] Engineering Record, March 21, 1896.

12-inch pipes on end, the tops of the pipes being 4 feet above the nominal flow line of the sedimentation basin.

Sedimentation Basin. The sedimentation basin has an area of 5 acres and is 9 feet deep. To the overflow, it has a capacity of 14,600,000 gallons, and to the flow line of the filters, 8,900,000 gallons. There is thus a reserve capacity of 5,700,000 gallons between these limits, and this amount can be drawn upon, without inconvenience, for maintaining the filters in service while the pumps are shut down. This allows a freedom in the operation of the pumps which would not exist with the water supplied direct to the filters. The sedimentation basin is built on the river bank, largely above the natural surface of the soil.

From the eleven inlets already described, the water enters one side of the sedimentation basin, and is withdrawn from eleven outlets directly opposite. The aerating devices bring the water into the basin without current, and evenly distributed along one side. Both inlets and outlets are controlled by gates, so that any irregularities in distribution can be avoided.

When the basin is being cleaned, the supply is maintained by opening the by-pass from the pumps to the filters and pumping direct.

Filters. The filters are of masonry, and are covered to protect them against the winters, which are quite severe at Albany. The piers, cross walls, and linings of the outside walls, entrances, etc., are of vitrified brick. All other masonry is concrete.

Floors. The floors consist of inverted, groined, concrete arches, arranged to distribute the weight of the walls and vaulting over the whole area of the bottom. The bottoms were put in in alternate squares running diagonally with the pier lines.

Walls. For the outside walls the brick linings, 8 inches thick, were built first to the full height. A certain number of bricks were laid endways, and projected into the concrete. The projecting bricks occupied about 4 per cent of the area of the wall. Afterward, wooden forms were put up on the outside, and the concrete backing was filled in. Above the vaulting there are two feet of earth and soil, grassed on the top. The tops of the manholes are 6 inches above the soil to prevent rain water from entering them.

Inlets to Filters. Water is admitted to each filter through a 20-inch pipe from a pipe system connecting with the sedimentation basin. Just inside of the filter wall is placed a standard gate, and beyond that a balanced valve, connected with an adjustable float to shut off the water when it reaches the desired height on the filter.

Overflows. Each filter is provided with an overflow, so arranged that it cannot be closed, which prevents the water level from exceeding a fixed limit in case the balanced valve fails to act. An outlet is also provided near the sand run, so that unfiltered water can be removed quickly from the surface of the filter, should it be necessary, to facilitate cleaning.

Effluent Drains. From the lower chambers in the regulator houses the water flows through gates to the pipe system leading to the pure-water reservoir. Drain pipes are also provided which allow the water to be entirely drawn out of each filter, should that be necessary for any reason, without interfering with the other filters or with the pure-water reservoir. The outlets of the filters are connected in pairs, so that filtered water can be used for filling the underdrains and sand of the filters from below, prior to starting, thus avoiding the disturbance which results from bringing dirty water upon the sand of a filter not filled with water.

Pure-Water Reservoir. A small pure-water reservoir, 94 feet square, and holding about 600,000 gallons, is provided at the filter plant. The construction is similar to that of the filters, but the shapes of the piers and vaulting were changed slightly, as there was no necessity for the ledges about the bottoms of the piers and walls; while provision is made for taking the rain water falling upon the vaulting above to the nearest filters instead of allowing it to enter the reservoir. The floor and roof of the reservoir are at the same levels as those of the filters.

The Metropolitan Waterworks Including Boston

Boston has been most fortunate in its water supplies, having at hand lakes as natural storage reservoirs and being situated in a zone of considerable rainfall. The density of population has, however, brought many perplexing problems as to quantity and the maintenance of quality. A concise account of the completed works is taken by permission from Mr. Dexter Bracket's paper presented at the twenty-sixth meeting of the American Waterworks Association.

In this system the quality of the water is maintained by prevention rather than restored by the renovation process. Instead of collecting everything as a fluid and filtering the heterogeneous mixture, the polluting streams are filtered, the watershed policed, and strict rules enforced as to new construction. In other words the watershed is largely owned by the Commonwealth, and all that area not so owned is under strict sanitary supervision. For instance, in the year 1903, 1534 premises on the Wachusett watershed were inspected and 1376 found satisfactory. The owner of a mill having appealed to the Supreme Judicial Court from the injunction of the Superior Court, against a discharge of polluting material into a stream without treatment, a temporary provision is made. In general a readiness has been shown to comply with the requirements without recourse to the courts.

The preparation of this watershed as a suitable collecting ground for potable water will be described under Chapter VIII, Regeneration.

The investigations as to the effect of soakage on color and growth of organisms were carried on for five years, at first in the laboratory of the State Board of Health under the author's direction, 1893, and afterwards at the temporary laboratory at Clinton.

In the year 1892 the city of Boston had nearly reached the capacity of its sources of water supply, and there were several other metropolitan municipalities whose sources of supply were either inadequate in quantity or inferior in quality. It was evident that for the future supply of the Boston Metropolitan District a comprehensive scheme was demanded. After a very careful and thorough investigation of the possible sources of supply, the State Board of Health, in February, 1895, presented its report recommending the taking of the water of the South Branch of the Nashua River at a point above the Lancaster Mills in the town of Clinton.

The Metropolitan Water Act, Chapter 488 of the Acts of the year 1895, approved June 5, 1895, provided that the governor should appoint three water commissioners who should constitute the Metropolitan Water Board. This Board was given broad powers, not only for the construction of the works, but also for the taking of property, for the changing of highways and railroads, and for the conduct of such operations as should be deemed necessary for protecting and preserving the purity of the water.

The works, as at present constituted, comprise the Wachusett Reservoir on the Nashua River, capacity 63,000,000,000 gallons;

Eight storage reservoirs on the Sudbury River watershed, with a combined capacity of 13,616,100,000 gallons;

Lake Cochituate, capacity 2,242,400,000 gallons;

Wachusett Aqueduct for conveying water from the Wachusett Reservoir to the Sudbury Reservoir of the Sudbury supply, capacity 300,000,000 gallons in 24 hours;

Weston Aqueduct and Reservoir for conveying water from the Sudbury Reservoir to the Metropolitan District, capacity of aqueduct 300,000,000 gallons per day;

Sudbury River aqueduct for conveying water from the reservoirs on the Sudbury River to Chestnut Hill Reservoir, capacity 103,000,000 gallons per day;

Cochituate Aqueduct for conveying water from Lake Cochituate to the Chestnut Hill Reservoir, capacity 18,000,000 gallons per day; Chestnut Hill Reservoir, which receives and stores water supplied through the Sudbury and Cochituate aqueducts, and from which water is pumped for supplying the Metropolitan District;

Five pumping stations located at Chestnut Hill Reservoir, Spot Pond, West Roxbury, and Arlington, containing 13 pumping engines having an aggregate capacity of 204,500,000 gallons in 24 hours;

Six distributing reservoirs, of which Spot Pond is the largest, and two standpipes, located in the Metropolitan District, having a combined capacity of 1,881,230,000 gallons;

84.2 miles of pipes, ranging in size from 60 inches to 12 inches in diameter, through which water is delivered to a population of about 900,000 residing in eighteen cities and towns.

The Wachusett Reservoir is located in the towns of Clinton, Boylston, and West Boylston, and is formed by a dam across the South Branch of the Nashua River located about half a mile above the settled portion of the town of Clinton, and by two earth dikes, one on either side of the valley a short distance above the main dam.

The river above the dam has a watershed of 118.32 square miles. The reservoir is 8.41 miles long, with a maximum width of 2 miles, an area of 4195 acres, or 6.56 square miles, and a capacity of 63,068,000,000 gallons. The maximum depth of water is 129 feet; the average depth 46 feet.

The land required for the reservoir contained 6 large mills, 8 schoolhouses, 4 churches, and about 360 dwelling houses occupied by 1700 people.

The construction of the reservoir necessitated the discontinuance of 19¼ miles of roads and the construction of 11.8 miles of new roads, one of which crosses the reservoir on an embankment 700 feet long and from 50 to 70 feet in height.

The Wachusett Dam is a granite masonry structure comprising the main dam 944 feet long, including abutments at each end, crossing the valley of the river, with its top 20 feet above high-water level in the reservoir, and a waste weir 452 feet long, over which the flood waters can be discharged into a channel 1150 feet long, excavated in rock, following the contour of the hillside of the river channel below the dam.

The Sudbury River, above the point of diversion, has a drainage area of 75.2 square miles, on which eight storage reservoirs have been built by damming the river and its tributaries at various points.

The following reservoirs are located on this source:

	Area of water surface (acres).	Available capacity (million gallons).	Elevation above Boston city base (feet).	Date when completed and filled.	Total height of dam (feet).	Maximum depth of water (feet).
Framingham Reservoir, No. 1	143	287.5	169.27	Jan., 1879	22	16
Framingham Reservoir, No. 2	134	599.9	177.12	Aug., 1879	26	20
Framingham Reservoir, No. 3	253	1,183.5	186.50	Dec., 1878	29	24
Farm Pond	159	167.5	159.25	....	12	12
Ashland Reservoir	167	1,416.4	225.21	Apr., 1886	58	48
Hopkinton Reservoir	185	1,520.9	305.00	May, 1895	59	53
Whitehall Reservoir	601	1,256.9	337.91	....	13	18
Sudbury Reservoir	1292	7,253.5	260.00	Apr., 1898	13	65
Total		13,616.1				

Lake Cochituate, situated about 18 miles west of Boston, is a natural pond or chain of ponds about 3½ miles in length. It has an area of 776 acres and a watershed of 18.87 square miles.

The Wachusett Aqueduct conveys water from the Wachusett Reservoir to the Sudbury Reservoir, a distance of 12 miles. The first two miles is a rock tunnel, followed by seven miles of masonry aqueduct, including a bridge over the Assabet River and three miles of open channel. The tunnel section has a fall of one foot in 5000, is lined for about one-half of its length with brickwork 12 inches thick, and where lined is 12 feet 2 inches wide and 10 feet 10 inches high. The masonry aqueduct has a fall of one foot in 2500, and is 11 feet 6 inches wide and 10 feet 6 inches high. The open channel is 20 feet wide on the bottom, and has side slopes of 3 horizontal to 1 vertical. All sections have a capacity of 300,000,000 gallons per day.

The Weston Aqueduct conveys water from the Sudbury Reservoir to a point in the town of Weston a short distance west of the Charles River and a little more than 10 miles from the State House. The distance from the Sudbury Dam to the terminus of the aqueduct is 13.42 miles. At the lower end of the reservoir there is a screen chamber, from which the masonry aqueduct extends 5658 feet to the terminal chamber, from which pipes are used to convey the water into the Metropolitan District. On the line of the aqueduct there are five tunnels having an aggregate length of 12,165 feet, lined throughout with concrete.

The Sudbury Aqueduct conveys water from Framingham Reservoirs Nos. 1, 2, and 3, located on the Sudbury River, to the Chestnut Hill Reservoir in the Brighton district of the city of Boston, a distance of 17.4 miles. It is of horseshoe shape, constructed of brick and stone masonry laid in cement mortar. From the beginning at Dam No. 1 to the gatehouse at Farm Pond, a distance of 1½ miles, the aqueduct is 7 feet 6 inches wide and 6 feet 10½ inches high, and has a fall of one foot in 2275. From the Farm Pond gatehouse to Chestnut Hill Reservoir it is 9 feet wide, 7 feet 8 inches high, and has a fall of one foot per mile. It has a capacity of 103,000,000 gallons in 24 hours.

The aqueduct crosses the valley of Waban Brook and the Charles River on granite masonry bridges. The Waban valley bridge is 536 feet long, and consists of 9 semicircular arches of 44 feet 8 inches span. The Charles River bridge is 475 feet long, 79 feet above the river, and is formed by 7 arches, the largest one having a span of 129 feet. At the valley of Rosemary Brook two lines of 48-inch and one line of 60-inch cast-iron pipe, each line being 1800 feet long, take the place of the masonry structure. There are four tunnels on the line of the aqueduct, the longest of which is 4635 feet in length.

This aqueduct was built by the city of Boston, and was completed and first used in 1878.

The Cochituate Aqueduct is 13.7 miles long and extends from Lake Cochituate to the Chestnut Hill Reservoir. It is egg-shaped in section, 5 feet wide, 6 feet 4 inches high, and is built of brick masonry 8 inches in thickness, with the exception of a tunnel 2410 feet long, which is unlined, and at the crossing of the Charles River, where four lines of cast-iron pipes 1100 feet long are substituted for the masonry structure. Two of these are 30 inches in diameter, one 36 inches, and one 40 inches. The masonry portion of the aqueduct has a fall of one foot in 20,000.

The Chestnut Hill Reservoir is located in the Brighton district of the city of Boston, about five miles from the State House. It receives water from the Sudbury and Cochituate aqueducts, and serves as a storage reservoir from which the pumps at the high- and low-service stations draw their supplies.

All water delivered into the Chestnut Hill Reservoir by the Sudbury and Cochituate aqueducts is pumped at two stations located on the southeasterly side of the reservoir. At one station water is pumped to supply the higher land in the southern portion of the Metropolitan District; at the other it is pumped into mains leading to Spot Pond, which is the principal distributing reservoir for the lower portion of the district.

The quality of the water has so far justified the careful provisions as to stripping and planting with pines. Time only will prove its lasting efficiency. For the conditions under which the work could be carried out the author believes it a much wiser plan than to have allowed the collection of débris to remain and to have trusted to filtration.

" In carrying on the work of construction both of the Wachusett Reservoir and the Weston Aqueduct, medical inspectors have been employed under the supervision of engineers in charge, whose duty it has been to examine the camps which have been constructed for laborers and all other buildings in which laborers upon the works have been lodged, and to make constant effort to keep all such places in clean and sanitary condition."[1]

[1] Third Annual Report of the Metropolitan Water and Sewerage Board, page 27.

"It has been the policy of the Board to introduce at its own expense the works which are required for remedying causes of pollution when the sources existed prior to the operations of the Board. In cases where the sources of pollution have arisen since the operations of the Board began, it has been made the duty of the owner to pay the cost of such work."[1]

It is not claimed that the work is perfect or perfectly carried out, but there may be just pride in the statement that may be made that since the establishment of metropolitan control there has been no epidemic traceable to Boston water supply and no proved case of disease.

Cincinnati, Ohio, Supply

Water was taken from the Ohio River and distributed by a private company with exclusive privileges for 99 years from 1817. In 1839 the city took possession. In 1842 the need of a reservoir on high ground was urged by Mr. Nicholas Longworth, who offered a site at $500 an acre but was refused the price. In three years he was selling the land at $10,000 to $14,000 an acre.

In 1853 the water was examined and fears of pollution allayed for a number of years. In 1865 Mr. J. P. Kirkwood submitted recommendations for a future supply and a filtration plant, the estimated cost to be three million dollars. Other extensions were put in piecemeal for the rapidly growing sections, not always wisely, and from 1878 to 1884 there was frequently a scarcity of water, and in 1890 with a population of 297,000 the city was facing a water famine. Repairs and extensions brought the capacity up to 47,000,000 gallons daily in 1895. Uneasiness as to the quality of the water was prevalent at various times during these years, but by 1895 the demand for improvement became insistent. Various commissions investigated possible sources, but came to the conclusion that the Ohio River was the only practicable source but that there must be a new site for the intake and a treatment of the water such "as to make it comply with the requirements of the highest practical standards

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[1] Third Annual Report of the Metropolitan Water and Sewerage Board, page 28.

for purity in water for domestic uses." In 1897 the construction of an experimental filter plant was authorized and in 1899 the report of Mr. George W. Fuller was submitted. In some respects this report is a more valuable source of information than the famous Louisville report. In 1900 the mechanical system for the purification of the Ohio River water was adopted.

The following extracts illustrating the complicated machinery of a modern water supply plant are made from the report of the chief engineer on the completion of the $11,500,000 plant.

The intake pier of the Cincinnati water system consists of solid stone masonry structure supported on a timber caisson 57 by 29 feet, carried down through the sand and gravel of the river bottom into the bedrock to elevation – 34.50, 0.00 being datum at 3½ feet below low stage of water.

The top of the intake pier supports a handsome stone building, finished off with a sightly tower on the upstream end. This building contains the electric traveling hoist, pumps, hydraulic cylinders, screen car, tools, and other material, and forms the shelter for the men engaged in hoisting, cleaning, and lowering the various screens.

Intake Tunnel. The shaft well of the pier, extended downward, forms the connection between the inlet well and the intake tunnel and below elevation – 8.00, consists of a brick-lined shaft of 7 feet interior diameter. At elevation – 69.00 the shaft makes a curved connection with the tunnel, the latter extending in a straight line from this shaft to the base of the pump-pit shaft, a distance of 1430 feet eastward to the Ohio shore of the river, with a descending grade of 1 in 400 feet. The pump-pit shaft, which is 8 feet in diameter, is also connected with the tunnel by a curve being made by the soffit of the tunnel arching. The tunnel, which is 7 feet in diameter, was excavated through rock.

Above the rock the pump-pit shaft consists of a steel shell 10 feet in diameter, extending through the pump-pit floor to elevation + 109.00. Below the pump-pit floor the steel shell is lined with two rings of brick set on edge.

The pump pit, 98 feet in diameter and 85 feet deep, is formed by a circular stone masonry wall 15 feet thick at the bottom, where it rests upon the caisson.

Pumping Machinery. The pump pit contains four self-contained, triple-expansion, crank-and-flywheel pumping engines, which take their supply from the pump-pit shaft through the 48-inch openings and discharge through 48-inch delivery mains into two lines of 60 inch diameter pump mains, laid in the embankment, and through these to the settling reservoirs at an elevation 145.00 feet above city datum.

Settling Reservoirs. The two settling reservoirs serve alternately in removing by quiescent sedimentation of from forty to forty-eight hours' duration a large part of the matter which is held in suspension by the river water. This is accomplished by drawing the water from one reservoir from near its surface, while the other is rapidly filled, and given not less than forty hours for sedimentation. The service is alternated when the water has been drawn down 30 to 31 feet.

Provisions are made for washing the accumulated sediment out of either reservoir by means of large effective hose streams, which cut up and carry the mud to four drainage outlets in the bottom of each reservoir, dispersed nearly equal distances apart, these outlets being connected to 16, 20, and 24 inch cast-iron drain pipes laid in the clay blanket under the bottom of the reservoirs, the drain pipe passing as a 30-inch cast-iron main through the archway and out at the bottom of the shaft to a paved ditch in the ravine leading to Lick Run.

The filter plant consists of three coagulation basins, a head house, filter house, and chemical house, also of a wash-water reservoir and the clear-water basin, together with the necessary piping, valves, and valve houses.

The capacity of basins Nos. 1 and 2 are each 10,250,000 and of No. 3 is 2,160,000 gallons.

The clear-water basin is located north of the coagulating basins, and has a capacity of 19.6 million gallons. All the walls of these basins except the dividing wall between coagulating basins 1 and 2 are made of rolled embankments, with a 2 to 1 slope on the outside and a 1¾ to 1 slope on the inside. The outer slopes are sodded and the inner slopes and bottoms are covered and protected by a revetment like that used in the settling reservoirs, consisting of clay, broken stone, concrete, asphalt, burlap, and brick, excepting that on the bottom of the clear-water basin, instead of the layer of brick, a layer of concrete is placed over the asphalt in the form of inverted groined arches, forming pier bases for future columns, should it be found necessary to cover this basin with a roof. A dividing wall between basins 1 and 2 is buttressed, and consists of concrete suitably reënforced with steel rods. The maximum depth of these basins, except coagulation basin No. 3, is 23.5 feet below high water, and in No. 3 is 17.5 feet. The coagulation basins are each provided with two mud valves and outlets, connected to a 24-inch cast-iron drain pipe leading to a branch of Lick Run.

The head house, chemical house, filters, and filter house, excepting the outer walls, are constructed entirely of concrete. The outer walls are of brick, with stone trimmings.

The settled water from the reservoirs or the raw water from the pump mains is conveyed from either one or both of the 60-inch mains through six 36-inch branch connections to the circulating chambers in the head house.

The filter house, located between the head and chemical houses, contains the 28 filters, each consisting of two sections, 14 by 50 feet in the clear, having a rated capacity of 4,000,000 gallons per day.

As the water passes through either one or both of the circulating chambers, the first chemical, in the form of a solution of sulphate of iron of required strength is injected into the same through two 2-inch pipes opening into each chamber. The solution is brought from the chemical house through two lines of 3-inch cast-iron pipes laid through the pipe gallery of the filter house. Either one of these lines can be put out of service and cleaned by flushing with filtered water under a head of 40 feet.

From the circulating chambers the water flows through one or two 60-inch Venturi meters, which measure all the water passing to the coagulation basins, and indicate upon dials as well as record upon charts located upon the ground floor of the head house the rate at which the water is passing out of the head house to valve chamber B, located about 35 feet east thereof and at the southwest corner of coagulation basin No. 3. This information, constantly attainable, permits of regulating the rate at which either chemical should be applied. By a 30-inch branch from one of the 60-inch mains in front of the head house to both lines of 60-inch pipes between the head house and chamber B provision is made for by-passing either settled or raw water to the coagulation basin up to a rate of 70,000,000 gallons per day, thus permitting the 36-inch piping entering the head house to be drained for examination and repair without interfering with the operation of the filter plant.

At the bottom of this chamber the solution of lime of necessary strength is admitted through a 24-inch opening, becoming mixed with the water as it passes on through an 84-inch diameter steel conduit to basin 3 or to valve chamber C, which is located at the south end of the dividing wall between coagulation basins 1 and 2. The lime solution is brought from the saturators in the chemical house through a 24-inch pipe laid along the west side of the buildings to and in front of the head house and thence east to the bottom of chamber B.

The steel conduit is laid in the basin embankment, and is encased its entire length in concrete.

While passing through chamber E, basin 3, the water may be given a secondary treatment with either one or both chemicals.

It is not intended to have complete sedimentation take place in the basins, as it is desirable and necessary to have the water, when reaching the filters, still contain a small amount of coagulated material to form the gelatinous film on the surface of the sand in the filters to serve in retaining the remaining bacteria and all other matter in suspension, a very large percentage of these being already removed by the coagulation and sedimentation which take place in the basins.

The water passes through the filters at a uniform rate of about 125,000,000 gallons per acre per day, and is collected in the manifold piping in the pipe chambers underneath the filter, and conveyed to the two effluent mains.

The rate of filtration is maintained constant by a rate controller at the outlet end of the effluent piping of each filter. Only a sufficient number of filters are run to meet the average daily needs, and their period of operations between washings varies from six to twenty-six hours, and occasionally as high as fifty hours, according to the condition of the coagulated water.

The head necessary to pass water through the filter medium at the rate of 4,000,000 gallons per day per filter of 1400 square feet area amounts, when the filter is clean, to a little over two feet, and as the difference of elevation between the water coming on to the filters and that going out of the effluent mains varies from 12 to 14 feet, nearly all of that difference may be utilized in passing water at the constant rate through the increasing deposit upon the sand until the total loss of head has become 12 feet, when the filter must be cleaned and the accumulated deposit be removed by washing. This is done with filtered water and by reversing the flow through the filters at a rate seven to ten times as great as the rate of filtration, or at an upward rate of from 1.80 to 2.50 feet per square foot per minute.

To bring about a thorough washing of the sand, the water is admitted beneath the strainer system under a pressure of about six pounds per square inch at that point.

The process of washing is divided into two periods. The first, lasting from one-half to one minute, admits the wash water under about half the above pressure, which lifts the mud layer from off the sand without disturbing the latter, while during the second period the wash water is admitted under full pressure for from three to five minutes, which, without disturbing the gravel, brings the entire sand bed above the screen into complete flotation, yet not to such an extent as to carry off any of the sand with the wash water.

This process of washing is very thorough and complete, and no other or additional means for cleaning the sand bed are needed or provided. A small amount of the sediment is allowed to remain in the water at the close of the washing so as to form at once a film over the sand bed on the admission of the coagulated water. Samples taken from the effluent immediately after the filter has been replaced in service show as good bacterial efficiency as at any time during the run of the filter.

The entire operation of cleaning a filter and of returning the same into service requires from thirteen to fifteen minutes.

The only chemicals used are crushed lime and sulphate of iron. They are delivered by the manufacturers in bags of 100 pounds each.

The water used for slaking the lime is metered and previously heated to 140° F.

The iron solution is prepared by dumping a bag of sulphate into a tank, where it is stirred and from which it is injected into the circulating chambers.

As the required strength of these solutions must continually vary with the constantly changing character and condition of the settled water, this variation in the solutions is brought about by regulating the intervals between the time of dumping 100 pounds of one or the other chemical into the stirring tanks while a constant and uniform flow of water through these tanks is being maintained. A systematic and accurate regulation is made possible by the striking of a gong for each chemical at intervals, controlled by a clock and contact disks so designed that the intervals for each may be made to vary all the way from three and a half to ninety minutes in time. Upon the determination of the strength of the solution of either chemical required, the inserting of the proper contact disk will, by means of the gong, direct the laborer to empty the bag at the proper moment to obtain the desired results.

C. THE INDICATED FUTURE

Nearly all great cities are approaching a limit of available water supply under present climatic conditions. When the cycle will be completed and a larger rainfall give an abundance is not within the range of prophesying, — apparently not in the next one hundred years.

If cities continue to grow, as they seemingly will, if they continue to demand more and better water, the young engineer of to-day will be called upon for some measures radically different from those in present use.

Two things have been urged in the author's lectures to classes for the past ten or fifteen years, — a saving of water for vegetable growth by sewage irrigation and a double supply for many towns and sections of some cities.

The hindrance to the adoption of either or both these schemes is in the ignorance of the masses and the prejudice of the legislators and leaders. While the people as a whole are ignorant of what safe water means, and so unbelieving that they will not take the trouble to cross a room to drink from a clean source, it is manifestly unsafe to have an impure water within easy reach.

Until the management of both water supply and wastes disposal is under the control of a corps of skilled scientific engineers, failure will usually follow attempts at utilization. But this line of conservation of the failing water resources is clearly indicated in the not very distant future.

Some plans now in process of development will illustrate the coming needs. The student is advised to keep well *au courant* with the great scheme for the New York water supply and with the very interesting developments certain to arise in connection with the needs of Minneapolis and St. Paul. Several other cities are engaged in improving the quality and quantity, and some of them are wise enough to think about waste disposal before it is too late to save the watershed.

CHAPTER V

THE DEVELOPMENT OF THE SANITARY IDEA ILLUSTRATED BY THE GROWTH AND MUNICIPALIZATION OF WATER SUPPLIES. WHOLESOME WATER THE PEOPLE'S RIGHT

BY the sanitary idea is meant sanitation, not medication — prevention rather than cure. One objection to the use of hygiene as a synonym is that its meaning is so allied to the practice of medicine. Although the goddess Hygiea was worshiped with enthusiasm and the use of medicinal waters is as old as man, yet all through the ages has lingered the belief that they that are whole have no need of the physician.

The maintenance of health by sanitary environment as a government duty could only come into the thought of men with the rise of democracy, the belief that one man's life was worth as much as his neighbor's, that the strong and the educated were bound to look after the weak and ignorant. The seeds of this element of modern life remained a long time dormant. But a few prophetic souls began to put two and two together in the last half of the eighteenth century. Robert Burns was the voice of the people, 1759–1796, and both poets and prose writers began to treat the mass of men as worthy of consideration.

The sanitary idea is essentially scientific and could not have come into existence before science had somewhat established itself. The discovery of oxygen in 1774 had a profound influence in modifying man's thought on the processes of life and decay. Benjamin Franklin, 1706–1790, and Count Rumford, 1753–1814, were both interested in natural science as affecting common daily life.

That early death and frequent sickness was a sufficient loss of productiveness to be a matter for national concern, was recognized by that remarkable group of Englishmen who between 1825 and 1850 laid the foundations of sanitary science. Dr. Edwin

Chadwick's effort to get behind fate to the causes of disease; Dr. Benjamin Ward Richardson's motto, "National Health is National Wealth" and his description of the city of Hygiea; Dr. William Farr's service in organizing a scheme for registration (1838) now known as vital statistics, proving the value of human life; Dr. John Snow's surmise that cholera was spread by the drinking of water impregnated with cholera poison, all tended to an awakening of a national consciousness. The disposal of sewage and its difficulties (1839); the establishment of a Journal of Health (1855); the development of statesmanship as a science, including the conservation of human resources (1859), were followed by scientific investigation as seen in the Rivers Pollution Commission (1865).

These steps taken in England were watched by the civilized world. By the middle of the nineteenth century the value of human life was recognized and a study of the causes that led to the sacrifice of so many citizens in the prime of usefulness was undertaken in many countries.

The economic value of a worker has been the actual fulcrum used to raise the status of the multitude, and perhaps it has been a more powerful force than any mere sentiment of lessening suffering.

Massachusetts followed closely along the same humanitarian lines, establishing the first State Board of Health in 1869. The early workers for it were actuated by the belief that healthy, happy human beings were the State's best, most valuable asset.

There also came clearly into reckoning a social idea, the brotherhood of man, duty to one's neighbor, as is seen by so much sanitary law being considered as founded on the statute of nuisance.

While the right of the family to keep a privy close to its well, no matter how much sickness might come, was jealously maintained, the moment the neighbors complained of *nuisance* the arm of the law reached the case. It was only with the approach of the twentieth century that the man himself and his family were protected from his own neglect.

Drinking water and living conditions occupied the attention of the able men who led Massachusetts opinion. By this time the possibility of prevention of most diseases, especially of those known or suspected to be water-borne, was beginning to be recognized by the laity, and the aid of science was invoked to furnish means of detecting dangerous conditions before human life was put in peril. Until about 1880 the appearance of disease was the first *proof* of an infection. For ten years all countries vied with each other in studies which should enable the health officer, by that time a recognized power in the State, to state positively that a given condition was a menace to the health of the people. It was then that sanitary science, in a certain distinction from medical science, was born.

One of the pioneers in formulating the somewhat vague ideas and insisting upon scientific conceptions of the office of the State in the promotion of sanitation was Dr. George Derby, the first secretary of the Massachusetts State Board of Health.

"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 disease 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."[1]

In the same report he writes, "The Board hope to be able hereafter to present such facts and conclusions as may be of some service to the citizen in the conduct of life, and to the legislator in the discharge of his responsible duty."

The high purpose of State investigation he has admirably expressed: "The pollution of streams by industrial establishments and by the sewage of towns has been several times during the past year brought to the notice of the State Board of Health. Judging from the history of still more densely populated manufacturing districts in other parts of the world, the general subject will continue to claim the attention of the people of Massachusetts for many years to come. As the interests of life and health become more definite and more valued, and as manufactories and population grow and multiply, the apparent conflict in this respect between health and industry will yearly become more evident. It is our duty, if possible, to show that these important interests are not irreconcilable, and to give a word of warning in season to prevent their relations from being forgotten until it is too late to remedy the omission except at enormous cost."

The first work done in Massachusetts on the question of pollution of water supplies was that of Professor Nichols of the Institute, in examining the water of Mystic pond. His report is given in the second report of the Board, 1871 (pp. 386–393). In all, nineteen samples were examined for mineral constituents,

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[1] First Annual Report of the State Board of Health of Massachusetts, pages 9, 10, Secretary's Report, January, 1870.

no attempt being made to determine organic impurities other than by the use of the permanganate test.

On the 6th of April, 1872, the Legislature of Massachusetts instructed the State Board of Health "to collect information concerning sewage and the possibility of utilizing it, the pollution of streams and the water supply of towns, and to report at the next session." Thus began the work of Massachusetts, now and for all time a notable example of scientific work.

The examination of the streams begun by Prof. William Ripley Nichols at the laboratory of the Massachusetts Institute of Technology was prosecuted with an ever-increasing sense of its value until sufficient data were obtained based on science as far as it was sure of its ground.

To the sanitary expert the authorities have seemed to be dilatory, to have been lenient to commercial interests rather than careful of the sanitary welfare of the masses, but it must be confessed that the science of organic growth and decomposition has been of slow development and with much controversy and many seemingly backward steps. So far as the water problem is concerned the crux of the fight was, first, organic matter, what it had to do with disease and how its presence could be detected and the cause removed.

Elaborate studies at this time were undertaken at the request of government authorities in order that they might be just in their decisions.

The State of Michigan followed Massachusetts in the establishment of an active Board of Health, as did Louisiana also, but the latter soon lapsed.

A most important link in the growth of the sanitary idea in America was the Act of Congress of March 3, supplemented by that of June 2, 1879, the first to establish a National Board of Health, the second to require it for five years "to prevent the introduction of contagious and infectious disease into the United States." The American Public Health Association and the National Academy of Sciences were named as consulting bodies, and the work first advised was the making of sanitary surveys of places remarkably unhealthy or liable to become so. The first Board consisted of Dr. Weir Mitchell, General Francis A. Walker, Dr. Wolcott Gibbs, and Prof. William Barton Rogers, the president of the National Academy.

If this Board did not accomplish what was anticipated, its part in the education of future leaders in sanitation in America should be recognized.

Dr. H. I. Bowditch wrote on sanitary legislation, Dr. Ira Remsen on organic matter in air, Dr. C. F. Folsom, then secretary of the Massachusetts Board, on disinfectants, Dr. R. M. Kedzie on adulteration of food, Colonel George Waring on flow of sewers, Prof. R. Pumpelly on soils and sanitation. The second report contained the most elaborate account of the investigations carried on by Dr. J. W. Mallett of the University of Virginia, on the best method of determining organic matter in potable water and its effect on health. A light on the science of the time is thrown by the naïve statement, "with the co-operation of three chemists each using a different method." Dr. Charles Smart of the United States Army prepared an extensive paper on the water supply of Mobile and water analysis in general. In two years the Board had spent $364,000. The third report brings forward two more pioneers, Rudolph Hering and Ernest Bowditch. The first reported on sewerage, the second on summer resorts.

It will be seen that the work was somewhat discursive and disconnected (as scientific research is conducted to-day) and did not lead to such definite results as seem now to be obtained by a more intensive study of a limited field. In regard to certain lines of work, it was felt in some quarters that conclusions had already been reached by more scientific methods, and the attempt to make binding some other conclusions met with opposition, and a charge of usurpation of authority and of extravagance led Congress to cut the appropriation at the end of the third year; the publication of the Bulletin was suspended at the end of the fourth, and the work lapsed by limitation on June 2, 1883; the property was transferred to the Surgeon-

General of the Marine Hospital Service in accordance with the original scheme of a study of "infectious and contagious disease and the exclusion of it from the country." The time was not ripe for the extended study of the causes behind disease such as several research laboratories are now engaged in. These, however, take each a small part of the field and do not try to cover it all. The charge of extravagance could not now be maintained of such modest expenditures. The education of the public has advanced in these thirty years and people are now becoming interested in their own welfare.

Since the ideal potable water of the time was that clear, colorless fluid which on evaporation left no black ring of charred substance on a porcelain dish, it was naturally organic substance, always high in carbon, that was held responsible for the danger in water.

The determination of this organic matter, how its presence could be detected, the decision as to what it had to do with disease, and the method of its removal,—all these were vital topics for discussion, and the differing views were held with tenacity and fought for with an acrimoniousness, happily past.

The English work was divided into camps. The Rivers Pollution Commission, 1859–69, evolved and used the Tidy modification of the permanganate process; Dr. Frankland used the combustion method; Wanklyn, Chapman, and Smith devised the albuminoid ammonia determination as an indirect determination of the organic matter, much as the agricultural chemist uses a factor to estimate the protein from the total nitrogen.

By organic matter was indicated that which was combustible; therefore arose the term organic and volatile, which is still found in textbooks and reports.

The solid residue left on evaporation in a platinum dish, when subjected to a dull red heat lost a certain amount in weight. This might be any carbon compound or moisture still clinging, or water of crystallization, it was all counted as foreign to good water.

Then as the recognition of the part played by living organisms began to be suspected, there came the effort to distinguish between the proportion of carbon to nitrogen — the ratio being 1 to 2 per cent in vegetable, 5 to 15 per cent in animal matter. For a time this held the field, until it was seen that the infinite variety of combinations between a little vegetable and much animal, and little animal and much vegetable, made exact figures of little account.

The small quantity usually present and the possible changes during concentration caused doubt as to the decisive evidence of the combustion method. The fact that many carbon compounds low in nitrogen reduced permanganate more readily than some known to be more probably dangerous, made both the Tidy and the Wanklyn processes of less convincing proof.

With the establishment of the National Board of Health in 1879–1883 the matter took again a prominent place in scientific discussion, this time naturally from a legal standpoint — When should a government prohibition be defended? The elaborate and costly investigation of this point, including animal experimentation, was one of the causes which led to the abandonment of the National Board, but the record of the experiments shows the difficulty of settling even the smallest points in organic chemistry.

The points bearing most clearly on this question were, — Is the organic matter in water deadly when injected into the circulation or when taken internally? This experimentation on animals was among the earliest made in the country, and the report of Dr. Smart's work fills 164 pages of the 1882 report.

The conclusions of Dr. J. W. Mallet were thus expressed in the report of the National Board of Health:

"Making the most liberal allowance for the imperfection of the different processes for the estimation of organic matter or its constituents, it is well worthy of notice how very small is the absolute amount of organic matter indicated as present in many of the most dangerous waters, an amount so small as to furnish important evidence against any chemical theory of the production of disease from this source, any theory based on the simple assumption that some of the chemical products of the decomposition of organic matter are poisonous or noxious in their effect upon the human system. Thus, if *the whole* of the organic carbon and nitrogen found in such waters as Nos. 35 and 36, of the highly dangerous character of which there can scarcely be a doubt, existed as strychnine, it would be necessary to drink about half a gallon of the water at once in order to swallow an average *medicinal* dose of the alkaloid. It is not easy to believe that the ptomaines, or any other chemical products of putrefactive change as yet observed, can possess an intensity of toxic power so very much greater than that of the most energetic of recognized poisons. While numerous facts go to support the belief that, not to the effect of any chemical substances (such effect necessarily standing in definite relation to their quantity), but to the presence of living organisms with their power of practically unlimited self-multiplication, we must in all probability look for an explanation of most, at any rate, of the mischief attributable to drinking water, it is of course possible that indirectly a large amount of organic matter in water may be more dangerous than a smaller quantity, as furnishing on a greater scale the suitable material and conditions for the development of noxious as well as harmless organisms. . . .

" Frankland clearly expresses his view as to this evidence of ' previous sewage contamination ' thus:

" ' Large quantities [of nitrates] convict water of previous pollution by organic matters of animal origin. They tell only of the contamination which is past; but, by inference, they also declare the probable nature of the organic matter now present. . . . Whether or no the analyst should form an unfavorable opinion of the water from the amount of nitrates must depend upon the proportion of organic matter actually present, and on his confidence in the efficiency and uniform action of the purifying process.' "[1]

" 1. It is evident on inspection of this table for Classes I to III,

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[1] From Supplement No. 19, National Board of Health Bulletin, Washington, D. C., May 27, 1882.

that the biological methods employed will not afford the means of deciding between a wholesome and an unwholesome natural water. Several of the waters believed to be fairly wholesome for human consumption, certainly in use for drinking purposes on a large scale, are marked 'suspicious,' while not one of the waters believed to have proved themselves pernicious when used by man are set down as 'dangerous.'

"2. In many cases the waters which produced most decided effects upon the rabbits contained *very large* amounts of organic matter, so large as to probably invalidate a comparison with the natural waters or with much more dilute specimens of artificial preparation.

"3. On the other hand, we find in several instances, on comparing the pathological results from three different strengths of a solution of the same organic material, that it is not the strongest which has produced the most marked effects.

"4. In probable support of the idea that it is not mainly the quantity of organic matter but the presence or nature of low organisms which render drinking water unwholesome, such cases deserve attention. . . .

"*Chemical results as to animal in contrast with vegetable organic matter in water.*

"1. In general the conclusions are sustained which have been usually drawn in regard to the source of organic matter, based on the more highly nitrogenous character of that from animal than that from vegetable *débris*. . . .

"*Evidence afforded by chemical results as to putrescent or non-putrescent character of organic matter in water.* . . .

"2. On the other hand, Dr. Smart has expressed the opinion, based upon his previous extensive experience with the albuminoid-ammonia process, aside from his work with it in connection with the present investigation, that *gradual* evolution of albuminoid ammonia indicates the presence of organic matter, whether of vegetable or animal origin, in a fresh, or comparatively fresh, condition, while *rapid* evolution indicates that the organic matter is in a putrescent or decomposing condition. . . .

"*Examination of water samples in general.*

"2. . . . It is very desirable that, besides examining a water in its perfectly fresh condition, samples of it should be set aside, in half-filled but close glass-stoppered bottles, for some time — say ten or twelve days — and one of these examined every day or two, so as to trace the character and extent of the changes undergone. Not only may conclusions be drawn from such a series of observations as to the general stability or decomposibility of the organic matter present, but light will be thrown upon the changes which may be expected to occur under ordinary conditions when the water is stored for use, as in cisterns, wells during periods of drought, or carelessly allowed to remain stagnant in pitchers, water coolers, etc. . . .

"*Albuminoid-ammonia process.*

"1. In order to avoid the uncertain ending of the collection of ammonia, whether 'free' or 'albuminoid,' it would be well to adopt the rule that the distillation be stopped when, and not before, the last measure of distillate collected contains less than a *certain proportion* — say 1 per cent — of the whole quantity of ammonia already collected. This would in many cases involve the necessity of replenishing the liquid contents of the retort with ammonia-free water."[1]

Chemists generally attacked the subject of water analysis as they did that of a clay or an ore and did not consider until about 1885-90 that they were dealing with a new set of conditions.

Little progress was made until some of them accepted the theory of ionization and applied the chemistry of dilute solutions. The great advance made in the laboratory of the Massachusetts State Board of Health was the fixing of standard rules of procedure. One chemist distilled off 150 cc. for free ammonia before adding 50 cc. alkaline permanganate and distilling for albuminoid ammonia, while another added 50 cc. of the alkaline permanganate to a second portion of 500 cc. From the readings

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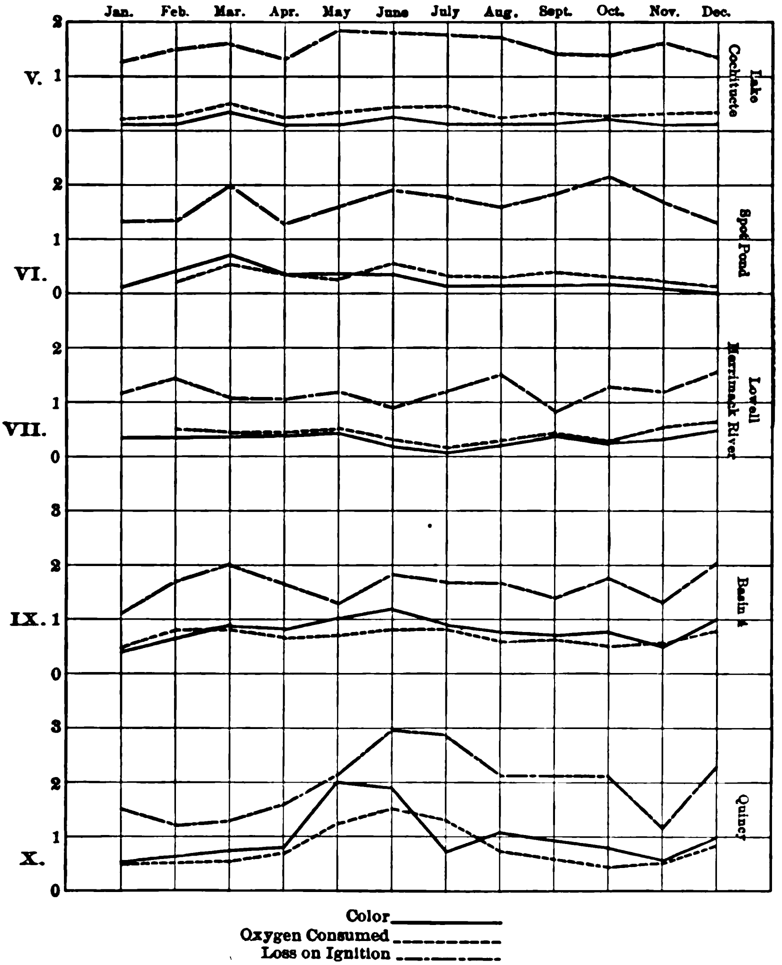
[1] From Supplement No. 19, National Board of Health Bulletin, Washington, D. C., May 27, 1882.

he obtained he subtracted the free ammonia from another portion and called the difference albuminoid ammonia. Because such results did not agree the process was condemned. In



all indeterminate methods absolute uniformity of procedure is necessary.

The studies made of methods of procedure resulted in certain rules as to quantities and times which allowed comparison to be made and which permitted a distinction between organic matter of peaty or humic origin and that in an advanced stage of decay presumably accompanied by the yet living organisms. Thus, a sewage-polluted water would show considerable organic matter, while a filtered water would not.

One of the most valuable comparisons worked out at this time is shown in the accompanying chart which is the basis on which the interpretation of color, loss on ignition or organic matter in surface waters, and oxygen consumed is made, never one alone, but the three taken together.

To-day the general opinion is that it is not organic matter as such, but organic or living forms of bacteria, protozoa, etc., and possibly some of the products of change as alkaloidal substances, which have been isolated from decomposed nitrogen substance.

These possibilities are to be kept in mind by the progressive sanitary engineer and noted in his record book for future reference, should further investigation show their importance. To prove the importance of this is for the investigators; the engineer's work is to keep an open mind. Further details will be given in laboratory directions.

Municipalization of Water Supplies

So far has education of the people progressed that the voters of many communities may be safely trusted to see that waterworks are honestly managed for the people's good. They will tax themselves for public uses as well as for their own bath tubs, and kitchen sinks. They may make mistakes, but, in general, municipal ownership of waterworks is an advance over private supplies. For one thing, the long look ahead, which will be spoken of in indicated chapters as especially necessary, may be taken by a city when a private company with precarious tenure would hesitate. But great pains should be taken to keep the people informed, to explain harmless tastes and odors which may occur, instead of hushing up their presence. Here come into play the knowledge and wisdom of the sanitary engineer. He should be a trusted and not a suspected character. He should make it a part of his business to instruct as well as construct.

Then, too, the city will tax itself for that moderate quality known as "wholesome water" rather than for the promoter's competitive cry, "This is the purest water," a cry which in past time has not infrequently led to sad results. The people are learning everywhere that it costs to be clean and healthy under modern crowded conditions. They are learning the wisdom of coöperation.

Wholesome water for municipal use has been defined by the Pennsylvania Supreme Court as water "reasonably clear from dirt, discoloration and odor, reasonably free from bacteria and B. coli and other infection or contamination which renders it unfit for domestic use, and unsafe and dangerous to individuals."[1]

This moderate requirement, if lived up to, will enable many cities to save money for extension of quantity.

The public discussion will be an education in itself and a certain sense of responsibility will inevitably develop.

The amount of money required for the modern plant is too great to be accepted from private sources. The investment is too liable to variation in value.

The paternal city can take care of its less fortunate citizens with less danger to their self-respect than can a private company.

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[1] Engineering Record, Oct. 31, 1908.

CHAPTER VI

ECONOMIC AND SANITARY EFFICIENCY OF WATERWORKS

A. STANDARDS OF PURITY. B. THE WATER ASSAY; THE ENGINEER'S LABORATORY

DOES it pay to spend a city's tax money for water of a known and maintained standard? Is it a city's duty? Why not allow the purchase of water as of clothing at risk? For one reason, because the city treasury suffers in an epidemic, and the community suffers many times more, making the cost greater than prevention. But there *may* not be an epidemic. So in the case of a water too hard or too corrosive, why not allow each manufacturer to use whatever rectifier he chooses and not compel him to pay for a municipal water-softening plant? He *may* be a dangerous neighbor if his boiler blows up. It will cost the city more for inspection and for damages.

All this amounts to but one thing. The modern city must pay for assurance against loss of life or of efficiency and consequent financial loss. It might actually take out an insurance policy of a few million dollars against loss by a typhoid-fever epidemic, let us say. This would be good economics, but there is a still better form of assurance. This is protection against epidemics — pure city water for instance. Banks have found the Bankers' Protective Association a decidedly profitable investment. The village, town, or city hesitating between two grades of water must settle the problem by pure economic reasoning. They must figure the risk from the use of each just as the fire-insurance agent would figure his risk on the town hall. The better supply is of course the least risk, but possibly the premium required to install and operate the plant is more than it would be good economy to pay. The premium to be paid in each case must be determined from the reciprocal of the risk rather than from the actual risk itself. That is, the less the risk of infection from a certain source the greater the premium that it is permissible to pay to obtain that source, and vice versa.

In figuring the risk from any given source of supply, everything affecting the possible economic loss to the city should be considered, not only fatal epidemics but minor epidemics, slight infections resulting in bowel and stomach disorders, causing temporary disability or loss of efficiency in the community's workers, injury to machinery or manufactures from the mineral contents of the water, and possibly the lessening of residential desirability of the town, by color, tastes, or odors in the water. All these depend on the quality of the water. The quantity should of course be figured on taking into consideration the possible loss engendered by lack of water for fire control or for industrial establishments, etc.

Of course the figuring of such risks and the resultant economically correct premium is going to be by no means an easy task, yet it is surely possible and it is obviously practical. The adoption of such a conception of insurance as the guiding economic principle of community sanitation would not only mean more money, but more money more freely and more understandingly given, or rather invested, by the taxpayer, as well as a much higher standard of efficiency in the various departments of control.

As the actual cost of sickness is being estimated on a higher basis the economy of even larger expenditure is seen.

The engineer to-day who says, "Pure water is the people's right," is right as far as he goes. He doesn't say whose right it is to pay for it, however, and that is just where the rub comes to-day in our big cities. The people all want pure water, but they are a long way from all wanting to pay for it. They must be convinced, in most cases, that by paying for it they are actually insuring themselves against *actual financial loss*, before they will vote for a larger issue of water bonds to raise the standard of quality of the water in the mains. The sanitarian is all too prone to harp on the humanitarian side of municipal improvements. In the tangled, many times compounded Babel of American citizenship of the twentieth century there is only one tongue that is universally understood, and that is that of *money*.

Before the value of an article is set, there must be some method of comparison between different qualities, and in a consideration of a water supply standards of purity have been sought as a basis for decisions as to sources, treatment, extension of works, and many other details.

A naturally treated ground water from spring or driven wells should be clear, cold, colorless, odorless, containing no ammonia, no nitrites, no suspended matter, therefore no bacteria, no dissolved organic matter.

It may contain dissolved mineral substances even up to 1000 parts per million without rendering it unpotable.

It will probably contain 20 to 50 parts even if derived from the early Archean horizon with glacier ground soil.

The decision as to its past history depends on the variation of the mineral contents from the normal of the region. Excess of chlorine and nitrates can come only from pollution of some sort, up to the sewage limit of chlorine; beyond that it is probably contaminated by sea water.

In eastern North America excess of sodium salts also indicates contamination, while the reverse is the case in the arid and semi-arid regions. The history of a water must be known by the engineer before he recommends its use.

Natural untreated water is that deposited from rain collected in streams finding its way from high collecting ground to the ocean by open chambers, now and then detained by resting places, as lakes and sluggish reaches.

Standards of purity for such waters naturally vary from those for ground treated water.

For such waters the above list of characters, clear, cold, colorless, odorless, sparkling, is replaced by the single requirement "free from pathogenic germs." The water may be thick with mud, brown as coffee, smell of fish, oil or cucumber, taste as flat as distilled water, and be as warm as the air, and it is taken in a contented spirit if it is pronounced "safe"; that is, sanitary cranks take it. Conservative persons fail to see the reason for change of ideal, and therefore typhoid fever continues to be spread by country wells and imperfectly purified rivers.

Water is the great carrier and solvent and will extract something from each obstacle in its flow. If it encounters a jam of logs, a pile of sawdust, a dead deer or fox, a barnyard or chicken farm, a paper mill, a village, each will leave its mark. He who knows will read.

Surface water as a rule should not have more than the normal chlorine, more than .200 nitrates, or more than .010 free ammonia.

The allowable albuminoid ammonia depends on the color derived from the humus, peat, leaves, etc. Other characteristics, as turbidity, vary with each shower.

Artificially treated water is brought as near to the ideal clear, colorless, odorless standard as is possible. It is brought down to a certain minimum of bacteria to lessen the risk. This is a purely arbitrary standard, a workable rule.

All artificial filters are hurry processes and only approximate the slow, natural ones in giving quality.

The chief purpose of a filter plant is insurance to lessen the risk. Æsthetic considerations usually come second; hence the substances that are without sanitary significance are often neglected. Color is one of these. The removal of dangerous bacteria may be accomplished without taking the color, because the sand filter is made of washed sand, the clay is removed, and the rate is very rapid as compared with natural ground filter. But it is possible to remove color as well as bacteria by the addition of chemicals. However, the standards for treated waters are yet uncertain. The waters themselves are receiving ever new varieties of materials, new combinations, and there is a shorter and yet shorter time between contamination and use. What effect these "repentant waters" have on the human system, whether there remains some subtile tendency, some unrecognized product from the action of the nitrifying organism, from the processes of conversion of the organic to the inorganic, is not known.

Nature's processes are always *time* processes and the healing power of time, whether for sorrow or disease or recovery of water, is the largest element. Certain it is that the quick processes to make polluted water as "good as new" have failed like such claims in other directions. No evidence has yet accumulated to show that well-filtered stored water retains harmful qualities.

Numerical standards, as well as the substances chosen to be indicative, have varied with the varying theories of the causes of danger in use of the water. At the time when "organic matter" was held to be the dangerous substance the amount of oxygen absorbed was not to exceed 0.500 part per million. 2.100 parts indicated impure water.

With the advent of the albuminoid ammonia theory, Wanklyn set 0.150 part of ammonia in a million as the allowable limit. When the bacterial count became the criterion 100 per cc. was a favorite figure.

Putrescible organic matter is of course to be removed, but sterile, soluble organic matter may be food for yet other organisms farther on. The only safety is, therefore, to use such water at once. For mechanical filters the standard has been the bacterial count given above, trusting that the human sterilizing fluids will take care of the few that escape. 100 per cc. may be far too many to allow, but for every ten less the cost is increased perhaps one-tenth, and until experts can prove this further reduction to be necessary, the standards permitted will not be more rigid.

All filtered waters should keep clear and bright with no development of bacteria for twelve hours. For setting the standard of the water the count at the instant of leaving the filter is of less moment than the count ten to twelve hours after.

The physical efficiency, or as we choose to call it, the economic efficiency, has very frequently little to do with the sanitary efficiency.

Physical and chemical standards will depend largely on the character of the water in each case. 99 per cent of suspended matter should be removed. Color follows in mechanical filters, but soluble substances except calcium sulphate and carbonate are not retained. Chlorine and to a considerable extent ammonia and nitrates are found intact in the effluent.

Cost is a limiting factor in modern standards. In the case of grade crossings, it was cheaper to pay for a few people killed than to raise the tracks. So in water supplies, it was cheaper to advise the boiling of the few gallons of water for drinking than to provide two hundred gallons a day of safe water for all uses.

In ancient times the wholesomeness of the supply was determined by animal experimentation, that is, survival of the people using it.

Epidemics became more frequent with increase of population, until authorities began to ask if there was a scientific basis for assuming that there was real economy in spending money to purify the water supply.

To-day the greater responsibility of the State for the care of its citizens and the greater estimate of the value of human life have shown the real basis of this economy.

The progress of the science at the basis of furnishing a satisfactory water supply is best illustrated by a few quotations.

STANDARDS

Nichols, "*Water Supply*," 1883: " . . . there will always be difficulty in deciding how near to any limit a suspicious water may come and still be used with a reasonable degree of safety. To condemn water without sufficient cause is of course undesirable, as the procuring a different supply may involve considerable expense.[1]

"Moreover it cannot be insisted on too strongly that different classes of water cannot be judged by the same standard, and the results of the analysis of waters belonging to different classes ought not to be put in the same table or otherwise arranged so as to invite comparison (the waters of the same geological horizon and area may be compared).

"To fix, however, a definite standard which will apply to all waters and by which any one can judge of a given water from the numerical results of analysis is impracticable. Every doubtful water must be considered by itself with all the light that can be brought to bear on it."

"Dr. Drown reporting to the Massachusetts Board of Health (1890) says: 'To determine whether or not a water has been polluted by sewage, a chemical analysis is sometimes insufficient, sometimes it is superfluous. It does not need a chemical examination to decide whether a stream has been polluted by sewage when one can see the sewage flowing into it.' And, again: 'Standards are relics of days in which the harmfulness of a water was supposed to be the direct result of the injurious action of specific substances found in it. The theory of to-day is that it is (in the large majority of cases) to the presence of micro-organisms in water that its harmful influence is due, and that the results of chemical analysis have their highest value in the light that they throw on the quality of the water from the standpoint of bacterial contamination.' 'An opinion regarding the wholesomeness of a water must be based on all the information obtainable about it, such as location, environment, and source of the water, and the character and population of the drainage area.' "

Mason, "*Water Supply*," 1896: "The term 'standard' is doubtless a poor selection. A hard and fast standard is simply an impossibility. Results which would be considered satisfac-

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[1] The Massachusetts State Board of Health has followed this rule in spite of all pressure.

tory for one locality might be entirely inadmissible in another, Local standards are the proper ones by which to be guided, and it is to be regretted that local 'normals' are not more frequently found on record.

"Mr. Reuben Haines recommended the following figures representing the averages of thirty-four different determinations of uncontaminated waters as standards for pure waters in the neighborhood of Philadelphia.

	Parts per million
Free ammonia	0.031
Albuminoid ammonia	0.044
Chlorine	11.9
Nitrogen as Nitrates	5.075
Total solids	125.7"

J. C. Thresh, "*The Examination of Waters and Water Supplies*," 1904: "At the beginning of this discussion we have spoken of the doubtful value of standards of purity of water based on the amount of the nitrogen compounds which it contains. In the case of ground waters there is an ideal standard of purity which is at the same time not an impossible one, namely, complete freedom from unoxidized or partly oxidized compounds of nitrogen. We do not know, as has been already explained, that a water which reaches this standard is safe if at the same time it contains much nitrogen completely oxidized, but we do know that as we depart from this standard we enter the region of known danger. It has been a very general custom hitherto to set limits for each of the substances beyond which the water should be regarded as polluted or as unfit for drinking.

"The application of these standards of purity made the interpretation of analyses a very simple matter but of very doubtful value.

"Before proceeding to discuss the results obtainable by the various methods of analysis, let me once more emphasize the importance of the inspection of the source of supply, both in detecting possible sources of pollution and in enabling correct inferences to be drawn from the results of the chemical, bacteriological, and microscopical examinations. This is now being recognized by sanitarians generally. In fact, Gruber, of Vienna, lays so great stress upon an examination of the source, as to assert that in ordinary cases even a bacteriological examination of the water can be dispensed with, and Flugge considers that an inspection carried out with the unaided senses, is the most desirable method, and seldom needs to be supplemented by chemical, bacteriological, or microscopical investigations.

" In America, considerable stress is laid upon the systematic examination of surface waters by biological methods, the number and genera (or sometimes species) of the organisms found being recorded. In this country little study has been made of the low forms of life (save the bacteria) which occur in water, although more reliable information as to the character of a water can be obtained sometimes by this method than by any other.

"I am convinced that standards cannot be adopted for any waters, but there is very little doubt that a water which gives no indications of the presence of the B. coli communis in 10 cc., of Streptococci in 50 cc.(?), and of the spores of B. enteritidis sporogenes in 500 cc., is at the time of examination so free from sewage pollution that it may be certified as safe for all domestic purposes, providing its source is satisfactory.

"This standard is attained by waters from all properly protected springs and from properly constructed deep wells. Upland and moorland surface waters, collected in reservoirs, I have regarded as satisfactory if they afforded no evidence of the presence of the Bacillus coli communis in a few cubic centimeters, and especially if the B. enteritidis sporogenes could not be detected in 250 cc.

". . . As the detection of sewage or manurial contamination by bacteriological methods must depend upon the discovery of the bacteria characteristic of excremental matter, a very important point remains for discussion, viz., the amount of water which should be used for the examination. Chemical analysis cannot be depended upon to detect pollution with 1 per cent of sewage, or with 1 per cent of most sewage effluents, which sewage effluents might practically contain all the organisms of the original sewage. Bacterioscopic analysis may be depended upon to detect a much smaller quantity of polluting matter. Unfortunately the number of the selected organisms found in sewage varies enormously, and the proportion of each to the others varies in every sample. In relative abundance they occur in the following order: Bacillus coli communis, streptococci and spores of the Bacillus enteritidis sporogenes of Klein. Houston and Klein find the variations are within the following limits:

Bacillus coli communis	100,000 to 800,000	per cc.
Streptococci	1,000 to 10,000	" "
Spores of B. enteritidis sporogenes	100 to 2,000	" "

"Assuming that efforts are limited to the detection of pollution corresponding to one-millionth part of sewage containing the minimum number of these organisms, it is obvious that 10 cc. of the water would be required to give indication of the presence of the bacillus coli, 1000 cc., or one liter, to afford evidence of streptococci, and ten liters for the detection of the spores of the B. enteritidis sporogenes. . . .

"On the other hand, assuming the polluting matter to contain the maximum number of the above organisms, one to two cubic centimeters would suffice for the detection of the B. coli communis, 100 cc. for streptococci, and 500 cc. for the spores of the B. enteritidis sporogenes.

"Prof. Sheridan Delepine, 1904, lays considerable stress on the importance of bacteriological examinations. As there is no general standard of purity he selects feeders which are uncontaminated, examines the water bacteriologically, and takes the results as a 'natural standard.'

"'To find such feeders,' he says, 'the bacteriologist of course inspects the gathering ground himself, and after noting the configuration and nature of the ground, the course of the feeder, its relation to the slope which it drains, the absence or presence of cultivated areas, of paths, of houses, the possibilities of human traffic, the presence of cattle or sheep, he can then determine whether the feeder inspected is likely to be contaminated or not. . . . It is necessarily free from any bacteria associated with decomposing organic matter, human or animal diseases (provided no carcass of a dead animal is found in its neighborhood). Such a water should be good, provided no abnormal chemical constituents are present. Even under these conditions water is liable to variations, according to the state of the weather.' "

Turneaure and Russell "*Public Water Supplies* " (1908, p. 126): "Desirable as it would be to have definite standards of water analysis that would apply to all waters, such are nevertheless impossible. The changing conditions under which various potable supplies occur make it altogether out of the question to have a standard that would be of general application."

In accordance with the tendency of each State to deal with its water problems through some Commission or Board, legal standards are being set up by which the authorities in each State may govern themselves in dealing with questions of prohibition of pollution or in compulsory measures of prohibition. The State of Pennsylvania has issued a definition of wholesome water (above, p. 57).

The State Board of Health of Illinois,[1] which covers an enormous area with very variable soil and water conditions, has adopted provisional standards as its guide. Other States are virtually doing the same thing for legal purposes. These provisional standards are in the right line, changeable to meet new knowledge, but finishing a basis for compulsion in carrying out State law.

STANDARDS OF PURITY

For the information and convenience of those who read this report, the following limits have been provisionally adopted as a reasonable basis for reaching conclusions regarding the whole-

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[1] Bulletin Vol. 4, Number 5, May 1908.

someness of waters in the State of Illinois. No absolute standards of purity whereby to judge the condition of any and all potable waters can be justly established, because of differences due to the nature of the strata from which waters are drawn or with which they have been in contact, the topography of the district, and the general environment of the sources.

SUGGESTED LIMITS OF IMPURITIES

PARTS PER MILLION

		Lake Michigan.[1]	Streams.[2]	Springs and shallow wells.	Deep drift wells.	Deep rock wells.
Turbidity		None	10.	None[3]	None[3]	None[3]
Color		None	.2	None[3]	None[3]	None[3]
Odor		None	None	None	None	None
Residue on evaporation		130.	300.	500.	500.	500.
Chlorine		5.5	6.	15.	15.	5.-100.
Oxygen consumed		1.6	5.	2.	2.-5.[4]	2.-5.[4]
Nitrogen as	Free ammonia	.00	.05	.02	.02-3.	.02-3.
	Albuminoid ammonia	.08	.15	.05	.20	.15
	Nitrites	.000	.000	.000	.005	.000
	Nitrates	.00	.5	2.00	.50	.5
Alkalinity		....	200.	300.	300.	300.
Bacteria per cubic centimeter		500.	500.	500.	100.	100.
Colon bacillus in one cc.		Absent	Absent	Absent	Absent	Absent

[1] Analyses of water ten miles from shore of Lake Michigan. Streams Examination Sanitary District of Chicago, p. 18.

[2] This standard of purity is seldom found in the unfiltered water, as all streams are more or less polluted.

[3] None when drawn from wells. They may become turbid and develop color on standing.

[4] Varies, as the waters contain ferrous salts.

"The formation of a reasonable and just opinion regarding the wholesomeness of a water requires that there be taken into consideration all the data of the analysis together with the history of the water; the nature of the source; character of the soil and earth or rock strata, and the surroundings. The interpretation of results is a task for the expert. The purpose of this explanation is, therefore, merely to present to the layman such information as shall aid him to an understanding and appreciation of the analytical data."

A marked contribution was made by Dr. Drown in the clear statement of *interpretation* of results or, as the author expresses it, the diagnosis. A judgment founded on the sum total of the evidence given by the twenty or more chemical tests, the physical characters, the local conditions, and the bacterial count as well as at times other special tests is the only safe one.

This involved path of evidence requires the skilled detective rather than the mere analyst. Numerical results may mean much or little as the circumstances exist.

This fact is now generally recognized, and no reputable water analyst will now allow himself to be induced to give results in terms of standards.

In the first place, the sample must be taken so as to have some meaning. Any gallon of water taken anywhere along the stream will not do. There is to be a decided relationship between place of collection and the inferences to be drawn from the analysis.

In the second place, care must be used in collection so that no contaminating influence shall affect the sample — dirty hands, dirty sticks or stones, etc.

In the third place, it is usually a comparison that is needed rather than an absolute statement, because the identical circumstances occur but once.

In the fourth place, since permanence is the best assurance, the test of a condition favorable to change is important, that is, tests on incubated samples or of the original sample after a week's standing.

Fifth, in studying the published results of other laboratories, methods of procedure should be known, since it has been true in the past that great differences were found. In 1897 a portion of the same sample of spring water was sent by the town authorities, to five chemists in three different states. The returns were as follows:

Parts in 1,000,000

Nitrogen as						Oxygen consumed.	Hardness.	Chlorine.
Albuminoid ammonia.			Free ammonia.	Nitrites.	Nitrates.			
Total.	Solution.	Suspension.						
.028	......	....	.016	.003	14.000	.595	61.6	39.0
.047	......	....	.002	.010	12.000	....	....	34.9
.014	......	....	.080	less than .010	10.000	....	chiefly mg. 122.2	31.2
.064	......	....	.010	nitrous none	nitric acid 62.000	none	67.0	36.0
.080	......	....	.000	.002	12.500	1.098	60.0	37.0

As recently as 1900 a printed bulletin was sent out purporting to come from a State Board of Health with, among others, the following remarkable statements:

"The following simple tests are issued in order that people who are not practical chemists may have a reliable method of detecting impurities in drinking water.

"(*a*) Good drinking water should not give any reaction with acid (red) or alkaline (blue) litmus paper.

"(*b*) *Transparency*, and (*c*) *Color*.

"*Test:* Fill a 6-inch test cylinder with the suspected water, and place it upon a white sheet of paper. Fill a similar glass with distilled water for comparison. Look through the water from the top. Any turbidity or want of transparency in the suspected water should be sufficient cause to have it condemned for drinking purposes, unless it be filtered and boiled.

"(*d*) *Odor.* — Drinking water should be absolutely odorless.

"*Test:* Fill a 500 c.c. (about a pint) Florence flask with water under examination. Heat it gently up to 43.3° C. (110° F.) or 48.6° C. (120° F.). If any odor develops, the water should be condemned, as it will generally be found to contain organic impurities.

"*Test:* Heat the residue in a platinum dish. If it is dissipated by heat or becomes charred, the water is unfit for use. (See also 2, below.)

"*Tests:* (*a*) Chlorine may be detected: (1) By its odor; (2) By turning paper dipped in a solution of potassium iodide brown; (3) By bleaching a solution of indigo or litmus.

"*Tests.* —*Nitrates:* 1. When heated with sulphuric acid, they evolve pungent fumes of nitric acid.

" 2. When heated with a solution of ferrous sulphate and a few drops of sulphuric acid, a black coloration is produced.

" 3. Evaporate 4 cc. (60 drops) of the suspected water to dryness and add a few drops of phenyl-sulphuric acid (1 part of carbolic acid, 4 parts of strong sulphuric acid, and two parts of water); if nitrates are present a reddish color of nitro-phenol is produced.

"Should water become contaminated by the excreta from cholera or typhoid fever patients, it will respond to the tests for organic matter and to those for nitrites and nitrates and the albuminoid compounds. The microscope will be able to differentiate between the micro-organisms of cholera, typhoid fever, etc."

As late as 1909, these were held as official in some quarters.

Legal enactments are not infrequently effective spurs to investigation. A notable example occurred when in 1886 the Legislature of Massachusetts passed an Act "to protect the purity of inland waters" and gave into the charge of the State Board of Health the experimental and supervisory measures required for this efficient protection. Stimulated by this responsibility, it instituted, for the time, a remarkable combination of scientific organization, engineering skill, chemical and bacteriological knowledge, which resulted in ten years of most fruitful investigation, although at the time so much seemed unproductive work.

The expenditure has been amply justified not only in the efficient work for the State continued along similar lines but also in the development of certain principles and methods which have served as points of departure for further investigation all over the world.

The value of these investigations lies not only in their comprehensiveness but in the long time given to each series to prove or disprove their lessons. Consecutive records of twenty-three years are available. Snap judgments are thus precluded.

The student is to take the "Outlines" in Part II as "subject to change without notice." The whole procedure as well as the theories on which it is founded is in a mobile state and will be for many years to come. There will be yearly need for revision, but that is no reason for delaying the trial of any scheme which promises in a given case to give information, for that is the end to be sought. Such information, however, must enable the worker to find his way—not merely give a mass of figures to print.

On the other hand, let not the worker despise pages of printed figures; they often reveal facts to another set of workers, twenty years later, facts which have been safely buried until needed. Also it has happened that a sudden illumination has come from studying columns of figures. Such was the origin of the idea of isochlors, or lines of normal chlorine.

Let the young engineer, impatient of routine work, therefore, not wholly despise the long columns of figures the laboratory files away for him.

REPORT OF WATER ASSAY

Parts per 1,000,000

Address for report

Locality

Date

Description of Water

Physical Examination	Turbidity		....
	Sediment		....
	Color		....
	Odor	Cold	....
		Hot	....
Chemical Examination	Free Ammonia		....
	Albuminoid Ammonia		....
	Nitrites		....
	Nitrates		....
	Hardness		....
	Chlorine		....
	Oxygen Consumed		....

Remarks

The purpose of the water assay is to permit an estimate on certain points, as for instance:

(1) If water is suitable at the present moment for domestic use, i.e., free from germs which indicate sewage pollution or free from those substances which accompany sewage pollution, to wit: " free ammonia," nitrites, odors, fermentative appearance, etc. It is well to examine for organic carbonaceous matters which may furnish food for decomposing agents (bacteria).

(2) To determine if it has been in the past a polluted water — even if it is now entirely safe — what has been may often be again. Nitrates, excess of chlorine, excess of total solids, etc., testify to past history if normal water is at hand for comparison.

(3) To determine the present character of the water with reference to its continued use or introduction as a supply. The analysis to be kept for reference as a control for possible changes.

To the engineer's laboratory may be brought for assay —

Safe water (supposedly) but which may be proved suspicious.

Natural waters from uncontaminated soil or from mountain streams.

Tests may also be asked for treated samples to determine the success (or otherwise) of the process.

The laboratory outfit should include the means for all this work on a small scale.

A special laboratory connected with a purification plant need not necessarily comprise all the appliances if it has a single problem to deal with.

The general laboratory should be supplied with materials for simple bacteria counts. Media can now be obtained of known quality, and the mere plating and comparison of counts is not beyond the average chemist or engineer.

The economic trend so often referred to is not wholly bad — not at all bad if it enables a greater benefit to be conferred.

In the case of water analysis, the old-time laborious concentration of gallons of liquid in the open laboratory regardless of the collection and absorption of dust and vapors, and of the solution of the earthen dish, in order to obtain sufficient material to weigh, was superseded in the latter half of the nineteenth century by colorimetric determinations which reduced quantities and times and avoided much contamination. There were, however, few laboratories where the degree of cleanliness and exactness now recognized prevailed. Room 36, Walker, M. I. T., was said to be the only really clean laboratory as late as 1887. Certain it is that the value of the ten years of classical water investigation, 1887–1897, carried on in that laboratory owed much to the refinement of method there maintained.

It is the engineer and not the chemist or bacteriologist who has the front rank to-day, and he must be, above all else, an economist. Why make twenty tests when five will tell him what he wishes to know? Why have an expensive laboratory when a simpler one will do five times the work of the kind he wishes to do? There has been great danger in this attitude lest the untrained engineer should think the simpler work always all-sufficient, the twenty tests never required. The fullest analyses must be made sufficiently often to establish a base line.

With education, the confidence of the worker has lessened, and a modest willingness to take the scientific attitude of "knowledge in suspension" has made possible the trusting of an engineer with the tools of a chemist and a bacteriologist with less fear that he will jump to conclusions or be rash in his judgments.

But a preliminary essential is that he shall have had experience in a well-ordered laboratory, not merely have read books, however clearly written. Some important points can never be put on a black-and-white page. A student will not catch himself doing a ridiculous thing as will the skilled worker watching him. Experience will, in the end, teach, but it is costly and sometimes fatal.

A man sent out to collect samples was found using an old stick picked up anywhere to push the bottle down to the prescribed twelve inches below the surface. One collector, having broken the glass stopper, glued it together. The laboratory, naturally, detected the dissolved glue by the abnormal excess of albuminoid ammonia, but that one of the all-important series of samples was irrevocably lost.

The collection and safe transportation of samples are of the utmost importance, as is a noting of all the surroundings of the spot where they were taken.

In the mining and metallurgical professions the assay or test for the one or two essential values in the ore sample has been developed to a high degree. When gold is the question the assay for gold proves its presence or absence; if absent, the character of the rock itself has no further interest.

In the case of the water assay, it is foreign substances that we look for to warn us of possible danger. The test for free ammonia or nitrites, for instance, if positive, gives the same decisive knowledge as absence of gold in the ore assay. The material is useless for its purpose. In neither case is further search precluded in another spot.

What is the decisive test which may be included under the head of preliminary but decisive enough to be classed as assay?

Water rightly read is the interpreter of its own history, and the untrained worker, not having this background, did not appreciate his own limitations. Several biologists have exceeded the bounds because of lack of training on the chemical side — of experience with great varieties of water. It is in this wider scope that the Mass. State laboratory had the advantage over the city laboratories of London, Berlin, and Paris.

Given the trained worker, he may safely use the five instead of twenty tests, with the permanent standards and the field kit, to aid his mature judgment.

Whatever tests are decided upon, the investigator is to bear in mind that the end sought is a correct diagnosis of the condition and of the causes of that condition. All sanitary work aims at prevention in future, not merely cure of present trouble.

In doubtful cases a long series of experiments, week after week, month after month, will, if studied carefully, finally reveal the source of trouble. Therefore, the laboratory must be prepared to carry out some of the exactly comparable examinations without deviation of methods and solutions.

These reports will be more elaborate in character than the simple water assay and more minutely follow directions.

Whatever value is attached to the results of the lesser or the greater examination is dependent on the conscientious exactness in measuring and recording, the sensitiveness of the eye to color, absolute cleanliness, and unswerving honesty in reports.

WATER SUPPLY INSPECTION

1. The engineer's laboratory.
2. Field work.
3. Interpretative diagnosis.

In the rapid development of resources, the American has frequently reversed the order of scientific procedure to the ultimate delay of good engineering as well as of good government.

The inspection of watersheds, for instance, has often been intrusted to the topographer or to the surveyor, whose eyes and nose have not been trained in the laboratory to see things and to follow the scent. Hence he has to draw many important lessons.

The laboratory is the elementary school where the sanitary engineer learns the A B C and the simple language needed. Here he learns to understand the signs of the trail, the broken twig, the plucked leaf, the flower bent by the moccasin. It is after the attention has been called to signs, and observation has been trained, that the engineer may go over the country and see what the careless eye fails to catch. Therefore the laboratory is an indispensable adjunct to the engineer's training. (The sanitary official will become more and more an engineer rather than a medical man as prevention becomes more clearly the duty of the community.)

But the laboratory must be an engineer's laboratory, not the old-time one of the chemist or the bacteriologist. Some one, of course, must go over all the steps that have led to the conclusions, but the engineer wishes to know the conclusions and how he may use them. Time fails for both. It is seen that the machine is to be controlled, not built, by the engineer.

As some one has said, the sciences are no longer in water-tight compartments, but flow freely from one to the other. The library and the laboratory are the engineer's tools as much as the theodolite and the transit. A certain modicum of fundamental chemistry — general principles and names and reactions — is necessary to the reading of modern scientific literature and to the understanding of current conversation. But laboratory processes are highly educational. The first sanitary law — quick removal of all wastes — applies to clean hands, clean apparatus, clean methods. Sterilization of *unclean* bottles is still not uncommon.

The water assay in distinction from a complete "water analysis" is intended to furnish material for the diagnosis. Not all these facts may be useful, but it is best to record them against a possible value in the future.

Just as in a case of sickness the physician keeps the daily range of the bodily temperature of his patient, since it may give him the clew he is seeking, so the analyst makes the determinations for free ammonia, nitrites, and chlorine, not because they are always significant in themselves but because they may furnish the clew to what is happening. It is the active condition that the sanitary engineer is looking for, what is likely to happen. The chemist and bacteriologist may tell what has occurred and what the condition at the present moment may be. The family asks of the physician what will be the patient's condition when this attack is over. The community is coming to ask the sanitary engineer what will be the character of the water supply after this treatment.

A noteworthy instance of an attempt at interpretation on new lines is the study which is, after several years' trial, now reported in Bulletin No. 7 of the Illinois State Survey.

Extracts from Bulletin No. 7, University of Illinois, State Water Supply

"If a water contains high free ammonia which is being produced by bacterial action, one should be able to continue the production by supplying the suitable food material. On the other hand, one may have a water high in ammonia content but almost free from bacteria which produce ammonia. Hence there is no agent to cause the further production of ammonia even in the presence of suitable food material. This principle was tested first with two samples of water, one of unquestionable purity from a deep well and the other from a polluted stream. The bacteriological analysis of the deep well water showed 80 bacteria per cc. on gelatin 20°, with no gas formation in glucose broth. The chemical analysis gave 4.5 parts per million of free ammonia. For the polluted stream the bacterial count was 800 per cc. with gas formation from .01 cc. of the sample in glucose broth. The chemical analysis gave 1.2 parts per million of free ammonia.

"The high ammonia in the deep well water is presumably derived from a deposit of glacial drift. The ammonia content of these two samples bears no relation to the bacterial condition of the waters in question.

"This experiment not only gives a method for distinguishing the source of origin of the ammonia in the two water samples, but it furnishes a definite method for studying the significance of the free-ammonia determinations.

" Although ammonia production is a very general property of bacteria, this table would indicate that the colon group is not especially active, giving even much lower results than ordinary saprophytes such as B. megatherium and B. mycoides. This finding is of significance in its relation to the interpretation of analytical data. High free-ammonia determinations do not, therefore, in any way indicate the presence of intestinal bacteria, but are merely an indirect qualitative test for the presence of bacteria without giving any definite idea concerning the number or species present.

"A preliminary test was made upon the same samples of water used in the free-ammonia experiments: namely, a polluted creek and a deep well. Except where otherwise noted the following technique has been uniformly employed throughout these experiments:

"The medium used was an ordinary meat extract broth of double concentration with an acidity of 2 per cent of normal acid, and to this was added 2 per cent of gelatin and 0.05 per cent sodium nitrite. Precautions were taken to adjust the final acidity before adding the sodium nitrite in order that any loss of nitrite during heating and sterilization might be uniform in different lots of media. No attempt was made to introduce inhibiting agents into the medium, though preliminary results with ammonium chloride and glucose indicated that these substances might be used to advantage. Instead of the 1 per cent concentration of glucose used in the fermentation tests, it appeared that concentrations of 10 per cent or even 20 per cent might have some slight selective action in the presumptive gas tests. Five cc. of the broth were measured accurately into test tubes. Intermittent sterilization was employed. The medium was stored at a temperature of 8°, and under these conditions it was solidified. Inoculations were made with 1 cc. quantities of the waters to be tested, or where pure cultures were used, bacteria were inoculated directly without correcting for the volume of 1 cc. used in the water sample. As in Table III, letters and numbers after the bacterial species indicate cultures from different sources. Incubations were carried on at from 37° to 39° C. for forty-eight hours.

"The nitrite determinations were made by the customary naphthylamine-hydro-chloride and sulphanilic acid color method. It was originally planned to make careful quantitative analyses, but the differences were so pronounced that this was unnecessary. The data in the tables represent only approximate determinations.

"Analyses of the polluted creek and the well water gave results as follows:

	Nitrogen as Nitrites. Parts per Million.
Pure Well	.25
Polluted Creek	0
Sterile Media	.25

"This experiment was repeated three successive times with similar results.

"Experiments by the first method gave well-marked differences. In the case of four dug wells representing moderate pollution, the time required for the complete destruction of the nitrites varied from eighteen to thirty-six hours. Upon deep-driven and carefully protected dug wells the time was much longer, ranging from four days to two weeks.

"It is possible, of course, that reducing substances such as dissolved oxygen in the inoculated water sample, might be responsible for the changes which occur. This possibility is practically eliminated in cases where pure cultures are used. For the water samples, control tests also showed that bacterial growth is the essential factor.

"The estimation of the value of any tests in water analysis frequently presents considerable difficulties. If the test is applied directly in routine work, where a large number of samples are examined, extreme waters give definite results, but variation will occur in the important border-line cases."

The author believes very strongly in the significance of the simultaneous presence of free ammonia and nitrites as a valuable aid in the diagnosis. There are some indications pointing to the presence of urine as a precursor of the appearance of nitrites. In a solution containing both ammonia and nitrate the reduction of nitrate to nitrite takes place much more quickly than the oxidation of the ammonia. Variations in the percentage of dissolved oxygen will affect the results more than any other conditions besides the presence of fermenting substances.

SANITARY ANALYSIS

1. Detection of substances dangerous to health.

2. Detection of substances indicating a probable or possible danger.

3. A series of standard or normal determinations to serve as a base for 2.

No. 2 is in the nature of a diagnosis; no method is likely to make one test of supreme value, for value lies only in the series and in the relation of each to the rest. Hence the effort of the past three years has been to secure standard methods so that the work of one laboratory may be compared with that of another and in order to detect changes.

The test of a sample of water may be for the purpose of deciding upon its suitability for domestic use, — drinking, cooking, laundering, — for manufacturing, boilers, production of steam, or for dyeing. Or there may be required a test of water from filtration plants, sewage purification works, etc., to decide how badly a stream is polluted.

The tests for the presence of dangerous substances include those for arsenic, lead, etc.

Certain substances not harmful in themselves may indicate the presence of organisms which are harmful, such as ammonia and nitrites. Chlorine and nitrates, on the other hand, show that the soil through which the water has percolated has been polluted.

This exercise of judgment in the practice of drawing conclusions from insufficient data is an important one, for the engineer should be able to decide when the data *are insufficient* in order to refuse to give an opinion.

CHAPTER VII

PROTECTION OF WATER SUPPLIES AS A CONSERVATION OF NATURAL RESOURCES. WATERSHEDS AND PROSPECTING FOR ADDITIONAL SUPPLIES

BY 1877 the preliminary survey of the drainage basins of Massachusetts was concluded and the opinion reached that while there were some things to be remedied, "as a whole throughout the State the evil from the pollution of streams is small compared with that arising from the accumulation of filth in cesspools and accumulations near dwellings." . . . " In order to encourage towns . . . it will be necessary to regulate rather than wholly prohibit the contamination by filth of our waters." . . .

In 1887 there were one hundred and twenty-three sources of public water supply, furnishing 82 per cent of the population, fifty ground waters, seventy-three surface waters, only five streams.

The oversight of these was given to the State Board of Health instead of to a separate *Rivers* Commission, and it was enjoined especially to *prevent* further pollution and to advise towns as to means of prevention.

Protection of water supplies as a conservation of natural resources means (1) Clean soil and prevention of fouling; (2) Husbanding rainfall by storage; (3) Legal protection of the storage basins.

The carrying further of the idea of prevention as both a sanitary and an economic measure involves the long look ahead in a close study of watersheds both for quantity to be available in years to come and for quality maintainable according to the standards already discussed.

Husbanding of Rainfall by Storage. Water-supply problems have changed in the last one hundred years from the securing of a gallon or two of "pure" water for drinking and cooking to thirty gallons for cleanliness and one hundred to two hundred gallons for manufacturing or transportation purposes. At present it is all drawn from the same source and returned as dirty water for the use of another community. Just how dirty the supply may be allowed to become is one of the burning questions of the day. When commercial interests are 98 per cent of the whole, the 2 per cent interest in the health of the people is apt to be disregarded, and only the high commercial value being now set upon human brain and energy has brought the question to a business point. It is slowly being recognized that safety of human life is to be considered in the advance of mechanical and manufacturing processes. Accidents on the one side and conditions of living on the other are robbing the nation of thousands of valuable citizens.

Air and water are two of the conditions now most before the world. It is being shown that in terms of human life it will pay to care for the water supply. Just how much that means we shall see later at the point of intensive interest — the great cities. The question of "pure" water may be dismissed. There is no such supply available. All abundant sources, rain, lakes, streams, wells, have been contaminated. The deep unpolluted sources from rocks and sands, so-called artesian wells, contain for the most part large amounts of mineral salts, and in most regions such sources are not sufficient, so that impounded rain is the chief supply of most large cities.

Water is the universal solvent and the common carrier; hence *anything* is liable to be found on or in it, — animal, vegetable, mineral.

There is held to be less danger from mineral substances, unless near arsenic works or lead mines. Vegetable decay used to be held responsible for malaria, and even now waters carrying much dead organic matter or those highly colored are looked upon as suspicious, but animal matter is in disrepute the world over, both on account of the disease germs which *may* accompany it and on account of the solubility of its more or less alkaloidal compounds which may prove depressants of vitality if not direct poisons.

Certain things should be borne in mind: — (1st) that at times of low water surface supplies are subject to vegetable growths of which they may show no trace at high water.

Ground supplies are subject to contamination in low-water times from sewage which may be held back in high water.

If it is true that good water is becoming scarce and that water pure and undefiled is as nearly gone as the coal supply, it behooves the nation not to think of a substitute as in the case of coal, but of a more provident manner in its use.

However, unused land is rare; even public domains have travelers, and careless travelers, as fire ravages show. It is no longer safe to assume that mountain streams are clean, and irrigation is making unused water scarce.

Wastes must be disposed of somehow, and soil, air, and water are all unclean.

In man's hurry to get through with his inheritance, he cannot wait for nature to filter, so he adopts nature's methods with a hurry attachment.

The impurities are either coarse or fine — either mineral, vegetable, solid or in solution, harmless or poisonous, but impurities all the same.

Some will settle out if left in quiet; some may be strained out. Some must be caught and clotted and some must be actually filtered through the finest net. It is a mistake to say that water once soiled can ever be made "pure" again. It may be made clear if turbid, palatable and colorless if disagreeable and brown, safe if suspicious or dangerous, but that does not mean pure. However, accepting it as a conventional term, since neither rain water nor the best spring water is really pure, "purification," as used, means renovating spoiled water — almost as good as new.

Man has made himself much extra trouble by reckless waste of nature's provision. The rain has been allowed to flow away to the sea without doing its full work. Ten gallons have been used and fouled where one would have served. Pipes have leaked and water run to waste. Used water has been allowed to soil many times its volume in good water. Crops have thirsted for water which might have refreshed them and brought a portion of food as well.

The future is to bring more care for both quantity and quality as bearing on the food supply as well as the health of the people. Even wash waters may be turned to increasing national wealth.

Because, through ignorance of biological principles, the first attempts at sewage farming failed, it is not wise to neglect so positive a source of income, but it is largely the water that is of great value, and while the plant food it carries is of minor consequence, yet it is in a most available form. When more is known of the office of mineral matters in plant growth, these "farms" may be better carried on.

Just as insurance companies balance facts and probabilities and count on a law of chance, so the sanitary engineer is to be called upon to balance the two risks, damage to business and damage to health.

Men have refused to insure and come through life safely. Also others have lost their all in a month.

It is the province of the future sanitary engineer to make good his promises to protect both business and health, till that time when both interests will become identical.

To do this the following questions are essential.

How contaminated may a water be by business uses before the sanitarian protests and the authorities demand protection for the people?

How bad may a water get before it must be treated?

How may it be treated and how much is the insurance policy to cost?

The following table shows the quality of water which various cities have found at hand, to use or to treat.

PARTS PER MILLION

	Ammonia		Nitrites.	Nitrates.	Hardness.	Chlorine.
	Free.	Alb.				
Burlington, Vt.	.010	.138	.0000	.0100	42.0	1.4
Minneapolis.	.072	.298	.0000	Trace	136.0	2.0
Passaic, N. J.	.000	.084	.0020	.0800	35.1	3.5
Schenectady, N. Y.	.050	.170	.0040	.2890		4.5
Gloucester, Mass.	.088	.136	.0010	.0180	3.0	8.7
Springfield, Mass.	.016	.138	.0020	.0770	7.0	1.4

Sources of Water Supplies

Various conditions which cause contamination or pollution.

Meteorological.

Like air, water is in constant circulation, rising from the sea and from all vegetation and earth surfaces in the form of pure vapor; carried by winds to high altitudes, condensed by cold, and precipitated through the earth's dusty, gas-thick atmosphere in the form of rain or snow, in anything but a pure condition. This precipated rain soaks into the dirty soil and, by the great solvent power of water, dissolves whatever is soluble.

Geological.

A larger part of the rainfall in temperate zones washes the leaves of trees, the fields of grain, the roofs of houses, the streets of cities, the farmyards, the fertilized fields, the dump heaps, and flows in channels to the large lakes and the sea to begin its course again.

Water for domestic use is drawn from either the ground circulation or the surface flow. In pioneer regions that ground-filtered and cooled water was searched for and camped by, which flowed in sparkling volume, as springs. Such water may have traveled miles and been in the earth layers dozens of years, and become charged with tons of mineral substances, but it was usually free from organic matter, and if it ever carried any "germs," time and cold had destroyed them. Hence in pioneer times in temperate and tropical areas such spring water was the ideal drinking water, clear, cold, sparkling, pleasant to the taste.

In contrast to the muddy, warm, "flat" water of streams which primitive and pioneer peoples have used only as laundry tubs and sewers, one has only to travel in uncivilized lands to understand the preference for "springs" and the early worship of these fountains of life.

The nineteenth century, with its inventions, changed the habits of the people to such an extent as to exert a marked influence on the character of such apparently permanent features.

Changes due to Mechanical Processes.

Families no longer gathered at streams to wash themselves and their apparel. They dug wells near by their permanent homes and allowed that surface water which soaked from barnyard, garden, and near-by fields to collect. They were lucky if they tapped an underground source flowing from distant collecting grounds to dilute this supply. The quality of this water was dependent on the geological character of the rock and rock débris, the kind of cultivation, and most of all on the *habits* of the occupants of the homestead.

If they took pains to carry the waste water some distance, it was well cleaned before it soaked back. It they allowed it to penetrate the ground near by, it was often only partly cleaned. Time and distance are factors to be reckoned with.

Then came the house tank for supply to bathroom and toilet, with the necessary concomitant, the leaching cesspool at twenty to fifty feet from the well. Trouble was thus invited by the very means which civilization has been most proud of, cleanliness of person and belongings.

As in every other advance of mankind, the knowledge of right and safe methods has been gained at the expense of human life and suffering. As more people living on an acre of land needed more water, supplies were sought for and brought from a distance, and carried away in drains after using. At first these were surface waters flowing by gravity, the people using the wells in their own back yards.

More cities grew up and polluted the sources. Thickly settled countries allowed wastes to percolate through rock crevices in the hills and valleys until it is now a rare occurrence to find an uncontaminated water within two hundred miles of any town. By uncontaminated I mean a water which shows no evidence of past pollution.

The fouling of water supplies like the littering of streets is a result of selfish carelessness, which reacts on the doer.

It is mainly ignorance and a clinging to traditional half truths, like "the ground is the purifier," "out of sight, out of mind."

Clean Soil.

Since all water (except cistern water) comes in contact with earth, flowing over it or through its interstices, dissolving, washing, wasting, leaching, and transporting, the character and condition of the soil are of the utmost importance as regards the purity of water.

Much if not most of the danger from impure water comes from habits of people as regards soil.

Theories of purification by earth were very crude until about 1880 and the discovery of the nitrifying organism.

WATERSHEDS

A. Prospecting for additional supplies.

B. Inspection and care of surface and tributaries.

C. Conservation of certain clean underground waters for domestic use.

All successful mining operations include "prospecting" — a careful exploration of the whole tract, both superficial and by drilling, to ascertain the extent of the resources at command.

Available water is a mineral resource in several senses. Pure ice is an actual crystalline mineral and pure water is mineral in its composition. Like the precious metals there is only so much water in existence and man is totally dependent on nature's supply. The conservation of this natural resource is becoming one of man's important duties. The municipalizing and federalizing of water plants makes it possible to use methods of investigation for future supplies. The rainfall may be conserved or wasted.

The quality may be maintained or allowed to deteriorate. Which shall it be?

Prospecting for a Town Water Supply. The profound influence which the geological and topographical conformation has on the water supply at any given spot, as well as the effect the surface soil has upon the water collected in the area, makes these studies of the first importance. Naturally this investigation must be carried out in the field.

The party may well consist of three persons — a geologist, a topographic engineer, and a sanitary engineer with a degree of chemical and biological experience. The sanitary engineer is the leading spirit. He knows the aims of the survey and he should know enough of the economic conditions to appreciate results. In any new undertaking there will be social and legal problems to be considered, buildings to be moved, lands to be overflowed, water rights to be acquired, complaints to be anticipated.

A. Prospecting for Additional Water Supplies

This field work, sanitary survey as it is sometimes called, has two objects: (1) the search for quantity; (2) the inference as to lasting quality.

Since the total supply of water on the earth is limited by the rainfall and the available supply by atmospheric and geological conditions, the engineer must avail himself of meteorological data — rainfall records of at least fifty years, cycle of wet and dry years, etc. The quantity of rainfall in a given year may be distributed somewhat evenly in time and downpour, or may come in deluges at long intervals — the total quantity may be two inches or less over desert and alkali plain, or three hundred to six hundred inches in tropical countries. Panama and Costa Rica are giving illustrations of excess of water.

The fertile temperate regions of the globe, the great food belt of the world, receive annually forty to sixty inches of rain, equivalent to about six hundred to eight hundred million gallons of available water per square mile.

Since this area contains much arable land, it is probable that about one-half the rainfall will sink some three feet below the surface; a portion, depending on character of rock formation, position of strata, etc., will penetrate depths hundreds of feet below the surface. About one quarter of the rainfall in the temperate zone may flow over the surface without having soaked the ground for more than six inches in depth or six hours in time. The remaining quarter will, in forested and arable regions, be evaporated from the leaves of trees and crops and from bare soil.

In one of the western states, it has been estimated that one hundred tons of water are needed to raise one ton of crops. The desert air has been shown to take up from water surfaces seven or eight feet a year where the rainfall was less than ten inches.

The study of water circulation is a science by itself, hardly established as yet, but of the utmost importance, as will be considered later.

The prospector is concerned with the evidence he can collect from observation and in some cases by boring.

The rain water, as it falls on the earth, tends at once to find the lowest level and to flow back to the ocean whence for the most part it came. The speed it makes is lessened by the obstructions it meets — impervious rock, broken strata, deep fissures, fine clay, etc. The rate of surface motion is greatly modified by the slope of the land. The force of gravity pulls water down, while capillarity pulls it up, hence evaporation from arable soil and plants.

The underground circulation of water is a mystery to the average man, and his ignorance is the cause of many of his ills. Although he knows that surface water flows approximately horizontally, it seems to him that the perpendicular rain must continue down in the same direction instead of being deflected almost at once in a lateral direction. Else, why does he place wells and cesspools within a few feet of each other and express such indignant surprise at the proof that their waters mingle?

The art of a Sherlock Holmes is often needed to draw out the facts affecting soil and water pollution, the habits of the community, and their attitude toward the need of conservation and toward the legal aspects of the care of watersheds.

Just as in prospecting for ore deposits, so in looking for drainage horizons, boring, cross-cutting, and trenching are often needed, and bore holes, perhaps ditches, and certainly wires and sounding lines come into use.

One visit will not suffice. Unexpected appearance, exceptional meteorological conditions must be taken into account, the cycle of wet and dry years, the position of the time of examination in that cycle. All these things take time; not less than two years, and probably longer, will suffice for a reasonably clear idea of the quality of a given watershed as a source of supply. No genuine mining company is satisfied with a less thorough report and no town should risk the lives of its citizens with less. Tests should be continued over a long enough time to prove either variability or permanence. One test or several in one season is not enough.

B. Inspection and Care of Surface and Tributaries

Field work may be made instructive to the communities in a way which shall help to make that solid public opinion which sustains improvement work.

It is not enough, as has been found by sad and costly experience, to engineer beneficial reforms, to plan and construct. It is the daily use which tests the scheme, and if the inhabitants of the district are hostile or even unsympathetic or perhaps only ignorant, any water-improvement scheme is likely to fail of its object.

For instance, the residents on the watershed of a lake taken for a water supply are simply made stubborn by a law which forbids boating, bathing, and fishing. It seems to them aimed at their rights. They honestly believe in most cases that it is aristocratic nonsense. As one California countryman said: " This is all graft. The Board of Health wants to get good fat salaries, so they get up a scare and we have to pay for it."

The sanitary education of the people proceeds slowly — more slowly than we know. Deep down in their hearts most of them consider the reforms only passing fads. Therefore, each engineer should constitute himself a missionary at every opportunity.

The greater good of the greater number should not blind the investigator to the needs of the individuals. Instruction as to *how* to improve conditions, and explanations as to why they ought to be bettered, must be given at every opportunity. Here is a call for tact and forceful personality.

The possible removal of contaminating causes, farmyards, factories, the probability of new enterprises, the distance around the reservoirs to be owned by the city, the quantity collected in dry years, effect on tastes and odors of raising and lowering the shore line, trolley lines, picnics, summer resorts, all add their quota to the problem.

Lakes and reservoirs should be tested in midsummer as well as in cold weather for evidences of layering and consequent deficiency of oxygen.

Much is learned of the contributing causes when a careful inspection is made of the small streams, pools, etc., since any water supply (in large quantity) is derived from numberless small sources. Seepage is in some cases one-third the total. The prospector should be able to trace the greater part of these additions, for the nitrates this class may bring in are food for the pests of reservoirs, — algæ.

Many a water supply has been spoiled beyond recovery for want of this foresight. As in all sanitary work, prevention is more effective than cure. A reservoir once seeded is at best forever a trial.

The country population is thoughtless and has not had the consequences of its careless habits pointed out. In the beginning certain streams should be diverted and swamps cut out before the mischief is done.

It is a fashion to say: "Oh, better let everything go in and then filter." The complete purification for safety is as yet unknown. Comparative safety is all that can be demanded, and too late it may be discovered that a little foresight would have saved money and lives.

In discussing watersheds, it must be borne in mind that there are three great divisions geologically and topographically in North America: (1) The once glaciated region full of lakes and tributary mountain streams, north of 40 degrees — a region of abundant water, as a rule cold and frozen in winter, frequently attaining 72 or 75 degrees F. for a short time in summer.

(2) The Appalachian and southern slopes, below 40 degrees North Latitude, over which the products of ages of rock disintegration have for the most part remained *in situ*, covered by vegetation and liable to erosion, furnishing turbid streams. This is a lakeless region and all reservoirs are artificial, the supplies from streams or deep wells, sometimes artesian.

(3) The so-called arid and semi-arid regions, where the rainfall is less than ten inches and sufficient supply is brought from a distance or derived from underground stores, laid up in past ages, liable to be exhausted by lavish use, as Denver used its forty years' collections in twenty.

C. CONSERVATION OF CERTAIN CLEAN UNDERGROUND WATERS FOR DOMESTIC USE

Principles of conservation must vary and standards of allowable supply must be somewhat dependent on possibilities. The soft, colored, corrosive water of eastern and northern America may be conserved without much treatment. The muddy, often harder waters of the South must be settled or filtered or both, for domestic and industrial use. The saline, often alkaline waters of the arid areas and their borders may be most profitably distilled for the table and treated for industrial purposes.

Most farmers know of the "hardpan," or impervious clay layer, which in many regions divides the deep waters from the shallow circulating waters. It is these latter, whose upper surface is called the "water table," which easily become polluted from the surface. Their movement is in a diagonal direction toward the lowest outlet, the speed from two inches to two feet a day according to the porosity of the soil. These waters collect an infinite variety of contributions on their course. They also dissolve whatever soluble substances come in their way. If undisturbed they flow out in the banks or bed of the nearest watercourse or gully.

It is these underground sheets of water that are tapped by shallow wells (sometimes they collect in hollows scooped by the ice sheet and filled with gravel); in glaciated regions this is a common source. These basins depend on the rainfall of a limited area and these wells go dry in dry times and are frequently dangerous. The slow percolating movement is the only safeguard for farmhouse or village supplies, and this depends on the porosity of the soil. Even town supplies have been drawn from these ground sources. They serve for a limited use, but if drawn on heavily the movement is hastened, not allowing time for the changes, and as the area is increased the quality deteriorates.

The care of wells used more or less by the public — town well by the country store, schoolhouse wells, factory wells, our neighbor's well — all have at times failed to pass the tests. Great-grandfather's well served for the gallon a day that a person of 1776 required, but not for the one hundred used by city-bred grandchildren of 1910.

Density of population has changed conditions to such an extent that, even in village communities, wells are in close proximity to cesspools, stables, hen yards, intensively cultivated gardens, and other sources of pollution.

There is a limit to the amount of pollution a given cubic foot of soil will dispose of in a given time. It is time that the modern citizen will not give. It is only a thoroughly model filter, like Lawrence No. 2, which will, year after year, take a dose of city sewage in the morning and deliver good "spring water," clear, sparkling, and low in bacteria, the next morning, with five feet of filter material, and bacteria trained to their work for twenty years.

The retaining power of the soil is great, and rather than wait to wash out the accumulated salts, it is usually best to seek a new source. However, our records show several wells on abandoned farms which five years have restored to nearly their original value.

The farmer is more likely to be alarmed at a certain peculiar "flat" vegetable odor which results from the presence of thirsting tree roots than at more serious drain contamination. The latter is protected from change by dark and cold and absence of green plants. It is this subtilty that has made sanitarians so suspicious of wells. In a recent milk-borne epidemic some firms sent out their inspectors to examine the farm premises supplying milk. The percentage of good wells was alarmingly small.

The annual report of the Health Commissioner of the State of Virginia for the year 1909 states that "the absence of practically all legislation on the subject has resulted in a gross neglect of many important considerations. There is not a statute on the books of the State to-day requiring any regulation or protection of water supplies other than an old act prohibiting the throwing of dead bodies into any stream or on any watershed."

The hundreds of thousands of wells throughout the States can never be individually inspected. People must accordingly be taught the essentials of protection in order that they themselves may apply them without outside aid.

So wedded to the idea of well water are most people that the health officers frequently are compelled to resort to the expedient of dosing a well with kerosene to prevent its use.

Jordan, Winnipeg report, says "the highly offensive stenches arising from decomposing matter in sewers have often been shown to exercise a depressing and weakening influence upon human vitality. . . . Under certain conditions, an individual may be able to resist infection even when typhoid bacilli enter the alimentary canal; the same individual, when in a weakened state, may be unable to ward off invasion.

"An element of special danger exists in the accumulation of night soil that has been removed from the city privies and placed above the town at the 'dumping grounds.' On two occasions in the same year when the raw Assiniboine River water passing these 'dumping grounds' was turned into city mains to eke out the supply a distinct rise in typhoid fever occurred."

"It must be remembered, however, that in sanitary matters the welfare of one section of the city is inseparably connected with that of another. The interests of the community so far as public health is concerned are not restricted by geographical or social boundaries."

The pollution of the water supply was detected last summer in an unusual manner by one of the sanitary engineers of the New York State Department of Health.[1] "A village constructed works drawing a supply from a spring rising in a shaly limestone formation. One day this spring suddenly dried up, and an investigation was made to ascertain the reason for the sudden cessation of the supply. It was finally discovered that in another watershed, about a mile from the spring, there was a small stream fed by a lake. During dry weather the flow in this stream was so small that practically all of it disappeared in a fissure in the limestone; so a neighboring farmer, who required the water for his stock, dammed up the stream and prevented any further passage of the water into the fissure. This was done about the time that the stream went dry. Analyses of the water in the stream and of the water obtained from the spring when the stream was allowed to fill the fissure, proved conclusively that the water passed through the seams of the rock for the intervening mile. More important than this, the analyses demonstrated that the supply itself was polluted, something that would not be suspected in spring water drawn from a wooded watershed like that in question. This is a remarkable long-distance record of the flow of polluted water, and compares, in a way, with the results of the investigations made in connection with the Paris water supply a number of years ago, when certain

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[1] Engineering Record, June 25, 1910.

springs from which water was supplied to that city were found to be polluted by conditions existing far from the point where the water emerged from the rock. As a rule, pollution of such springs arises from sources within a distance of a quarter of a mile or less, but this recently discovered case shows that where water is drawn from fissured rock it is advisable to analyze it or at least to trace its source to considerable distances, in order to be certain that the supply is uncontaminated."

An Example of Polluted Water from ———, Massachusetts.

"Collected Sept. 9, 1908, 7 A.M., from well 15 feet from house coming to pump through lead pipe in all from bottom of the well about 60 feet.

"The well is 63 feet from our own cesspool and 68 feet from neighbor's cesspool, all on about same level of ground. Waste water enters our own and neighbor's cesspool from sinks and water-closets, our own used but little as we have an outhouse used mostly by us, the deposit of which is received by a box emptied occasionally. Before using the box, 55 feet away from the well, the water in summer was offensive to smell and taste, but I am not sure there was especial change near the time of putting in the box. Before the box was added the deposit went on to the ground."

REPORT ON THE SAMPLE.

"BOSTON, Sept. 10, 1908.

"DEAR SIR:—The sample of water was received in good condition and has been examined, with the following results:

"The odor is disagreeable, indicating contamination. The appearance is slightly milky, increasing on standing, also indicating contamination. Little fresh-water surface organisms are visible to the naked eye, indicating a direct access of surface drainage to the well. The 'free ammonia' is .600 part per 1,000,000, which *proves* pollution when taken with the other results, as nitrites .015, chlorine 14, nitrates 7.800, and hardness 58. A good drinking water should have no ammonia or nitrites. This water shows nine times as much chlorine as the normally good waters about ——— give. Human wastes always yield much salt (chloride of sodium), both from cooking and from bodily wastes. Cattle do not eat as much salt, and because the nitrates are twenty times as high as they should be, I should suppose there must be some barn drainage in the water. The sum of all the tests shows that the water is wholly unfit to drink, and I see nothing for it but to abandon the well and find another source of water. It would take years to wash the soaked soil free from these objectionable substances if all the cesspools, etc., were removed. Besides, the water carries sufficient lead to make it dangerous. You may be very thankful that you have escaped without fatal illness. I have added the test for lead without charge."

These shallow wells are not a suitable reliance. It is only when found in the deeper layers — much older water — stored in the ground for years and traveling hundreds of miles, perhaps, that water is to be depended upon; even then mineral substances may be in excess. Some of the deep waters in Europe have been known for two thousand years to be the same in quality and yearly flow. But most American supplies are soon lessened, if pumped.

In surveying a watershed, the outflow of all small springs should be tested for hardness, chlorine, nitrates. The results will indicate the collecting ground and often enable the observer to trace the source and direction of concealed channels. The surface configuration more often conceals than reveals the underground flow.

The seepage or lateral flow from soil into stream and from stream into soil is an important factor.

Rainfall on the earth for ages before man's occupation was probably in much larger quantity than at present, and the fraction that found its way into the deep layers from which we are now drawing, or that was imprisoned during the processes of solidification of the rocks, must have been considerable.

The deep sources, 500 to 5000 feet, appear to be for the most part free from organic matter and often of the most desirable quality for drinking purposes. To use such waters for manufacturing and flushing purposes seems a waste of precious material—such clean and safe sources should be guarded as valuable assets.

Ground water from deep borings has been successfully found in many localities. Like oil, it may not be permanent.

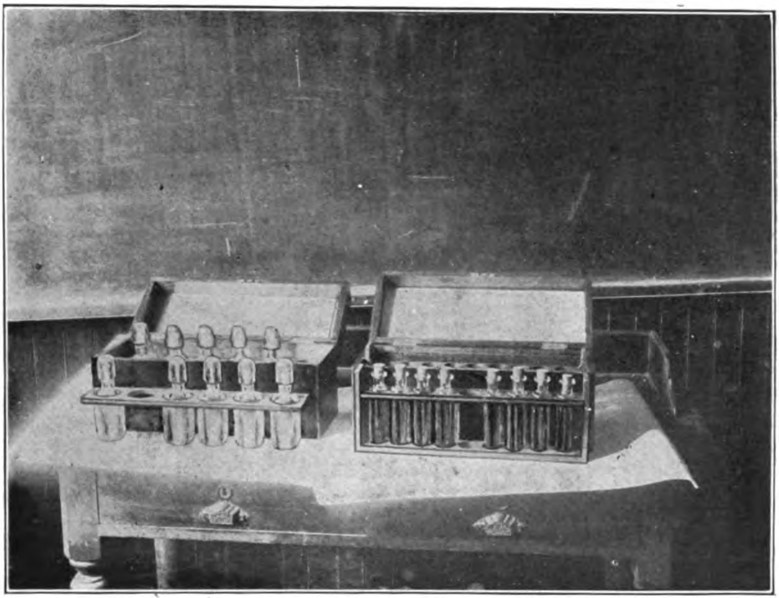
In the case of underground supply, determination must be made of the extent of the flow and the change in quality which prolonged pumping may bring, causing quicker movement, and yielding more iron, more solids, etc.

The depth of the water table, the quality of the hardpan or impervious layer if there is one, the faults and slips in the rock ledges, — all these fundamental earth statistics have the most important bearing on the direction, depth, and rapidity of the underground flow and therefore on the dangers of contamination from, for instance, a new sewage-disposal plant.

The chemistry of the sewage field is helpful to bear in mind just here. Whether flowing directly or through a septic tank on to a sandy loam—preferable to sand—the earth first has a selective straining action and within a few yards or rods retains the suspended material already existing. That which forms in the course of purification is strained out at various points. The chemical products of the decay are H_2S, the various soluble nitrogenous compounds finally, as ammonia, and in the end nitrates and CO_2 in great abundance. The organic acids formed have acted somewhat on the soil unless there was calcium carbonate (lime) sufficient to "fix" them. The iron content of both soil and sewage is liable to combine with the carbonate and make an artificial hardpan which may stop or deflect the flow. The engineer has to bear in mind the fact that while modern science has almost annihilated space he has not yet succeeded in annihilating time in most processes. The coming years have to be reckoned with.

If underground sources furnish the most satisfactory drinking water, it is the part of wisdom to protect the soil adjacent. In the case of the deep sources this is impracticable since hundreds of miles may intervene, but for the driven wells on which many small communities depend, as well as for the wells for farms and country places, it is of the utmost importance that a clear understanding should be disseminated as to the dangers of unclean soil. No simpler way is at hand than the theory of the sewage farm to show the course of the soiling and cleaning of land and water. This has been considered here a little in advance of its logical place because of the close connection with ground waters.

The Inspector's and Prospector's Outfit, or the Field Kit



Portable Case for Field Work in Water Analysis.
Length, 16 inches; depth, 6½ inches; height of each box, 7½ inches.
Designed by Mrs. Lily Miller Kendall.

Many once good wells have deteriorated since the introduction of purification plants.

More and more frequently is coming to the laboratory the question, " Is this water carrying chlorine and nitrates dangerous or liable to become dangerous?"

Tablets for field work have been used by many analysts. The English firm of Burroughs and Welcome put out many years ago a beautifully fitted, portable case at thirty dollars, similar to the field outfits the Germans provided for assayers in the early days of mine prospecting.

Many of the most useful "soloids" can be put up to order in this country and added to the above outfit.

Two boxes fitted up after the manner of instrument boxes are to be strapped together when carried by hand, but when separated may be slipped under the berth or wagon seat and kept right side up.

The removable racks, with the permanent standards and free bottles for comparison, will be found to facilitate observation. The bottles for reagents, with double ground glass stopper joints, may prove too frail for rough carriage; but fastened with the yoke, as shown in the left hand of the illustration, they should stand well.

The padded cover furnishes a safe resting place for the pipettes, and the narrow space behind the racks allows for the carriage of the various additions which each chemist would choose for himself.

FIELD WORK. WATER SURVEYS

May be for different purposes:

1. Search for source of known contamination.
2. Search for possible future contamination.
3. Search for possible more water.
4. Search for possible cause of some already noted change.
5. Survey for general condition to file as a basis for future work.

In any case the man sent out should have laboratory and engineering experience and should be suited to this kind of detective duty.

Testimony of the inhabitants of the watershed is often not reliable because there is no knowledge of the course of water under ground and of the different effects of the various kinds of soil and rock formation. There may be old watercourses, filled wells and cesspools, unsuspected drains, new crevices caused by earth movements or blasting. New houses or barns, even at some distance, may affect under-ground drainage very quickly.

One of the signs to be watched for is green algæ in quiet pools, an indication of food present It is doubtful if much can be predicated on the presence of any given organism. The blue-green algæ must have more nitrogen than the yellow-green and are abundant only in presence of food, the same is doubtless true of the oily, fishy uroglena only they thrive on very little. Abundance of cyclops and daphnia doubtless may have some significance, but at present we can only say that spongy soil always gives up to water more substance than gravel gives. Cultivated fields lose a quarter or more of the artificial fertilizer used; pasture land, less, but a perceptible amount. Along the banks of a pool or stream may be grass and weeds which harbor insects, animals, or birds. All these possibilities for food supply are to be taken in with a keen eye for indications. A man keen in woodcraft should accompany every considerable surveying party.

Having spotted a doubtful brook or pool the field tests may be applied. If Nessler reagent gives a precipitate, pollution may be assumed; if a deep color, it is probable, but such surface water may not be held to freedom from it. Nitrites are a useful indication sometimes; color, always. Chlorine in excess and hardness will serve to trace sources. Chlorine should be normal and the degree of hardness depends upon the geological formation.

If the suspected sample is from a well or spring, ammonia color, organic matter, and nitrites should be absent and chlorine and hardness only relative.

At times the bacteria count is essential, but in all exposed waters the bacteria are so abundant that not until the various forms are better known and readily isolated can too much be predicated from *mere* numbers.

No field survey may be completed in one season. Times of flood and drought may cause vital changes. Surface water may even flow in an opposite direction.

Indeed the field work is only one of the sources of information, even though it be repeated four times in the year to note the conditions due to seasonal changes. In the United States at least, there are well-defined cycles of high water and of drought which affect the water supplies. The position in the cycle of the particular year should be taken into account.

In this work of inspection a peculiar quality comes into play — the genius of a detective on which are grafted the skill of the analyst and the judgment of the lawyer. It is not a simple matter, not work for a freshman, or even for a graduate, without some apprenticeship. The trained worker can, however, gain a valuable knowledge of many square miles with a hand kit, a keen nose and good eyesight, and some skill in drawing forth information. In every rural community there is at least one unappreciated observer, and if he can be found many threads may be gathered. In a survey, danger spots are to be scented, bad practices to be ferreted out, and the trails of infection uncovered.

The final tests go to the laboratory for confirmation. The best results may be expected from various traveling exhibits when developed in connection with field work. Close observation of the habits of the people helps greatly.

WATER A NATIONAL ASSET. CONSERVATION OF NATIONAL RESOURCES A PUBLIC DUTY

Preservation of *quality* of water for man's uses is a public duty.

Clean water implies a clean soil. A clean soil can be found only where wastes are properly cared for and the principles and methods of disposal are both understood and faithfully carried out.

Modern civilization demands a close interrelation of all the practical applications of science so that one man's benefit shall not be the detriment of many. It is because of this growing need for wide surveys that government control for the benefit of all the people is becoming more and more thought possible.

The very life of the nation depends on its water supply. As has been stated, food, power, manufacturing, sanitation, as well as personal use, are all intimately bound up with water resources. A study of contamination and purification, of prevention and reclamation, is imperative.

The time is here, already come, when the preservation of the quality and quantity of such water as remains to us is of paramount importance — not only its storage and metered use, but care of the collecting grounds, where the soil must be kept clean because there are no longer vast areas of unused collecting grounds. Fifty years ago both chemists and laymen had a partial justification for their opposition to cremation; to-day there is little excuse for the continued fouling of the soil. Sanitation means not only clean water but also clean air and clean soil. Clean water is especially dependent on clean soil, and with the great traveling propensity of moderns the rules for clean soil become more and more imperative.

Education by sanitary legislation is being widely considered, but is not yet accomplished. Since a goodly part of the duty of *governments* is to educate the people in means for the promotion of their own well-being as well as to make laws, the new social consciousness expects the knowledge gained in the laboratory to be put at the service of the people. In fact legal restrictions are now almost always explained.

The principle of risk referred to has been used in the *dilution* of doubtful waters to a degree where the risk was no greater than allowable. For example, Chicago drainage canal case.

Another phase of the economic use of the nation's water supply is found in the development of the water power of a stream previous to its use as a source for the domestic demands of a city. This will require the closest scrutiny of the watershed, as well as of the immediate surroundings of the power plant. Here, too, the office of the trained inspector is of value.

The addition of mineral substance, acid or alkaline, causes a perceptible decrease in value of the water. In such cases water on its way to the citizens of a community can hardly be used for industrial purposes other than power.

The study of water as a national asset must include that element of conservation of quality by dilution and sedimentation known in earlier days as *self-purification of rivers.*

In the case of shallow water with a sluggish movement, with coves of quiet waters, a river may be aided in recovery by the same causes as have been discussed above, but for the most part the improvement is due to sedimentation and dilution with cleaner water. The deterioration of a stream or lake may be due to increased population on the watershed or to manufacturing changes.

The following examples of Massachusetts streams will serve as illustrations: Charles, small stream with slight but steady increase — more affected by wet and dry years.

Neponset, sluggish stream.

Merrimack, diluted in dry months by a supply of good water from Lake Winnepesaukee.

PROGRESSIVE POLLUTION OF RIVERS ILLUSTRATED BY DIFFERENCE IN ABOUT TWENTY YEARS.

	Date.	Solids.	Free ammonia.	Alb. ammonia.	Chlorine.
Charles River at South Natick.....	1873	44.5	.050	.110	3.6
" " at South Natick.....	1893	51.5	.002	.200	4.6
" " at Waltham........	1873	57.2	.060	.164	4.0
" " at Waltham	1893	70.2	.083	.244	7.0
" " at Waltham	1901	57.5	.061	.303	4.7
Neponset River at Readville.......	1873	58.0	.047	.270	5.0
" " below Hyde Park...	1873	66.4	.110	.300	5.2
" " at Readville.......	1893	77.0	.151	.320	11.9
" " at Readville.......	1901	101.4	.146	.579	12.0
Concord River at Lowell..........	1873	61.3	.082	.257	3.4
" " "	1888–90	44.8	.019	.237	3.0
" " "	1901	55.6	.158	.735	4.0

VARIATIONS THROUGH THE YEAR GREATER THAN THROUGH A SERIES OF YEARS IN MYSTIC LAKE

	June,	Solids.	NH_3 Free.	NH_3 Alb.	Chlorine.
Horn Pond outlet.................	1873	104.6	.134	.244	20.2
" " " average.........	1893	98.3	.061	.455	21.0
" " " maximum, Jan...	1893	135.4	.008	.858	30.3
" " " minimum, March	1893	47.5	.134	.208	6.7

THE PROGRESSIVE POLLUTION OF RIVERS, ILLUSTRATED BY THE MERRIMACK, A RIVER OF LARGE VOLUME INCREASED FROM A LARGE LAKE

Parts per 1,000,000

	Above Lowell.				Below Lowell, above Lawrence.			
	1873	1893	1901	1906	1873	1893	1901	1906
Free ammonia.......	.047	.026	.060	.080	.044	.057	.092	.119
Alb. ammonia.......	.114	.148	.207	.194	.110	.181	.251	.239
Residue.............	41.0	33.9	40.0	41.2	41.0	38.6	42.7	47.3
Loss................	17.3	11.8	17.0	16.5	16.9	14.8	17.3	19.3
Chlorine............	1.4	1.7	1.90	2.1	2.00	2.00	2.4	3.1
Nitrites............	......	.001	.001	.002	......	.002	.004	.003
Nitrates............	......	.083	.062	.036	......	.081	.082	.032
Color...............	......	.33	.38	.38	......	.42	.41	.41

Nov., 1891, Bacteria, 1,930 per c.c.

Oct., 1891, Bacteria, 12,400.
Nov., 1891, Bacteria, 2,500.

	Yearly Range.			
	Below Lawrence.		Above Lowell.	Above Lawrence.
	1873	1891	1893	1893
Free ammonia.........	.031	.043	.004 to .054	.012 to .124
Alb. ammonia.........	.127	.309	.102 to .210	.160 to .236
Residue..............	44.30	59.10	26.5 to 38.0	27.5 to 43.5
Loss.................	17.90	20.4	8.5 to 15.0	10.0 to 25.5
Chlorine.............	1.8	3.9	.7 to 2.3	1.0 to 3.0
Nitrites.............	....	.002	.000 to .002	.000 to .006
Nitrates.............	....	.095	.030 to .180	.030 to .180
Color................	....	.30	.10 to .50	.12 to 1.0

Oct., 1891, Bacteria, 13,600.
Nov., 1891, Bacteria, 2,700.

MERRIMACK RIVER. INCREASE DUE TO POLLUTION FROM ABOVE LOWELL TO LAWRENCE

Parts per 1,000,000

Date	Color	Residue on Evaporat'n		Ammonia				Chlorine	Nitrogen as		Hardness
					Albuminoid						
		Total	Loss on Ignition	Free	Total	Dissolved	Suspended		Nitrates	Nitrites	
Increase 1887–8	0.1	2.3	0.9	.007	.027	.017	.010	.26	.003[1]	.000	0.
" 1890	0.5	6.2	2.2[1]	.016	.023	.017	.006	.28	.020[1]	.000	2.
" 1891	0.2[1]	2.9	0.7	.021	.023	.021	.002	.35	.030[1]	.000	1.
" 1892	0.6	4.8	1.2	.019	.037	.037	.000	.39	.013[1]	.000	0.
" 1893	0.9	4.7	3.0	.031	.032	.021	.011	.35	.002[1]	.001	0.
" 1894	0.2	1.5	0.4	.028	.032	.032	.000	.49	.000	.000	1.
" 1895	1.1	5.2	3.3	.022	.063	.046	.017	.63	.005	.001	1.
" 1896	0.2	5.1	2.4	.034	.053	.047	.006	.70	.017	.002	2.
" 1897	0.6	3.0	0.8	.019	.051	.033	.018	.50	.000	.000	1.
" 1898	0.3	4.7	0.7	.024	.039	.019	.020	.44	.010	.002	1.
" 1899	0.2	3.9	0.7	.038	.045	.023	.022	.59	.004[1]	.001	1.
" 1900	0.3	4.1	1.1	.037	.027	.026	.001	.55	.011	.000	0.
" 1901	0.3	2.7	0.3	.032	.044	.023	.021	.50	.020	.003	3.
" 1902	0.3	5.2	2.0	.032	.063	.027	.036	.60	.000	.001	1.
" 1903	0.4	5.6	1.8	.043	.065	.045	.020	.72	.014	.002	2.
" 1904	0.2	3.1	0.6	.092	.047	.026	.021	1.0	.004[1]	.001	1.
" 1905	0.4	4.4	0.9	.047	.042	.024	.018	1.02	.002	.002	1.
" 1906	0.2	5.6	2.8	.039	.045	.029	.016	1.0	.004[1]	.001	2.

[1] Decrease.

CHAPTER VIII

THE REGENERATION OF THE WATERSHED

Effect of Storage. Office of Oxygen Dissolved and of Green Plants. Color, Odors, and Taste in Water

With the unexpected development of a city it sometimes happens that the long look ahead was not taken, could not have been taken perhaps, and a watershed is needed for collection of a water supply, but is not in a suitable condition. How shall it be improved? Most evident is the condition of the soil, saturated perhaps by waste of farms, enriched by years of cultivation, dotted with cemeteries, cattle runs, etc.

It may be true that signs of pollution are not very plain, but no sensible official will to-day advocate the "*laissez faire*" policy which has given so much trouble in the past. There are two alternatives, — to filter the water as used or to clean the watershed. New York is doing both for her new supply.

Just as the conditions of modern civilization demand the storage and transportation of grain, so they demand a storage and transportation of water, and this brings in a whole new set of elements.

Pathogenic bacteria are not the only objectionable foreign elements in water. The air carries the seeds or spores of countless kinds of green algæ. These finding a resting place on the surface of water thrive in the sunlight, and if the food they need is in the water they soon cover the surface, are stirred into the water by winds, and take possession of the storage basin. Their decay, and sometimes their growth, gives rise to odors more or less unpleasant. Such is the cycle of life that animal forms always accompany vegetable life and these too frequently produce, living or dead, disagreeable odors. The water engineer finds these conditions among the most difficult he has to meet; not that means are not at hand but that the results of treatment have to be considered in their effect on the quality of the water. For instance, the copper-sulphate remedy for certain forms of algæ, the sulphates of aluminum, iron or manganese used for coagulation, the hypochlorite treatment for sterilization, — all these chemicals need to be very nicely adjusted lest the remainders be objectionable. For these reasons, among others, a certain understanding of chemical relations is necessary to the equipment of the engineer to-day.

Small-scale laboratory tests are more and more demanded, as they are in mining and ore dressing and various forms of manufacturing. The control of large plants needs the bacteriologist and the chemist to watch the unexpected changes constantly occurring, due to climate and to giving out of machinery and to the carelessness of workmen. The very idea of control implies standards to be met.

What shall be the standards of clean and safe water to-day? Many of those set up in the past are inadequate with our present knowledge. Thus Wanklyn's is not applicable to highly colored waters.

Water containing 100 bacteria to the cubic centimeter is safe only when the bacteria are of a harmless kind.

Odor and color are undesirable but not harmful properties.

Nitrites may or may not be indicative of direct pollution, depending upon various circumstances.

Only gross pollution may be surely predicated by one or two tests.

The decision as to the safety of that excessively dilute, infinitely varying substance is not confirmed even after the trial. If the man dies, the water was bad; but if he lives, he may have been strong enough to withstand its effects.

The regeneration of a watershed is accomplished first by removal from the surface of such material as will contribute constantly increasing amounts of food for organisms; second, by requiring the disposal either by cremation or by such treatment as will quickly and completely decompose the organic material, of noxious material constantly arising from the occupation of dwellings, and factories; third, by a control of the cycle of life, both animal and vegetable, within the watercourses and the reservoirs so that a balance may be maintained. It is true that knowledge sufficient for this control is not now at hand, but it should be sought most diligently. However completely the precautions for waste disposal are carried out, if the watershed is not made completely barren, a condition not to be thought of over any considerable area, then arable land will yield (see p. 105) water rich in nitrates to the underground flow, and this flow will eventually find its way into the surface supplies. If the underground water is kept as the source of supply, then it must be stored in the dark for fire supply unless the community is to be subjected to the annoyance of unpleasant tastes and odors.

The most notable instance of the regeneration of a watershed is that of the Metropolitan supply, described in Chapter IV, where, in order to build the Wachusett reservoir on a clean bottom, 6.44 square miles (4200 acres) had to be renovated by the removal of pasture and farm lands, mills, villages, a cemetery in which 3902 bodies had been buried, and a smaller one in which were 65 bodies. Six million nine hundred and twenty-six thousand cubic yards of soil were removed and used for filling roads and for retaining-dikes. Trees, brush, and weeds were cut and burned, houses, gardens, roads and railroads and an old mill pond were removed and cleaned up. Cremation and safe disposal were carried out on a large scale at a cost of $2,536,612. Following the investigation made in Room 36 where the trial samples were tested, four hundred and sixty-seven samples of soil were tested in the Clinton laboratory for percentage of organic matter for the guidance of the inspectors. Other areas amounting to six square miles were acquired for protection, several large filtration systems were installed, and scores of small plants were constructed for institutions, hotels, and farms, without which the soil would have been liable to deliver polluted water into the tributaries of the system.

In January, 1897, purchases were made of fifty-four private estates within the limits of the reservoir, both village property and farms, also 950 acres from the Catholic churches in West Boylston and Boylston. The amount paid (Jan. 1, 1897) was $863,164 for 1210 acres, $203,000 paid for diversion of water.

In January, 1898, "homes, lands, and other valuable property have necessarily been taken from individuals and a large community has been broken up. It is but justice to say that few complaints have been uttered by those who have been affected by these operations, and in general all sections have seemed to unite in the endeavor to speed the progress of the work.

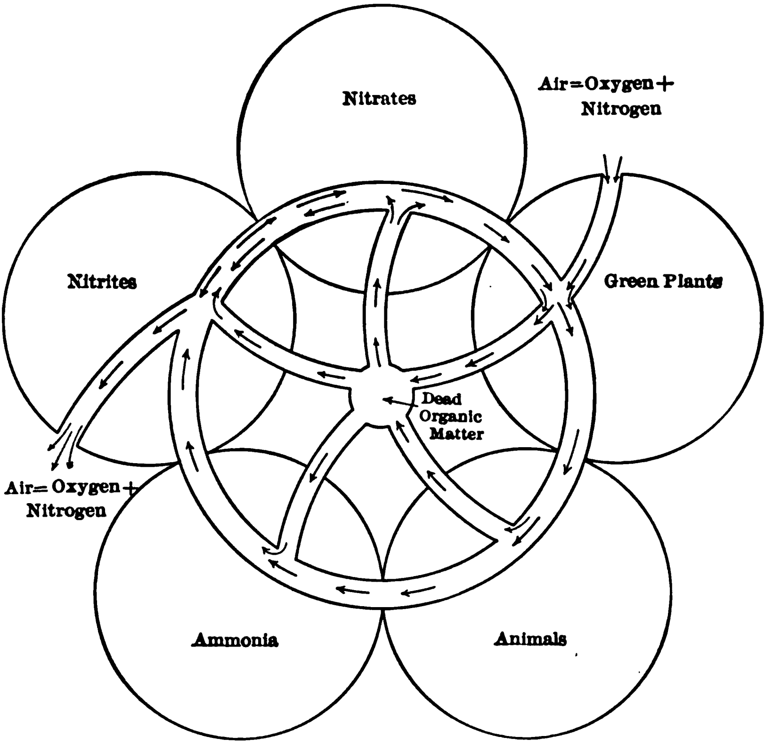
"The reservoir site was staked out into squares of 500 and 1000 feet on a side to aid in determining the amount of soil removed by the contractors; 640 acres were cleared of brush and timber.

"The taking down of the dam of the Lancaster Mills laid bare the bottom of a mill pond which had been flooded for many years."

The only reserve at present in danger is the original Lake Cochituate in the midst of a growing population. The increase in drainage is proved by the fact that the chlorine has doubled in the last forty years, but the care of the lake watershed has so increased that there is less trouble from plant growth which gives tastes and odors than was then frequent.

The topographical formation is such that the drainage of several cities and towns must eventually find its way into the ground water. A study of the utilization of the now escaping nitrogen is the next step toward complete regeneration.

Great improvement is possible on any tract of land, but cultivation means productive soil, and such ground is a nitrifying medium which must be supplied if fertility is to be maintained, and yet bare soil *washes* in heavy rains. An extensive study of the color and other soluble substances given up by various soils, shrubs, and trees led the Metropolitan Board of Massachusetts to strip the Wachusett reservoir site to a layer of sand carrying 1 per cent of combustible organic matter and also to the planting of the slopes with pines, which give to the water much less soluble color than deciduous trees, and grow on less enriched soil. It has kept a constant watch over many square miles of territory now used as collecting ground and over many more planned for as an extension of the system. In 1895 the Board prided itself on having compassed the scheme for supply one hundred years ahead, but before the great reservoir was completed in 1900 the fifty years' limit was being drawn upon, and if urban growth and demands increase, long before the one hundred years end, Massachusetts will be confronted with water



Graphic Representation of Cycle of Nitrogen
By Royce W. Gilbert

famine. Some new adjustments must take place to prevent American wastefulness of water resources.

The western cities using rivers have little control over distant watersheds, hence their greater use of filters; but many small towns with growing prospects are now looking ahead. For them advice is timely, and the sanitary engineer should have some facts and estimates as reasons for money outlay. Certain lines have been so far proved as a working plan, and, once begun, other details will suggest themselves.

From the line of thought hitherto followed it is evident that any discussion of the storage of water (and it is acknowledged that the supply for any considerable community of people must be stored unless it is taken from a large stream like the Merrimac, the Hudson, or the Mississippi) must include the effects of the presence of life during the periods of stagnation and circulation; and while this properly belongs to the biological side, there are chemical changes to be considered.

In case of surface waters we may call this change purification by life. Here is the Cycle of all matter; chlorophyll-containing cells and sunlight combine mineral matter; this produces organic substances and sugar, starch, gluten, etc., upon which other living matter not green or chlorophyll-containing lives.

Regeneration of collected water by storage includes natural sterilization and bleaching in the sunlight and a crowding out of undesirable organisms for the most part more delicate than others. Pathogenic organisms which thrive in the warm dark interior of the body, in rich fluids, die out rather quickly in the light and in cold water.

It is advisable, on all accounts, to keep the stored water as cold as possible. Therefore a depth of over thirty feet is advisable, since water at that depth is probably below 65°, a temperature favorable only to diatoms, survivals of a colder age.

The storage of surface waters involves chemical processes of oxidation and growth by means of nitrates and CO_2, and the production of oxygen from green plants, even from the floating plankton.

Recovery of diseased water is, in nature, accomplished by the above-mentioned cycle; decomposition by one set of organisms using up oxygen in the so-called mineralizing or oxidizing processes; fixation of oxygen,

$$CHON \rightarrow CO_2 \cdot HNO_3 \cdot H_2O,$$

and the utilization of these products in making new vegetable foods for animals, by aid of the sun and chlorophyll. Green plants, whether the silo corn of the sewage field or the floating plankton of the lake, are the important agents in natural water purification, both in " fixing " the carbon and nitrogen, and in yielding oxygen gas to enable the cycle to go on revolving.

A weak point in the care of waterworks is still a lack of knowledge of all the values of these helpful agents. Because among them are some of the worst plagues, all are apt to be condemned.

While there are a few large rivers sufficient for the needs of the cities likely to grow up on their banks, the greater number of towns and some of the largest cities must depend upon collected and stored water. The great lakes, if not used for collection of wastes, would furnish ideal supplies. They are fast becoming fouled by increase of population and manufacturing. The majority of towns depend upon collecting reservoirs, natural or artificial, and the management of these brings forward a whole set of new conditions intimately connected with the cycle of life and the decay of organic matter.

If the collecting ground upon which the rain falls is clean, if the flowing water does not traverse cultivated or polluted soil, and is finally held in a clean basin, the exposure to air and sunlight is most beneficial and the resulting water is of excellent quality. But under the circumstances of modern living such water is very rare. Any watershed may be infected by travelers or tramps, camping parties, or isolated dwellings. Occupation has become so general that fertilized fields washed by the rains yield a large part of their waste waters to the collecting basins, as well as the underdrain seepage to the general underground flow.

"In August, 1906, more than 100,000 fish died in Weequahic Lake, Newark, in less than forty-eight hours. This lake is in one of the county parks. It has an area of 80 acres, an average depth of 5 or 6 feet, and is fed largely by ground water. The fish fatality occurred during a period of hot, sultry weather and immediately after the sudden decay of a heavy growth of Anabæna and Clathrocystis in the water. Analyses made two days after the fish commenced to die and about as the fatality was ceasing showed the water to be devoid of oxygen, except in a thin layer near the surface. It was the sudden exhaustion of oxygen brought about by the decay of the algæ that killed the fish.

"Observations made for a number of days after the fish episode showed first a gradual return of the oxygen and then a noticeable supersaturation, or more properly a surcharging of the water with oxygen. Coincident with this the water lost all of its dissolved free carbonic acid, and even some of the carbonic acid from its bicarbonates. At times the water contained two and even three times as much oxygen as that required to saturate it from the air, while the deficiency in half-bound carbonic acid sometimes amounted to 10 or 15 parts per million. These phenomena were apparently due to the growth of several algæ, such as Melosira, Cyclotella, Scenedesmus, Raphidium, Cryptomonas, Anabæna, etc. The phenomena mentioned were noticed only on quiet days when the water as shown by temperature observations was thermally stratified. They were noticed only near the surface, — that is, within the limits of the greatest activity of the sun's rays. Near the bottom of the lake at such times the water showed a deficiency of dissolved oxygen and considerable amounts of free carbonic acid. On windy days there was a general mixing up of the waters throughout the vertical, shown by the chemical analyses as well as by the temperature observations.

"Besides illustrating certain well-known influences affecting algæ growths (such as the effect of the sunlight at various depths, the influence of quiet weather, etc.), the data apparently indicated that certain algæ have the power of seizing carbonic acid from the bicarbonates, leaving normal carbonates dissolved in the water. They also show that at times of intense growth algæ may give off more oxygen than the water can hold in solution." — HERBERT B. BALDWIN, Newark, N. J., and GEORGE C. WHIPPLE, New York City.

The non-chlorophyll-bearing organisms produce other less complex organic substances and finally reduce them to mineral matter, ammonia, CO_2, H_2O, to begin again the cycle. Rain water washes mineral CO_2, NH_3 from air, seeds of green algæ diatoms, etc.; green water plants feed upon this in sunlight; infusoria, protozoa, crustaceans live on the algæ; small fish live on these and when dead decompose and the cycle begins again.

The balance of animal and vegetable life must be kept in order to have the stored water delivered sweet and pure. To all this purifying life oxygen is as essential in water as in air, and if it is cut off when there are organic matters in transit, then serious disturbances follow.

But with the advent of spring the surface becomes warmer than the bottom, and this warmer water remains uppermost, leaving the bottom layers undisturbed at depths below 25 or 30 feet according to the size and shape of the lake. The mixing of the upper layers is accomplished by the wind. Whatever sinks into this lower, still cold layer decomposes, but does not oxidize unless the bottom is so clean and the contaminating material so little that oxygen is still abundant.

The unique character of water as to density plays an important part in the storage of water. The greatest density is at 39° F., not 32°, so that ice floats and the colder water is next it, while the bottom of the pond is warmer than the surface.

Water as stored in lakes and large artificial reservoirs undergoes many changes not common or possible in streams. Such basins are in the first place quite commonly fed by underground waters as well as by the immediate watershed. This water is often cold, clear and colorless in a region where the surface water is brown, there being enough lime or clay to decolorize it during the slow downward movement.

The cycle of life in these lakes is like that in a well-kept aquarium, — a balance between vegetable and animal forms, — but the bane of lakes and especially of small ponds is that food for green plants, nitrates.

Copper sulphate has been successfully used in checking the growth of anabæna flos-aquae in the Canal Zone, where the temperature is favorable to its growth. Odors of stagnation were removed by aeration by compressed air. [Isthmian Canal Com., appendix C.]

In the *Biochemical Journal* for June (Vol. V., No. 4) Prof. Benjamin Moore and Dr. Stenhouse Williams detail experiments on the effect of an increased percentage of oxygen on the vitality and growth of bacteria. Of 26 organisms tested, two may be termed oxyphobic. These are the tubercle bacillus, which is not only arrested in growth but is actually killed by a high percentage of oxygen, and the plague bacillus, which, though not killed, uniformly refused to grow in percentages of oxygen from 60 to 91. The staphylococcic group was adversely affected, but the remainder, including typhoid, dysentery, glanders, diphtheria, anthrax, and cholera organisms, were unaffected. [Nature, Aug. 11, 1910, p. 181.]

Ammonia washed from the air by rain and snow is the first source of nitrates in clean waters after they have traversed the film of " living earth " seeded with nitrifying organisms.

The second source of nitrates is from the decaying vegetation on hills and dales, the humus in the soil, the slow return to the mineral kingdom of the combined nitrogen.

From the first source, rain or melted snow, from .2 to .4 part per million seems to be an average amount, less over uninhabited areas or from constantly rain-washed air, more over cities in times of stagnant circulation. The earlier deduction that nitrates came ready formed from the air was due to ignorance of the part played by the nitrifying organisms. No reason was known why the water in the rain gauge should change with a month's keeping. In clean soil the balance of growth and decay is so nearly equal that only a small excess of nitrate escapes into the flowing water. Of the hundreds of such samples tested, the content of nitrates found has been from none in clean surface water in the month of October when the plankton has exhausted the small store, to .4 or .6 part per million in the early spring.

It was Sir Edward Frankland who pointed out the significance of nitrates as proof of animal contamination of the soil. Although his deduction was ignored or opposed by Wanklyn and others, it has stood the test of time, even though his theory that no such water could be made safe to drink is not held to-day.

The composition of animal tissues and fluids is markedly variant from vegetable in the proportion of combined nitrogen yielding ammonia on decomposition. While most vegetable substance is economical in its use of the precious element, animal albumen contains 16 per cent and so on down. Animal wastes, guano, barnyard manure, sewage carry considerable percentage of nitrogen readily converted into nitrate and used as food for green plants to begin again the cycle.

Here, then, in the luxuriant growth of plants is an indication of the presence of food. In excess of what can be used the nitrate drains off in the sub-soil water or is washed into streams by heavy rains. An excess of nitrate therefore over .4 to .6 indicates a soil drainage; over 1. to 2., an escape of unused nitrate, perhaps applied as fertilizers; while gross pollution of water often results in 10 to 20 parts nitrates.

The same excess of nitrates without indicating human occupation might be found in the waters of Chili and the islands where birds now congregate or in the past have congregated. The wastes of human activity are, however, so far in excess of other sources of nitrates that the presence of the latter is for the most part a sure trail to the origin of contamination.

Occasional exceptions may occur, — unexploded powder in drilling, deposits from manufactories, but in by far the larger number of cases the source of nitrates present in water may be traced to wastes of human occupation, — the cesspool, the barnyard, the pigpen, the hencoop, the fertilized garden or plowed field.

Since the sources of contamination carry varying degrees of danger from pathogenic germs, it is of consequence to distinguish if possible between them. The ratio between chlorine and nitrate gives a clew. Sewage carries about equal percentages of chlorine and nitrate, the farmyard more nitrates than chlorine, the sink drain more chlorine than nitrates. This theory led to the discovery of the source of the nitrates in many instances.

No infallibility is claimed for this rule, but it is a working hypothesis. There is at present no method of determining nitrates as delicate as that for the determination of ammonia, but for the engineer this does not signify, since the nitrogen compounds are so unstable that the forms undergoing oxidation — nitrites and nitrates — are indicative only in relative proportion.

It is clear that the storage in a lake or reservoir of a water carrying high nitrates will, sunlight and temperature favoring, produce a fine crop of green plants. The varieties of these depend on unknown variables, — the seeding, the conditions favoring one form over another, besides temperature, rainfall, duration of storage, and, no doubt, the mineral constituents of the water.

It is well known that green plants give off oxygen during the process of growth in sunlight and thus regenerate a stored water. It is rare that a green alga becomes offensive, even in decay, but the blue-greens, richer in nitrogen, are not infrequently offensive in growth as well as in decay. These must indicate a richer food material, and while they may be killed out in a few hours by a judicious application of copper sulphate, one tenth to one part in a million parts water, the nitrogen is not removed, only started again on its cycle. It is only when the green plants take the form of long tough grass-like fibers that may be raked out in order that a remedy may be applied to the water itself.

Removal of the source of the food is the desirable thing. Since all arable soil is rich in food, there arises the question of making the collecting ground barren. It will be of great advantage if the laws of rotation of crops can be worked out for bodies of water, for there is a natural rotation of crops in the plankton of a reservoir, dependent on varying conditions, and whatever interferes with that rotation causes trouble. The use of copper sulphate to clear a reservoir, either natural or artificial, disturbs the balance of living forms, and not enough data are at hand to say what is liable to happen in any given case. One of the most valuable investigations is waiting for an investigator.

At present the superintendent of a waterworks who uses copper sulphate takes a risk of causing worse evils in the end. In some cases it is quite in line with the best policy to take the risk. But meanwhile a constant search must be made for the source, that is, the food.

The most conclusive indicator of the character of stored lake or reservoir water is the quantity of dissolved oxygen it contains in summer when the water below about 25 feet is stagnant. The following illustrations are instructive: Basin 4 (Ashland Reservoir) of the Boston Waterworks collected its supply from a clean watershed, and the organic matter it carries is of a peaty character, nearly aseptic — if the expression may be allowed. All soil and vegetable matter were carefully removed before the reservoir was filled about forty years ago.

Jamaica Pond is a natural basin dating probably from the age of glacier retreat from New England, never cleaned, in the midst of cultivated estates, used for many years for ice cutting, skating, boating, and well stocked with fish. Moreover it derives its supply chiefly from springs, but is subject to surface wash from rather steep banks.

For at least forty years this sheet of water has supported abundant crops of water plants, sometimes of one variety to the exclusion of others, as the oscillaria referred to, page 128, or asterionella, or the common form of rooted grass-like plants.

OXYGEN DISSOLVED

Jamaica Pond, July 14, 1891.			Basin 4, Aug. 20, 1891.		
	Temp. C.	Oxygen per cent of saturation.		Temp. C.	Oxygen per cent of saturation.
Surface	24.	100.0	Surface	23.6	84.5
10 feet below	23.8	100.0	10 feet below	21.6	84.3
20 feet below	12.0	49.0	20 feet below	16.6	28.0
30 feet below	5.8	29.5	30 feet below	21.1	27.4
35 feet below	5.6	4.2	35 feet below	12.6	16.3
40 feet below	5.4	0.	36½, bottom	12.6	15.1
47 feet below	5.2	0.			

The lower layers of the pond are offensive in odor, containing hydrogen sulphide and other offensive compounds.

There was sufficient oxygen in Basin 4 to prevent bad odors.

Several other uncleaned reservoirs examined showed an absence of oxygen below ten or fifteen feet, while Lake Winnepesaukee held nearly the full amount at a depth of 120 feet.

Aeration may be used to advantage in small reservoirs, as at Panama. But when an artificial basin is being built it is wise to have a clean bottom and sides and to protect the upper slopes. Beautifully kept, highly fertilized banks are not sanitary, if they are æsthetic.

The odor of ground waters is closely connected with the absence of oxygen in such water as is recently filtered either naturally or by a filter well sunk near a pond or stream. Such water frequently gives a fermentative odor, sometimes as strong as that of an empty wine cask. Such an odor is also noticed in the effluent from a filter with insufficient aeration. A clayey odor is not uncommon, but the majority of clear ground waters are odorless. Such is not the case with surface waters; on the contrary they usually give a distinct odor when they are heated, if not in the cold, and this odor may prove one of the most distinctive characteristics of the water year after year or month after month, or it may vary with the season. In the early autumn, when the leaves begin to fall, many waters give a peculiar sweetish odor quite different from the astringent peaty odor of the spring.

Rivers receiving pollution almost always betray the fact in winter when the ice sheet prevents aeration. The odor is then "musty," the odor of the straw from the horse stable, not "offensive" like sewage, but distinct and characteristic wherever found. "Mouldy," means having the smell of clean leaf mould from the forest, with no suggestion of sewage.

The various plants and animals inhabiting the water, especially stored water, have each their characteristic odor, as do the earth-borne plants and animals. Some are very strong, the onions of the plankton or rootless plants; some are the skunks of the water, while others float unnoticed.

Anabæna and the varieties of the "blue-green" group, rich in nitrogen, give both in growing and in decay very disagreeable, characteristic odors. Asterionella, the diatom of the glacial age, which abounded in the infusorial silica beds, gives a rather fragrant geranium odor when growing, but a vile fishy odor when in the process of decay. Since it is a cold-water organism, this bad odor arises with the rising temperature of the water. Anabæna thrives best in water of 70° or more. Synura gives a cucumber or fishy odor; Uroglena smells oily; Peridinium and Trachelomonas both are fishy in degrees. Each distinctive odor once learned by any one with a sensitive nose always conveys a definite meaning.

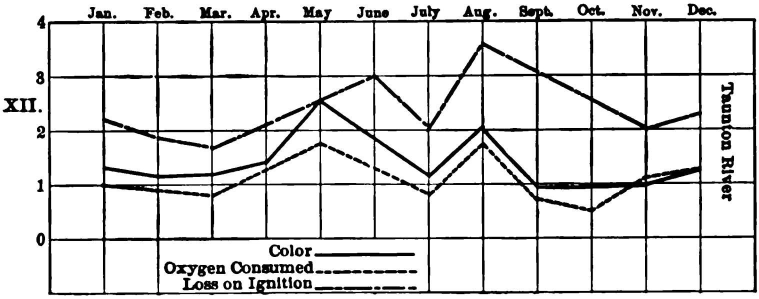
There is still a field for investigation for the chemical botanist in the curious alternation of the organisms and their sensitiveness to slight variations in condition.

The definition of ground water includes "colorless" as a descriptive term. "Colored" may also be used as a descriptive term for the surface waters derived from the region of the oldest rocks, the Archæan or Laurentian of Canada. All soils without lime in quantity yield water with color from slight to a rich tea color. The color is due in fact to the same cause as that of well-fermented tea leaves, and to the still further stage of caramelization approaching the blackness of burned sugar. The black water of

Ireland, Alaska, and elsewhere is an extract of peat approaching complete carbonization. There is not the slightest proof that this color has any sanitary significance, and yet it brings with it to the chemical analysis an amount of nitrogen which in a colorless water would be objectionable. It also requires an amount of oxygen consumed which would make one hesitate if the sample were a colorless water. The three determinations must then be considered together in a group and no diagnosis made on either one alone.

Number XII while illustrating the general correspondence also shows the variations due to varying conditions.

The color given to a water by the seepage from swamps and woodland brooks is much higher in spring (in this case reaching its maximum in May) the oxygen required being less with the higher carbonization of the organic matter.



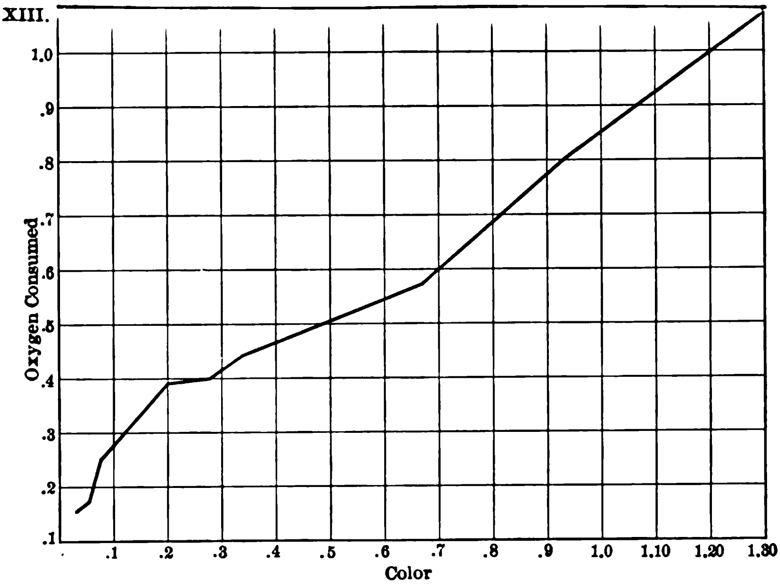
As might be expected the loss on ignition is higher the greater the activity in plant growth which yields less color but has more soluble organic matter.

Albuminoid ammonia follows in a general way the color in clear soft surface waters, so that the color must always have weight in the interpretation.

Brown waters rarely give much free ammonia. A series of experiments made in 1887 resulted in the following estimates: A pound of dried leaves, elm, maple, oak, could give to 2000 gallons of water an extract which would yield albuminoid ammonia .150 per million on Wanklyn's limit of allowable contamination. About 80 per cent of the albuminoid ammonia is removed when the color is taken out by aluminum hydrate. Nitrogenous substances of animal origin do not usually give color, with the exception of blood in strong solution, and aluminum

RELATION OF COLOR TO OXYGEN CONSUMED IN MASSACHUSETTS SURFACE WATERS

XIII.



Average of color for 12 months given by 12 samples. Average of oxygen consumed given by the same 12 samples for the same 12 months.

hydrate does not remove this soluble nitrogenous matter to any extent.

Organisms, well studied, are valuable indicators. For instance, abundant growth means abundant food, and food of green plants is the product of decay, hence there has been food for the organisms by which decay is accomplished. If this supply may be cut off, the cycle is broken, but it is worse than useless to stop the organism without stopping its food.

This is the cause of some hesitation as to municipal sterilization. Prevention at the source is more logical.

Storage of suspected waters, exposure to sunlight and oxygen, and opportunity for chlorophyll purification, give surer results.

Biological Examination of Water

		Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
No. 8	Arlington Reservoir										
Blue-green algæ......		....	7.5	0	pr.	pr.	.8	4.	0	8.	pr.
Other algæ..........		....	22.2	191.6	77.4	70.6	20.0	5.7	37.2	11.5	4.0
Fungi..............		....	0	0	0	0	0	0	0	0	0
Animals............		....	pr.	pr.	pr.	6.2	1.1	.2	1.6	.4	6.0
No. 18.	Blackstone, Millville										
Blue-green algæ......		0	0	0	0	pr.	pr.	pr.	16.	0	0
Other algæ..........		1.7	.2	2.7	5.8	3.1	2.8	.8	.7	.1	.1
Fungi..............		0	.0	.8	.3	1.2	0	0	0	0	0
Animals............		1.2	pr.	3.0	1.4	.2	3.4	.2	2.3	0	0
No. 19.	Basin 4. 1 ft.										
Blue-green algæ......		0	0	0	0	0	0	0	0	0	0
Other algæ..........		.2	.5	16.5	1.2	11.0	4.7	.3	.9	0	.1
Fungi..............		0	0	0	0	0	0	0	0	0	0
Animals............		10.	.2	pr.	.3	.7	.1	.4	.1	0	0
No. 21.	Basin 4, 40 ft										
Blue-green algæ......		0	0	0	0	0	0	0	0	0	0
Other algæ..........		pr.	.5	3.8	.4	.1	.7	.8	1.1	pr.	.4
Fungi..............		0	0	0	0	0	pr.	0	pr.	0	pr.
Animals............		pr.	pr.	pr.	.3	pr.	.1	.2	.2	0	pr.
No. 27.	Farm Pond										
Blue-green algæ......		0	0	pr.	0	40.6	pr.	1.	0	0	0
Other algæ..........		pr.	13.8	5.0	.5	7.0	8.	.7	pr.	0	1.4
Fungi..............		0	0	0	.1	0	pr.	0	0	0	0
Animals............		pr.	pr.	pr.	.1	pr.	.6	.3	0	0	0
No. 29.	Lake Cochituate										
Blue-green algæ......		0	0	.4	5.	6.9	12.0	7.	pr.	0	0
Other algæ..........		pr.	pr.	8.9	.5	4.4	2.6	2.	10.7	7.9	16.2
Fungi..............		0	0	0	pr.	0	0	pr.	0	.4	.1
Animals............		pr.	pr.	pr.	pr.	pr.	pr.	.2	.2	pr.	.2
No. 30.	Chestnut Hill Reservoir										
Blue-green algæ......		0	0	0	5.1	5.	4.	pr.	0	0	0
Other algæ..........		22.2	25.0	3.5	4.2	2.6	.7	3.	6.6	3.0	10.1
Fungi..............		0	0	0	0	0	0	0	.1	.4	0
Animals............		6.	pr.	pr.	1.	pr.	.1	pr.	.1	0	pr.

Water farming may be developed in the future. Certain it is that "cropping" of reservoirs whether natural or artificial will frequently be needed as intensive farming and closer settlement of now wild lands takes place, for a considerable proportion of the collected water has brought with it food for plants, and with food in water, and sunlight, growth is inevitable. Slight changes in conditions vary the crop. The weakest link in all water-supply theories to-day is the relation of the excess of green plant life both fixed and as floating plankton. The relation of these plants to the animal life and the significance of the various animal forms are unknown factors awaiting careful study. The smallest change in conditions effects great change in the fauna and flora of still waters.

Troublesome growths occur when the water is supplied with organic matter from sewage or cultivation. "The effect appears to be nearly the same when sewage is purified by filtration through the ground before entering the water supply as when it is discharged directly into it."[1] That is, it is *nitrogen* which serves as food, regardless of its source.

Some of the most baffling causes of bad odors and tastes seem to be due to ammoniacal and carbohydrate compounds or even to absorbed carbon dioxide, since they often occur in the absence of any considerable amount of nitrate.

Some otherwise good lakes develop plants for three or four weeks in certain seasons — asterionella in spring, anabæna in August and September, uroglena or synura in October and November, trachelomona and peridinium at various times.

Abundant growths of blue-greens, of evil reputation, such as anabæna, oscillaria, clathrocystis, and aphanozomenon, are indicative of waters rich in food and high in temperature. They become a very pest, but they do convert the nitrogen into plant tissue. In a lake there is no way of straining them out as there is of raking out the grass-like growths.

Sterilization leaves the food untouched, therefore, like filtration, sterilization demands immediate use of the treated water.

The difficulty in "cropping" a reservoir, which is a natural lake or artificial reservoir, is that the seeding cannot be controlled and plants of unpleasant odor may abound among the plankton. They are apt to be those doing the greatest ser-

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[1] Twenty-second Report of the Mass. State Board of Health, 1890, p. 365, "Quality of surface water."

vice, — using the most nitrogen. It is, however, not too much to expect that a means will be discovered of seeding with harmless plants which may be raked out.

Jamaica Pond in Boston affords an instructive history. Oscillaria, according to tradition, had appeared about 1865 or 1868 and 1870. No especial growth had been observed for sixteen years, when some peculiar unknown conditions in 1887 gave rise to an enormous development which continued for 18 years, when copper sulphate was applied in September, 1903. At this time, spore forms, or what seemed to answer to spores, appeared only in late September, so that seeds were left after the sulphate treatment. In three years the growth was again obnoxious, although other forms had appeared. An application of copper sulphate in August, 1905, when the layering of the pond prevented the mixing and at a time of low water, destroyed not only the oscillaria and anabæna but also the fish. The twelve cartloads of these which were removed took out a considerable portion of the nitrogen, and, taken in connection with the introduction of waterfowl (often 200 ducks in the fall, and 20 to 30 swans in a body of water one-half mile in diameter), changed the character of the plant growth. Usual water grass and a different plankton got the upper hand, and comparatively little oscillaria has since been found, although in July, 1910, a decided increase appeared. The waterfowl have, no doubt, made a considerable difference. They are fed each Sunday large amounts of bread, much of which disintegrates without being eaten.

"Experience shows that where the population exceeds 300 per square mile of watershed, the stored water, whether in natural pond or reservoir, is particularly liable to produce an abnormal growth of organisms."

OXYGEN DISSOLVED

That water held air in solution was known in the early days of science. The circulation in fishes' gills, however, was not understood until much later.

The application of the vacuum pump in glass vessels made visible the air bubbles leaving the water, and analysis showed the composition. Deep waters were seen to be charged with gas such as carbon dioxide, hydrogen sulphide, marsh gas, etc. But the office of air dissolved in water came to be understood only after the processes of decay and purification were related to the real agents, living organisms.

In the light of this theory the quantity of gaseous uncombined oxygen in the water took on a new importance and the means for its determination became of great interest. It is not necessary to review all the processes that have been proposed. Exhaustion of the air in a given quantity, usually a liter, of the water to be tested, and analysis in a gas apparatus is of course the most satisfactory process from a scientific point of view. The initial expense of the apparatus, the degree of technical skill demanded, and the time required to make the test, all tend to lessen the number of tests practicable in municipal work.

Short indirect methods have been sought, many of which are still found in the textbooks. Consensus of opinion points to some form of Winkler's indirect method by liberation and determination of iodine as the most practicable for routine work and as, under careful manipulation, sufficiently accurate for general purposes. It has also the advantage of adaptation to field methods, since the color given by the iodine may be watched for and an approximate determination made without further analysis. For this purpose are required a few bottles of standard solutions.

Because of the part oxygen plays in purifying processes it has taken a chief place in water analysis.

Pure water absorbs air according to temperature and pressure, but in the consideration of ordinary water supplies pressure plays the lesser part. [See table below.]

If the stream receives the organic matter from sewage, from a paper mill, from a creamery, or a cow pasture, or cornfield, there is danger that the oxygen will all be absorbed and putrefactive changes, yielding offensive odors, will go on. Artificial aeration may then help, but not very appreciably unless the temperature is lowered.

Revivifying of the stream takes place when the water flowing slowly over shallows becomes green from the various algæ chlorophyll-bearing plants that in their growth give up oxygen.

In investigation it is often of consequence to know how much impurity a given stream will take care of without offense.

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

Temp. C.	Oxygen.	Temp. C.	Oxygen.	Temp. C.	Oxygen.	Temp. C.	Oxygen.
0	14.70	8	11.86	16	9.94	24	8.51
1	14.28	9	11.58	17	9.75	25	8.35
2	13.88	10	11.31	18	9.56	26	8.19
3	13.50			19	9.37		
4	13.14	11	11.05	20	9.19	27	8.03
5	12.80	12	10.80	21	9.01	28	7.88
		13	10.57			29	7.74
6	12.47	14	10.35	22	8.84	30	7.60
7	12.16	15	10.14	23	8.67	......	....

By whatever steps the work is done, oxidation is the final stage of decomposition of organic matter and is called purification. It is for the most part accomplished by low forms of life, by sunlight and by chlorophyll-bearing plants, and in part by direct oxidation. But before a stable balance is reached there are many set-backs. Once formed, nitrates, for instance, are reduced in the presence of living organisms eager for food. A limited purification in the sense of elimination of nitrogen may take place in this way.

The rapidity of certain changes is well illustrated by the experiment first tried in 1890, of cultivating bacteria in a suitable food medium in the presence of nitrates. This form of nitrogen is no longer food for the decomposing agents, but when the oxygen dissolved in the seeded water is used up, the plants in their struggle for existence rob the nitrates, reducing them first to nitrites, and if food is still abundant and the proportions not too rich so that they die in their own atmosphere, the plants take the remaining oxygen, sending the nitrogen back into the air to begin again its cycle of change.

Boston tap water	8 liters
Skim milk	8 c.c.

KNO_3 2.5 gms. (40.3 parts per 1,000,000).

Nitrites

Jan.	9,	9.45 A.M.	.01	part	per	1,000,000
“	9,	3 P.M.	.05	“	“	“
“	10,	8.45 A.M.	4.5	parts	“	“
“	10,	11 A.M.	5.0	“	“	“
“	11,	9 A.M.	10.0	“	“	“
“	11,	12.30 noon	12.0	“	“	“

Where there is food there will be growth under favoring conditions of temperature; but what laws govern the *kind* of life we do not yet know. Many curious alternations are brought about by the use of copper sulphate in killing out the blue-green algæ and other delicate plant life. In most cases another form appears which was apparently inhibited in its growth by the first plant: copper sulphate does not remove the nitrogen, it merely makes possible a transfer. When the growth is of the long thread-like forms or the common chara, etc., it may be raked out and carried off.

A close study of these plant growths and their alternations under varying conditions is one of the most needed investigations of the time as regards stored water and the regeneration of many small watersheds.

The rectifying, recovering, or regeneration of a watershed may be carried out in a few years by nature's processes intelligently directed. Disposal of particular wastes will be treated of in a later chapter; but a general policing of watersheds is a necessity if they are to be kept as free as is possible, and this inspection must include the education of the people to the necessity of a clean soil. This care must extend back into the mountains or to the springs which add their quota to the volume of water.

All the tributaries, the quiet pools and large lakes, must be considered. Even if the greater part of the waste from houses and factories is burned, as it should be, there remains the underdrainage from arable land which the Rothhampstead experiment proved to carry from one-quarter to one-half the total applied nitrogen.

Food is supplied in two chief forms from two quite different sources. Ammonia and soluble carbonaceous substances are brought into lakes and reservoirs by surface flow, rain and melting snow.

The prospector must be armed with some knowledge as well as with a microscope if he would gain the most from his survey. The book is open to him who can read it, but he must have learned the alphabet.

Biologic purification in distinction from bacterial decomposition and as complementary to it is the great function of storage. Air, *i.e.*, oxygen, is necessary, but green plants growing in sunlight furnish free oxygen in excess of that held in solution in water at a given temperature.

The food-stimulative center, so to speak, is nitrogen; without it the other factors cease to be operative; hence the source of nitrogen is the aim of the search. This in any quantity must come from animal life, — guano beds, manure piles, cesspools, fertilized fields, sewage beds, or factory wastes.

If the prospector observes green plants in abundance in any water pool he may be sure there is food not far distant.

This food fosters one kind of growth, or many varieties. Diatoms, for instance, appear to thrive on such ammonia-containing water. (Miss Stickney's thesis, Jamaica Pond overturn; Mass. Inst. Tech.) But the mineral source of green plant food is *that* water, which travels through the ground, collecting carbon dioxide, nitrates, and mineral matter, bringing the most acceptable material to the greatest variety of plant life. A constancy in the particular variety year after year indicates a permanent condition; a variation indicates changes somewhere along the line.

Several instances have occurred in which the removal of a hen yard, a stable drain, or a picnic ground has been followed by the improvement in the lake water.[1]

In the case of Butte, Montana, the food for anabæna came from the mulch humus on the steep slopes of recently wooded hills. Copper sulphate proved an efficient remedy.

In the case of Jamaica Pond the development of oscillaria followed the season of great mortality of smelts. The pond has a foul bottom with much H_2S, and "layers" in summer with a sump minus oxygen 20 to 30 feet deep. The overturn in November brings all this to the surface, but except as fish are caught, the sum total of the food remains. Now and then the pond is completely stirred by dragging and dynamiting for the recovery of a drowned body; then the long grassy water weeds thrive to the exclusion of all else.

Such contaminated waters are liable to be high in organic matter — such wastes as wash water, leachings, etc., of various kinds. Creameries and starch or glucose factories, as well as laundries, deliver a large quantity of carbonaceous wastes, and frequently fats, the most objectionable from several points of view. Fats decompose slowly, yielding acids, but they envelop in a greasy film all else with which they come in contact. It generally costs more to recover them than they are worth. It is a wise policy to keep all such out of the streams.

A great variety of chemicals go down the drains — sometimes to great advantage, because one precipitates or renders harmless the previous addition; on the other hand, sometimes one only enhances the danger of the other. Antiseptics interfere with decomposition.

Special processes make special wastes and cannot be grouped. These will be discussed in a later chapter.

The wastes most talked of are those that cause odors, — tannery wastes, abattoirs, drains, packing houses, canning establishments, etc.

The relation between loss of oxygen and gain in carbon di-

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[1] See Report to Newport R.I. Board of Health by Dr. Thomas M. Drown.

oxide in ground water has often been sought, but so far without wholly satisfactory results.

The electrical processes of water purification, ozone and hypochlorite treatment, serve the double purpose of killing the organisms quickly instead of starving them out and of setting free nascent chlorine, or oxygen, which quickly destroys the organic combination.

Tests for *oxygen consumed* and *oxygen dissolved* in this connection are important as showing the degree of change. The germs present at any one time may be killed without the food having been destroyed and a new seeding will cause another vigorous growth. Many purification schemes have failed because of the neglect of the food factor.

The fixation of oxygen, like the fixation of nitrogen, is a distinctly purifying process. It means progress in the synthetic direction rather than degradation or breaking up of organized substances. The two usually go hand in hand. If there is not enough oxygen in the water to serve the purposes of the agents of decomposition, for their own purpose they will rob the nitrate of its acquired rights. So oxygen is sent back and forth, and its estimation may give valuable information of the conditions existing at any given moment.

CHAPTER IX

THE INTERDEPENDENCE OF TOWN AND COUNTRY[1]

RURAL SANITATION AS AFFECTING THE HEALTH OF THE CITY AS WELL AS OF THE COUNTRY. SANITARY MAINTENANCE AND PUBLIC EDUCATION

THE source of water, milk, and vegetable supplies is the immediate neighborhood, meaning five hundred miles. Cereals, meat, and fruit may be taken half around the globe. Canned milk and vegetables possibly will be depended upon more and more, but water seems, to present science, a local concern.

As has been discussed, soil pollution affects water supplies and atmosphere as well as, to a certain extent, vegetable products.

For clean water in the future the various communities must depend upon the slogan cry "Clean up the country," *i.e.* in the country. *There* is space and time, and *there* must be the knowledge of how to do it, but with the *how* must go also the "how much will it cost?" and "what will be gained by it?" The end will be even as the beginning — economy — but economy of human energy and power and not saving of dollars. Of the dollars many more will be required to secure an efficient race of men of whom 90 per cent (effective size) shall be efficient and 10 per cent inefficient, instead of, as now, 10 per cent strong enough to carry the burden of 40 per cent inefficient, leaving 50 per cent just able to care for themselves, not able to help in the world's work.

Rural sanitation — which means a high-school teaching of vital problems — and sanitary inspection as extended as a school supervisor gives, since education and reform, must always go together, and in no department more closely than in sanitation. Rural sanitation will include factory inspection and disposal of wastes, together with instruction of factory workers, usually

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[1] See frontispiece.

of non-American origin, with no knowledge of hygiene or sanitation, only traditional habits which are put out of joint by American conditions.

These same aliens are absorbing the farms and market gardens; and here, too, constant inspection and instruction are needed. The various milk-borne epidemics (see Framingham milk case) and cases of disease traced to vegetables arise from rural ignorance and carelessness. This is not universal, of course, but it is on the increase in certain sections, and with the constantly growing demands the subject must be coped with by authorities and from the sanitary point of view as a phase of preventive medicine.

Hitherto the country dweller has been so isolated and has had so much room to isolate himself in that he has not been amenable to the teaching of science. The telephone and rural delivery have helped to mobilize the countryman's ideas, and certain government undertakings will meet with more favor than local health officers. For while the city dweller has little use for Uncle Sam as compared with the big business concerns which overshadow the Custom House and the Post Office, in the rural districts, the United States Government is of much more consequence, and the greatest argument for a Federal Health Bureau comes from its possible help to the isolated country dwellers, all over the land. An economic as well as a humanitarian point of view should lead the sanitary engineer to give some thought to the scattered population and their needs.

The improvement of both public and private water supplies throughout the country will depend largely upon the education of the inhabitants by visiting inspectors, whom each State should send out to get fundamental information. This inspection must be made at as little expense as possible in order to have a good deal to show to the legislature for the money.

First. Tours of inspection to observe sources of pollution; character of soil and vegetation, land wooded or cultivated; topography — high or low land, and steepness of hills and banks; habits and occupations of the inhabitants; sheep-washing pools, cattle resorts, pigpens and hen yards; industries, especially those near streams.

Second. If more detailed, and if plotted on maps, called a sanitary survey (see Newport, above, for a small bit of work), number and size of summer hotels, picnic grounds, distinction between transient and permanent population, methods of refuse disposal, etc., recorded on map.

So many things are done that one would never suspect or think of, that a very close watch must be kept and checks made by field tests as far as possible. Thus, five minutes will tell which one of a number of streams or springs is bringing in hard water, which one of a group of wells is badly polluted, which stream is bringing iron or chlorine, etc. In a half hour's preliminary testing a decision may be made between a dozen samples as to which are so doubtful as to need to be sent to the laboratory for further examination. In this way much ground may be covered in a day or week and a fair idea be obtained of the chemical character of the water supplies.

Cisterns, wells, — deep and shallow, — springs, streams, reservoirs, ice ponds, lakes, etc., must be examined.

There are to be noted sink and stable drains, cesspools, etc., the progressive pollution of streams, the points at which contamination occurs and the distance to which it may be traced. A portable outfit *in the hands of an experienced person* may serve as a most valuable adjunct. It should permit of the estimation of the larger organisms by a powerful pocket lens, the estimation of free ammonia, nitrites, CO_2, hardness, chlorides and sulphates, color, oxygen consumed in the cold, iron, nitrates, and the approximate determination of the dissolved oxygen.

The outfit should be sufficient for, say, 100 to 200 tests, and the solutions should last a month without perceptible change. As many reagents as practicable should be in the "soloid" form. But previous laboratory practice and good judgment must accompany the outfit. It will not answer to send out a green hand, any more than the physician's office boy can be trusted to diagnose a case.

SANITARY MAINTENANCE

The weak link in the chain with which the platform of sanitation is held by the side of the building of civilization ready to be lifted as the people pull, is the blind confidence that once installed the plant will run itself.

It is the same with people: once grown the adult expects life to run to its end without his care. A ventilating system, a vacuum cleaner, a water supply, a sewer system put in according to plans is left to itself or to a caretaker without instructions.

The greatest social service to be done to-day is the convincing of authorities that this work is only half done when they have accepted good devices and ordered them installed, and the hardest task of all is to convince the taxpayer that the constant maintenance is a legitimate interest on the investment so that he will support the authorities in their endeavor.

Illustrations of this need may be found in the lack of maintenance of mechanical ventilating systems; in failure to create a fresh-air habit; in that lack of watchful care at every point which is insisted upon in the policing of water supplies; and last, but not least, in that demand for the spread of information and that arousing of civic interest which make the individual a responsible part of the community.

The sanitary structure is built to-day, as always, on clean air, clean soil, wholesome water, and good food. It is liable to be undermined at any one of the four corners. The casual passer-by who sees a crack in the edifice should make it his duty to see that it is repaired, and the man who is found digging a trench near by should be summarily dealt with. In other words, not only should efficient watchers be provided, but each one should report a failure to observe regulations. The informer has always had a bad repute, which arose from supposed spite or the personal advantage he gained. Modern philanthropy, however, interferes in the most private concerns: it prevents a man from drowning himself; it prevents him from poisoning himself with drugs; it should prevent him from unclean ways which harm the community. Information as to odors and smells in the air is recognized as legitimate; they come under the head of nuisance. Information as to misuse of land in the vicinity of water supplies should be held a public duty, and officials should be provided to investigate.

Patrolling of all watersheds is a necessity; and helpful advice, even money spent from public funds to aid the poor man in doing right should be given without stint. The watchwords in all this sanitary progress are helpfulness, education, conservation. Is it socialism to rely on the common interest and good sense of the citizen rather than on the paternal provision of early days when the common people took what was offered, asking no questions? No officer of the law will refuse to welcome an intelligent community, but not an erratic one, not one permeated with fads, unpracticable, irrational. Sanitary progress has been much impeded by the overzealous and the half-informed, and it is for that among other reasons that the sanitary engineer, trained to accuracy in testing materials and structures, is the best expert to tie to, if he can keep the community welfare first in mind and not yield to temptations of mere profit to a concern.

During maneuvers at a State military encampment in the summer of 1910, an illuminating incident occurred: A milkman who supplied a certain regiment was seen rinsing his empty milk cans in foul water in a pool formed by the overflow from the washstands in the rear of the mess halls. A soldier asked the man if he had been doing that sort of thing long, and received an affirmative reply. Asked if he intended to continue to wash milk vessels in that manner, the milkman said that he expected to. The private then made known his identity. He was a milk inspector of a near-by city and a member of the militia. Investigation showed that there had been sickness of an intestinal nature among officers and men.

The sanitary engineer's power for influence will depend on the intelligent progressiveness of the community and on the credence they will give him, as well as on his own accomplishment. He must be ably seconded by the instructive inspector, the trained woman who will educate the housewife and the children in the small everyday details of sanitation which make up two-thirds of the improvement.

For the rural districts there must be the public illustrated lecture, moving pictures, if possible, as of the fly and the mosquito; and frequent sanitary exhibits, as the tuberculosis and milk exhibits.

The isolated farmhouse, summer hotel or institution, factory or hospital, needs far more careful study than has been given, for from such spots, untouched by the spirit and knowledge of modern science, comes a large part of our infection.

The sanitation of a city will shortly include not only the sources of its water supply but also those of its milk and food supplies.

The cremation of refuse must, even on the farm premises, take the place of earth burial, and the fundamental principles of earth purification be taught in the rural schools. Then sand filtration will be so generally understood that its adoption for supplies will be readily granted.

As to the quantity of water to be supplied, past experience has shown that needs have increased far beyond estimates in every case. Larger populations and larger use per person; use of water for power (elevators), for heating, for various manufacturing purposes, and above all, wastes in adding pressure to old plumbing, — all these causes have led to an increase impossible to keep up with.

The engineer of the future will need to sound a warning, even though he recognizes these facts in his report. Many serious troubles have arisen from the too low estimation given by the engineer either through ignorance of the law or from a desire to give low estimates to please the people, trusting to a pressure of circumstances to force them to future expenditure. Epidemics are costly if efficient teachers.

The needs of a farmhouse or a country residence covering about twenty people may often be best met by a ground supply. It is cold, and so acceptable; it is clear, colorless, odorless, and sparkling. There is danger that it may show iron, may attack pipes, may draw from undesirable sources when the water table has become lowered.

Experience in the locality, records of other wells, geological knowledge, etc., are necessary to the inspector.

Except near foothills, streams are not to be relied on. The habit of common use is too firmly fixed.

Occasionally a clear mountain stream offers an abundance; for such be thankful.

Open risks may be more easily guarded against than underground cracks from earth slips and frost displacement.

The waste disposal from these detached establishments with plenty of soil and room offers no great difficulty.

Small factories, institutions with about 1000 population, are beginning to see the wisdom of careful planning in regard to water and sewage.

Deep wells or considerable streams are a common alternative.

Deep wells, as has been shown above, carry, usually, considerable dissolved mineral because of the long distances traversed and the strata percolated on the way. Sometimes softening plants are set up most profitably.

The securing of sufficient surface water within a reasonable distance may necessitate filtration or some preliminary treatment. What this shall be requires the advice of an expert as an insurance against failure.

The small town is only an expanded instance of the factory or institution, and the same rules apply even more emphatically as to the need of study of the various possible sources and their probable deterioration in the course of a few years.

This deterioration results from:

(1) Rapid percolation instead of slow; less complete reactions;

(2) Greater distance; polluted source; too short time for natural purification;

(3) Closer settlement near sources; new factories, etc.

Reckless waste includes the soakage of the collecting ground with refuse and the neglect to use the fertilizing portions. The purifying soil is so abused, overworked, that a whole watershed becomes needlessly contaminated.

A gang of laborers, a family on the mountain side, one individual on a small tributary, may pollute a town supply. It is only widespread education and a sense of responsibility, besides careful policing, that can protect a watershed; hence the trend toward letting it go and trusting to filtration before using.

The long time required to clean polluted earth should be considered in estimating the advantage of prevention. Keeping a water-collecting area clean is analogous to other sanitary ways in relation to streets, garbage, food, etc. The habit of proper disposal of wastes is one to be learned in childhood. People must be city-broken as a dog is house-broken. The offense of one person dropping a paper or a banana skin is of small account, but the offense of one thousand is intolerable. On a lakeside one picnic party a year did not show effects, but Sunday crowds all the season were a menace.

Since the danger is a thousandfold more when infecting material is washed directly into running or still water without earth filtration, the inspector of a watershed should have a watchful eye to such possibilities.

The protective distance has been arbitrarily set at 200 feet. The expert can decide if a less distance will serve.

In a city, collection of garbage and thorough draining are possible so that fertilizer for lawns may be used with freedom, but a village depending on wells, or any cluster of houses on a limited watershed needs careful study as to dangers.

The sanitary expert, in the bumptiousness of his youth, should not be too hard on the average man, since as late as 1871 the *Chemical News* quotes a water analysis of a spring at Tunbridge Wells which it rightly calls a curiosity:

" The water is clear, with a taste savoring strongly of steel, and from the experiments of different physicians it appears that the component parts of this water are steely particles, marine salts, an oily matter, an ocherous substance, a volatile spirit too subtle for analysis, and a simple fluid."

In the prospecting trip outlined above, the information and experience gained may be turned to account later. State boards of health have always concerned themselves with the rural needs, at least Massachusetts and Michigan have done so.

The newer schools of sanitation starting up in the universities have an excellent chance for public service in training some students along these lines — true economic prevention.

The Instructive Inspector for the country district must have, like the worker in the crowded alleys, a forceful but persuasive personality and a sympathy with the subjects of his teaching, an appreciation of their difficulties and an inventiveness to meet the countless objections.

Popular science has two sides: it makes it easy to stir people up, but on the other hand it makes difficult their sitting still long enough to explain fully the reasons for the slowness with which reforms must be entered upon.

LAND DISPOSAL AS AFFECTING WELLS

Well water is used at some time during the year by a large part of the population of the United States. Picnic grounds, summer resorts, country boarding places, the roadside spring, the town pump, the schoolhouse well, all offer added risks to the farmhouse supply.

The precautions taken by city authorities are all set at naught by the importation of typhoid fever each season through returning vacationists. The health rate of the country districts is unnecessarily lowered and waste is incurred all along the line.

It is one of the most difficult tasks allotted to the sanitary expert to convince people of danger in their own well. The most common question is, How far must the cesspool be from the well? Next, If the well is in solid rock, how can it become contaminated?

Whenever normal chlorine is known the proof is not very difficult. A bushel of salt often reports an unsuspected connection. Potassium iodide has been used as a tracer, but the high nitrate and chlorine content of the well water taken together give to the engineer his basis. How to interpret, is the question.

SANITARY LEGISLATION AS A MEANS OF EDUCATION

Sanitary inspection frequently shows conditions favorable to growth of disease germs quite unsuspected. Dwelling houses should not be converted into laboratories for the culture of disease-producing bacteria.

Sanitary maxims to be learned in school: quick removal of all wastes, cleanliness, dryness.

Isolation of all infectious and contagious cases for the purpose of destroying the germs excreted.

Life a compromise in this as in most other conditions.

Water, pure, not "repentant," was a demand of forty years ago; now reformation is accepted.

"The lives of most men are in their own hands, and as a rule the just verdict after death would be *felo-de-se*."

"Health must be earned, it can seldom be bought."

—Dr. F. H. HAMILTON.

The social machinery of sanitary maintenance includes boards of control, commissions, state boards of health, city health officers, inspectors, corps of engineers, chemists, and biologists. Many of these legally constituted guardians of public health have the power of regulation of conduct individual and corporate. Many are given certain powers of constructive operation and legislation. More and more generally the sanitary engineer is the executive officer of these bodies of public importance.

A most illuminating light on rural hygienic conditions has been thrown by a report on the Farm Water Supplies of Minnesota, Bulletin No. 154, Bureau of Plant Industry, U. S. Dept. Agric. and Am. Jour. Hygiene, August, 1910, p. 654. The authors say that rural sanitation is of vital importance to cities and may extend far beyond the individual farms exhibiting disregard for the laws of modern sanitation. Seventy-nine water supplies were examined; 20 were found in good condition, 59 showed strong evidence of pollution (this does not mean a percentage for the State, since selection of probable cases of pollution was made). Carelessness in regard to protection against surface wash and surface seepage is responsible for a large proportion of the contaminations indicated. The order of susceptibility was found to be dug, bored, and driven wells. The drilled well should be better than the driven, being as a rule deeper, but the seepage of surface water down the outside of the casing, contaminating the water-bearing strata, is evidently not sufficiently guarded against. *The rivers, surface reservoirs, and cisterns were all polluted* (this speaks volumes against the habits of the people).

The authors conclude that "the condition of the water supply usually represents the sanitary condition of the farm and therefore indicates the potentiality of a typhoid outbreak."

The greatest difficulty is often experienced by constructing engineers in keeping the workmen from drinking the water pumped from the trenching pumps if it is cold and clear. Several cases have occurred of disease contracted in this way.

EXAMPLE OF SANITARY WATER ANALYSIS

Parts per 1,000,000

Locality, South Shore, Massachusetts.

Description of Water, well in hard gravel.

			May 21, 1897	July 17, 1897
PHYSICAL EXAMINATION	Turbidity		none	slight
	Sediment		none	white flocculent
	Color		none	none
	Odor	Cold	none	faintly earthy
		Hot	none	" "
CHEMICAL EXAMINATION	Free Ammonia		.056	.394
	Albuminoid Ammonia		.044	.040
	Nitrites		.001	.150
	Nitrates		1.750	10.000
	Hardness		......	......
	Chlorine		44.0	54.0

Fifty feet away from this well was the uncemented cesspool with a drain from a house used by a small family during the three summer months and cleaned only annually. The quick response of the well to the use of the neighboring house showed the owner most conclusively the great value of the water for garden irrigation.

This belief in appearance has been fostered by physicians and health authorities, who have been known to publish statements that drinking water should be colorless and odorless and to prescribe bottled waters rather than allow the use of brown surface water which may at times develop an odor from the growth of some inoffensive plant. A few synura or asterionella in a reservoir will set the telephone ringing in the health office, when the same persons have been contentedly drinking filtered sewage from carboys. The latter of course looked right and smelled right.

The most skeptical are sometimes convinced that the chemical tests do mean something. A small city was increasing its supply by laying open-jointed drain pipes in a wet valley, as usual, without inspection of conditions after the work was done. The chemist's report that some pollution was certainly leaching in was combated by the authorities as impossible until all parties visited the spot where they found a new house just built, an open privy and plenty of horse manure distributed directly over the pipes.

A well, supposed by the owner of the house to be far distant from any source of contamination, showed decided nitrates, but not excess chlorine. A search revealed the fact that a large hotbed had been made within eight feet of the well.

The influence of temperature in permitting offensive decomposition should not be overlooked, especially when adopting a method successful in a warmer or a colder place. Breitzke[1] states in his investigation of the Gowanus Canal, Brooklyn, N. Y., that the bottom sludge gives off offensive gases at 65 to 70° F., and since a temperature of about 70° is maintained the year round it is easy to see why the nuisance exists even in winter. In many rivers nuisance is perceived only in the hottest summer weather when the temperature is high and the oxygen is lower because of that fact as well as because the organic matter is using it up faster.

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[1] Technology Quarterly, Vol. XXI, 1908, No. 3.

It is this influence of temperature as well as that of sunlight that makes advisable the covering of filtration works.

TYPHOID FEVER PREVENTED BY LAKE SUPERIOR WATER

(Extract from report by E. H. Pomeroy, M. D., Health Officer of Calumet township, Michigan.)

" Some interesting points have come to notice regarding somewhat of an epidemic of typhoid fever which abated on the advent of cold weather. The points are upon the effects of drinking water in the propagation of the disease. The Calumet and Hecla Mining Company have a system of waterworks by which water from Lake Superior is furnished all the families on the mining location, and to the village of Red Jacket, which is entirely surrounded by the mining location. Calumet village is on high and rolling ground immediately joining the mining location, on the east, but without the water privileges of the mining location. Calumet village has a population of about 1000 people. Red Jacket has a population of about 3000. The mining location has a population of about 8000. Blue Jacket is a local designation of one portion of the mining location and there are in Blue Jacket about 700 people. During the year 1889, without the benefit of the Lake Superior water privilege, there were 14 cases of typhoid fever in Blue Jacket. During the year 1890, with the Lake Superior water privilege, there has been but one case. In Red Jacket there have been 3 cases. On the mining location, including Blue Jacket, there have been 18 cases. In Calumet village there have been 51 cases. In the Blue Jacket case the disease was contracted while the person was visiting at another house on the location where others had the disease and where water was used from a well which was subsequently condemned, an analysis of the water showing it unfit for culinary or drinking purposes. Nearly all the cases on the mining location were developed in houses where well water was used during the warmest weather on account of the well water being colder than the Lake Superior water and, perhaps, because the wells were more convenient than the hydrants. Of the entire

72 cases only one was believed to have adhered to the use of Lake Superior water for both drinking and culinary purposes.

"That is to say, 11,700 inhabitants, with Lake Superior water to drink and use, had only 18 cases of typhoid fever, which is about 1.54 per 1000 inhabitants, while 1000 inhabitants of adjoining territory, without Lake Superior water, had 51 cases of typhoid fever, or 34 times as many as in the part supplied by pure water.

"Office of the State Board of Health,
Lansing, Mich., August 25, 1892."

The trained sanitary inspector will not wait until complaints are made by citizens, but will investigate the conditions affecting health on all premises in his district, especially with reference to soil pollution, the purity of the water supply, the storage and disposal of garbage, rubbish, excreta, and waste liquids. With records of these facts carefully prepared and conveniently arranged for reference, the health board is in a position to authorize operations for keeping the district free from refuse materials, the laws of the State being well adapted to the enforcement of all necessary ordinances for preventing accumulations of unhealthful substances.

"To retain the soil in the vicinity of dwellings in its natural condition of purity, or, if it has been polluted, to protect it as far as possible from further defilement, is the most useful routine service which can be rendered by a rural board of health."[1]

[1] Circular 110, New Jersey Board of Health.

CHAPTER X

FILTRATION. WHEN RESORTED TO, HOW EFFICIENT IT MAY BE. STERILIZATION, WHEN INDICATED. UNDERGROUND OR NATURAL FILTERED WATERS

If the water supply of a town present or prospective is *not* of the desired quality, how can it be made satisfactory and what will it cost?

Let it be clearly understood that there are two distinct purposes to be served by filtration, the one an improvement in appearance and the other the removal of dangerous qualities. The construction and management of the filter depend upon the predominance of one or the other of these ideas. Expense in maintenance is also a minor matter in cases of danger to the community from imperfect filtration. The time when legal redress will be given for careless management of so important a part of healthful city life is quite within sight.

There is no doubt in the author's mind of the *ideal* method of treatment of spoiled water. It is coagulation and decolorization by electricallyprepared aluminum hydrate in the water itself, followed by filtration after subsidence and then just before entering the mains an aeration by ozonized air. This will be difficult to regulate and will be hard on the first few hundred feet of the mains, but will yield by far the safest fluid and one to which nothing solid has been added.

Some experiments in the use of ozone as a renovating agent made in the preparation of a thesis by R. W. Horne and J. P. Wentworth gave on Charles River water a reduction of bacteria from 164 to 1 in a cubic centimeter, or 99.4 per cent and a reduction of oxygen consumed from 32.8 parts per million to 22.9, or 30.1 per cent.

On a Fenway (Boston) sample showing 88,200 bacteria per cubic centimeter, the ozonized sample gave 1200, a reduction of 98.7 per cent; oxygen consumed, from 10.5 to 7.2 parts per million, a reduction of 31.4 per cent; and an almost complete removal of the very disagreeable odor.

These were both clear-water samples. The results on turbid waters were not nearly so satisfactory, and the whole series indicated the need of further study of various kinds of accompanying conditions before any far-reaching conclusions can be made.

Water supplies for cities and towns are required to fulfill separate functions, each function demanding a different quality and quantity, the lowest quality and highest quantity being required for general purposes of flushing streets and garden watering, etc., a medium quality and quantity for manufacturing purposes, steam raising, etc.

Of the highest quality and lowest quantity for drinking and cooking — potable water — five gallons a day per person is ample. Surface waters, if potable, are usually good for all other purposes, better than necessary, and hence more expensive to a city.

Ground, or well, waters if from shallow sources are most variable and unreliable.

Deep ground waters are usually potable, but too "hard" for most manufacturing uses.

The changing conditions under which cities and towns are growing requires, or will soon require, a change of attitude toward water supplies, their sources, care, and variations. The point of view must vary as circumstances point the way and certain fundamental truths of science should give a watchful public warning as to needs of prevention.

The sanitary engineer trained to-day should hold present teachings with a certain elastic grip and use the utmost common sense in making plans ahead.

Filtration is a coarse and then a fine straining, accompanied or not by decolorization for the removal of bacteria and other suspended matters. Filtration may be followed by sterilization by chemical means, chlorine, hypochlorites, etc., by antiseptics, by ozone, these treatments resulting in general *cleanness* of the supply, and if sewage is treated, in the innocuousness of the effluent.

Since the theory of filtration is the separation of solids however finely divided from solutions of whatever degree of concentration, it is evident that the spaces between the grains of filtering medium must be infinitely small to prevent the passage of the infinitely little. From this mathematically impossible standard the practical ones recede toward the commercial requirement of good appearance obtained with considerable speed.

The study of sands in the complementary character of sizes and speeds of effluent led to the rule of effective size and of the coefficient of uniformity.

Filtration is resorted to —

(1) For æsthetic reasons, to improve the appearance of the water, remove turbidity, color, etc.

(2) As a precaution, a sort of insurance against risk of infection which is possible rather than probable.

(3) For renovation of spoiled water. To increase available supply demands the most rigid inspection.

(4) For cleansing dirty water to a degree that it may be admitted to respectable streams or lakes.

(5) For treatment of sewage to hasten its stages towards inoffensiveness.

The ideal water, clear, cold, colorless, is often possible only with artificial means. Turbidity is always objectionable to the consumer, whatever its source. The acceptance of color as harmless is an acquired taste based on more or less knowledge.

Ground waters are filtered waters and therefore free from color and turbidity except those carrying iron and iron compounds which cloud or precipitate on exposure to the air. Occasionally these waters prove very troublesome.

The exact treatment and the proportions of chemicals to use are matters of experimentation in each case. Rarely do ground waters carry clay for any length of time, even if on first driving the well shows it.

On the other hand surface waters very frequently need clarification, especially at certain times of year because of surface disturbance of clayey soil.

Surface waters cannot answer the requirements of cold the year round, and many such require filtration to remove turbidity and color. The turbidity of surface waters is caused by floating particles of many kinds which require removal.

- Filtration is preceded by
  - Clarification by
    - sedimentation,
    - straining, .
    - coagulation, then
      - straining, in order to remove matters in
        - *suspension*, as
          - clay,
          - leaves,
          - organisms,
          - bacteria,
        - *solution*, as
          - ammonia. Precipitation slight to nil,
          - nitrates, " "
          - chlorides, " "
          - organic substances,
          - various other substances.

There is no real purification unless these are taken out, but there is satisfactory *renovation* when "all that's going ashore" gets there — when activity stops.

The principles of filtration, like those of agriculture, are few and simple; it is the carrying of them out under diverse and changeable conditions that requires skill and judgment.

An artificial filter is a section of earth of graded sizes enclosed in water-tight compartments to control rate of flow.

The principle in earth filtration is slow percolation with the most active factors, humus and lime, left out. The rapid motion desired makes the earthy and clayey particles undesirable, so that the water filter as generally used degenerates into a merely mechanical colander or strainer which might as well be made of metal, provided any would resist the corroding action of water.

The effectiveness of the filter as regards quantity lies in the grading of the sand so as to permit free flow in the lower portions, suction helping to pull down through the thin top layer of fine sand and through a gelatinous skin of bacterial jelly, thus freeing the water from all insoluble particles. The real work of the filter is done in the top inch or less. The body of the enclosed section serves for aeration. It has been shown how great a part oxygen plays in the processes of purification.

The treatment of each water by filtration is governed by the results desired, by the willingness to pay for those results, by the character of the water to be treated, which may be

good, but unæsthetic,
sometimes doubtful,
generally bad,
variable.

The success of the treatment depends on the construction of the plant on correct principles, but far more on intelligent management.

There are two types of filters, first, that which approximates nature's method, called the slow sand filter, in which the material is washed and sized and spread evenly so as to avoid channels by which an untreated water may escape. The same general principle holds for water and sewage, although the latter is much better treated on unwashed sand (land treatment), a larger proportion of the foodstuff being saved. There is also the filter which improves appearance and adds safety by a coagulant which is then removed under pressure by mechanical means. This is well named the American filter, for its rates come up to 100 to 125 million gals. per acre per day, while the slow sand filter is only .5 to 5 million gals. per acre per day and the natural method may be $\frac{1}{1000}$ of that. The mechanical filter is truly a hurry process; it demands as much extra care as does the twentieth-century limited. This management has become so much of an art and is discussed in so many separate treatises, that only the laboratory phases will be touched upon here.

The engineer's laboratory is for control of daily routine and is fitted for the making of many tests of a kind, but of few kinds. Absolute cleanliness is demanded, even in a sewage laboratory. Watchfulness for indications which may not have attained the stage of proof is of prime importance. For instance, one of the great dangers in a filter is the formation of a channel or path by which untreated water may escape. A slight increase in bacteria count would show this possibility. Tests should be more frequent while this is in doubt.

Insufficient aeration shows itself in the peculiar odor familiar to workers but difficult to describe. Disturbance of the upper layers often shows itself in the increase of oxygen consumed. Eternal vigilance is the price of most things worth having.

If the city is willing to pay for it, artificially filtered water may be almost as safe as the ideal spring water.

To-day, however, the purification of polluted water for domestic use has reached that state of perfection at which it has become the practice of reputable engineers to take polluted water from a stream at the very doors of the city and purify it, rather than to expend large sums of money in conserving an unpolluted supply miles away in a sparsely settled district. The case of Philadelphia at the present time is pertinent. On January 4, 1901, the United States Senate Committee of the District of Columbia convened at New York to discuss with the engineering profession the question of filtration of water supply at Washington, D. C. Mr. Rudolph Hering, M. Am. Soc. C. E., stated in his testimony with reference to the experience of Philadelphia that in 1883 he was engaged by that city to make studies for the new city water supply. As the subject of water filtration was not fully developed at that time he recommended an unfiltered water, taken from the Blue Ridge. More recently, during his connection with the Philadelphia waterworks, he recommended the Schuylkill River and the Delaware, because of the fact that this water could now be made sufficiently pure for use, and under the circumstances it presented a more feasible plan from every standpoint, for both present and future generations.

It becomes necessary, then, in considering pollution in a river from the standpoint of water supply, to make allowance for the fact that the water can be purified and that its present pollution does not constitute a complete loss of resource. Under such circumstances the actual amount of damage done consists of the difference between the cost of pumping raw water for direct use and the cost and maintenance of a filtration system.[1]

Careless management may be criminal.

Previous sedimentation with or without coagulation, and limited storage, enable better and quicker work to be done.

The danger is decreased in proportion as the premium paid is high.

How much danger still remains from the minute organisms of which as yet we know little, protozoa and the like, is uncertain. While one builds inflammable houses one must take some risk; while man uses renovated water he must take his chance that the renovation may not always at all times be complete.

The engineer of to-morrow will need an open mind on all phases of water filtration and incidentally on sewage filtration. Researches by the experimental method will settle some now doubtful questions. Probably renovation rather than conservation will continue to be the rule in settled communities, but in new regions where there is yet unsoiled water to be had, the policy of preservation will undoubtedly gain ground.

All renovating action uses up oxygen, even the changes of the harmless matter, in tanks or beds.

Continued straining goes on when there is a little food and much air. Intermittent straining is required where there is much food and hence rapid diminution of air, then time is a decided element used largely as a preventive measure. From

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[1] Water-Supply and Irrigation Paper No. 72, U. S. Geological Survey.

what we know to-day straining does not purify, and effluents "good as spring water" still carry nitrates and ammonia into streams, because of hurry and because the action goes on away from green plants which alone can really purify — take out Nitrogen, Phosphorous, Potassium, Calcium, etc.

We shall refer to examples later, showing that self-purification of rivers is mostly accomplished in this way. It is logical, then, to try to reach a more nearly original quality in the water sent out.

For mingling with the waters of a usable stream it is not enough that the sewage effluent be non-putrescible as it leaves the filter, for if it carries dissolved organic matter, as the effluents of chemical precipitation works usually do, when diluted with water carrying organisms it will furnish them food.

In this respect the septic tank, which is planned to dissolve as much as possible of the suspended matters, is not suited to discharge into a stream without first passing its contents through a sand filter.

Certain controverted points are likely to occupy the attention of students for some years to come, such as how much pollution will a given body of water receive and care for satisfactorily? That is, will the oxygen dissolved and the clean water be sufficient to absorb the putrescible matters added?

When has a given stream reached the limit of safety?

Where shall its purification take place, at the intake or after it has been through several settling basins and reservoirs; that is, just after pollution or just before use?

Who shall be obliged to purify the water, those polluting it or those wishing to use it?

Shall the method used be the one which gives the *best* results or the one which costs least and gives fair results?

Trade wastes may be sterilized by boiling or by antiseptics and then need mixing with domestic sewage for the purpose of seeding for decomposition.

America is rapidly approaching that congestion of manufacturing existing in England. R. S. Weston gives the West Riding as an example, 2005 factories representing ten industries within an area of 2750 square miles. Only 290, less than 15 per cent, discharged untreated wastes into the small streams.

There is likely to be friction between factories and towns for some years to come until the community welfare is put before individual gain.

Cost of filtering river water is offset by cost of not filtering.

Whether to use raw or to filter depends upon many circumstances.

Questions to be Answered

When is a water bad enough to justify the outlay?

Cost per million gallons plus taxes ?

May cost be recovered in lessened death rate ?[1]

When is a water too bad to clean?

(This will lead to sewage filtration.)

When is simple sterilization without filtration sufficient?

When is sterilization with incomplete filtration advisable?

A Sand Filter

Depth of water, 4.2 feet.		Effective size, mm.	Uniformity coefficient.	Per cent of "voids" or air space.
2 to 3 ft. of filter sand	Fine......	0.21	1.6	44.2
	Medium...	0.28	1.6	43.1
	Coarse....	0.35	1.9	41.7
1.20 in. coarse "mortar" sand..		0.52	5.4	32.8
0.60 in. buckshot gravel.......		1.83	3.6	31.
0.75 in. pea gravel............		1.47	6.5	33.
0.75 in. walnut gravel.........		17.	1.2	35.
1.33 in. coarse stones..........		20.	1.5	36.

Rate = 1.5 to 4 million gallons per acre per day.

Rate = 1.44 to 3.84 gallons per square foot per hour. 58.5 to 156.0 vertical velocity, mm. per hour. Bacteria per grm. of sand: Dayton, fine, 180,000; Dayton, medium, 290,000; Dayton, coarse, 440,000; Coney Island, 280,000.

Organic matter (N. as alb. am.), 2 parts per 100,000; clay, 0.3 per cent; $CaCO_3 + MgCO_3$, about 1 per cent.

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[1] *Engineering Record*, August 21, 1909, p. 198. Profits of Water Filtration; Director Neff, Philadelphia. First half year of 1907, 5005 cases typhoid reported. 1908, 2195; first six months of 1909, 1383.

Effective size means that 10 per cent by weight is finer than that size. Uniformity coefficient is the ratio of $\frac{A}{B}$ when 60 per cent is finer than A and 10 per cent is finer than B.

The body of a filter is always a mass of clean sand of varying sizes but always fine on the top. This mass supports a thin gelatinous layer in which the particles to be removed, bacteria, clays, etc., are enmeshed and prevented from following the liquid down. This gelatinous film in a slow sand filter is gradually collected from the water itself, and so the efficiency of the filter is an increasing quantity until the slow rate demands a removal of the layer.

In the hurry or mechanical process the gelatinous substance is supplied by a chemical sponge of aluminum or iron hydrate in which the objectionable matter, color included (does iron take out color as well?), is imbedded. This thicker, more voluminous layer is removed by reversed clean water flow when too compact.

A satisfactory effluent from either filter must conform to standards of safety and of appearance. Such water is never cold, but it may be clear, colorless and so far as people notice, odorless. The sparkling quality which makes spring water so palatable is not usually found from the mechanical filter, but the added mineral substances may in part improve the taste, however little the average person notices them.

The sanitary engineer of to-morrow, who will, as we have said, be a social economist as well, has to consider the human side of the question as to the expense the community will bear to secure safety or pleasure.

The choice of a water supply may have been irrevocably made or it may still be open.

The best means of purifying or of filtering, especially of mechanical applications, have been the much-discussed problems of the past twenty years, and it is largely through these methods that the engineer has been gaining his foothold in sanitary purification.

If the particles were inorganic and harmless the matter would be simple, but with millions of living organisms, some of which may be pathogenic and all of which are undesirable, the difficulties of hurry processes are increased. Time is what nature requires; when man meddles, he must take the consequences.

Treatises on filtration and abundant current literature give details and illustrations which need not be repeated here. A brief statement of general principles will suffice.

A polluted (infected or dangerous or merely contaminated) fluid from which $\frac{1}{100}$ to 1 per cent is to be removed or rendered harmless is subjected, (1) to filtration through sand in large quantities, or through porous porcelain in small quantities, with or without previous chemical coagulation; (2) to sterilization by electricity, hypochlorites, or ozone; (3) to storage, *i.e.*, time and sunlight. Particles if not too fine may be thus disposed of, but what of the soluble substances? Are they, perchance, toxic? Too little is known as yet of the products of decomposition of the nitrogen substances, the time they remain stable, and the effect on the human organism to give any authoritative statement. The reactions given in Part II, Ex. 10, indicate possibilities of alkaloidal properties which may make filtered sewage undesirable for human consumption. This suspicion is growing in many minds, and prevention of contamination rather than cleansing operation is likely to come to the front in the next twenty years.

Wastes themselves in much more concentrated form will be treated and thus the objectionable substances be more completely removed, or they will be otherwise disposed of than into water which may be needed for domestic purposes.

The subject of trades wastes is too new to have extensive literature and is too complicated to be discussed as general practice. Some instances will be found in Part II, Ex. 11.

Notes on Sand Filters

Depth of sand and gravel in mechanical and slow filters is about the same.

The Jewell filter at Little Falls, N. J., an example of the best type of mechanical filter, has two inches crushed quartz, 5 inches fine quartz gravel, 130 inches screened quartz sand. The same filter at Cincinnati has 30 inches of sand of effective size, 35 mm. The slow sand filter at Denver is built with a 12-inch layer of gravel varying in size from between 2 and 3 inches to between ¼ and ⅜ inch. On this is placed 36 inches of sand of effective size of 53 mm. In the new Pittsburg filters provision is made for a maximum of 48 inches and a minimum of 36 inches of sand. At Columbus, Ohio, the mechanical filters have 10 inches of gravel and 36 inches of sand.

On the whole, a depth of about 36 inches of sand seems to give the best satisfaction. The best effective size seems to be from 35 mm. to 50 mm. Although theoretically the coefficient of uniformity should be as near unity as possible, practically, filters giving satisfaction are constructed of sand whose coefficient of uniformity varies from 1.1 to 2.1 and even higher.

The head used on any given filter must be decided from the desired rate of flow and the internal friction, together with experiments as to the best results for that particular filter.

The one great distinction in the action of the mechanical and the slow sand filters is, aside from the relative speed of operation, the fact that the mechanical filter merely acts as a strainer, though a very efficient one. No chance is given for any chemical action aside from that involved in the action of the coagulant. This produces an effluent free or practically free from all suspended matter, yet containing in solution all the substances contained in the raw water. The slow sand filter, on the other hand, allows of chemical action in the interstices of the sand as the water passes through, thus giving an effluent not only free from suspended matter but also free to a great extent from unmineralized solutions. It is an open question as to whether these organic solutions are at all harmful, and even if they are so considered, their effects are apparently so slight that the greater speed of the mechanical filter might be a controlling factor in the choice at a place where space or sand was at a premium.

Sometimes a combination of the two forms is the best solution of a given problem, as at Washington, where it was found necessary, at certain seasons of the year, to add coagulant to the water before passing it through the filters in order to take out the very fine clayey turbidity peculiar to the Potomac River.

The rate of slow sand filters is much more important in determining the quality of the effluent than is the rate of mechanical filters, and should, therefore, be largely dependent on the kind of raw water and on the quality of effluent desired. In the best filters of recent years it averages about three million gallons per acre per twenty-four hours. In mechanical filters, on the other hand, the rate seems to have a less direct effect on the effluent, and varies in good filters from eighty million to one hundred and eighty million gallons per acre per twenty-four hours.

SOME WATERS BEFORE AND AFTER FILTRATION

	Free A.	Alb. A.	Cl.	Nitrate.	Nitrite.	O. con.	Bac.	Har.
Lawrence Water.								
Raw....	.084	.202	2.2	.14	.003	3.9	14,000	......
Filtered..	.068	.109	2.2	.31	.005	2.8	258	......
Hudson, N. Y.								
Raw....	.070	.140	3.0	.100	trace	6.500	787	......
Filtered..	.024	.106	3.0	.100	none	4.100	57	......
Springfield, Mass.								
Raw....	.069	.227	17.0	.060	.001	5.100	......	10
Filtered..	.067	.191	17.0	.060	.001	4.500	......	13
Raw....	.022	.142	15.0	.120	.000	2.800	......	6
Filtered..	.005	.096	16.0	.170	.000	2.500	......	7

SAND FILTERS FOR POTABLE WATERS

The water used is the best obtainable, previously settled to be rid of coarser suspended substances.

Although a sand filter does not yield a germ-free water, it should be made to do the best it can. Experience shows that a well-managed filter may yield a filtrate with less than 100 per c.c. Channels may form or other disturbances of the filtering layer may occur so that a great increase may at any moment occur. Even daily bacterial examination may not show this, so that, while frequent examinations are necessary, it is usually too much to expect to make a daily examination of a large number of filters, except in times of cholera outbreak.

Each filter bed or basin should be so arranged that it can be shut off from the rest. The rapidity of flow has much to do with the success of filtration. The German rule is not over 100 mm. per hour through a layer of 30 c.m. of filter sand. If more water is needed, then more filters must be provided.

River water, owing to rapidity of flow, to turbidity, etc., is not often perceptibly full of algæ, as is that of ponds and basins, which we shall consider later, but there are many kinds of fungi, such as crenothrix and yeast and of algæ and diatoms in river water. In Poughkeepsie, on a hot day, the bed was clogged in 48 hours.

Clean sand strains only, but the nitrifying organism coating it does aid in burning up organic matter. *Clay is a decolorizer.* Better a little clay, except for the clogging, and better *clay and soil with humus for nitrification* than pure quartz sand.

Carbide of iron, the forerunner of coke, was used previous to 1877.

The American system of mechanical filtration was a pioneer system. Hurry is an American habit and this scheme forces water through sand after a treatment by aluminum hydrate, usually derived from alum. It has a great advantage of taking up little room for the quantity of water delivered. It needs careful supervision lest too much reagent injure the quality of the effluent or too little permit an escape of too many bacteria.

The effluent from a filter must be as clear as possible, and in color, taste, temperature, and chemical composition be not worse than before filtration. The sand must not yield anything to the water, and foul odors due to insufficient aeration must not be produced. As the size of the filters increases, this danger increases, especially with feed water impregnated with considerable decomposable matter. With fairly good water there is usually oxygen enough to carry on the process.

Ice-covered beds prevent oxidation and cause odors, not necessarily dangerous, but an indication of imperfect aeration and of reducing processes.

The mechanical action is straining while the chemical action of the filter is oxidizing, for the most part by the aid of bacteria. The slowness with which the water moves and the even temperature give opportunity for the decay of the organic substance and the final production of harmless substances. Hence, there will be stages in which the number of bacteria will greatly increase, and, in turn, they must be filtered out before the effluent leaves the filter. The pressure must not be too great therefore. Nature's processes work slowly.

Filtration of sewage will be referred to in Chapter XII. So far as the principles apply, the process requires more time between doses, because of richer food supply and more sludge accumulation even with previous sprinkling filter. More special modifications also are needed for special cases. The following questions are suggestions of points to be considered in the construction or criticism of filters.

Slow Sand Filters

Effective size of sand?
Layers?
Depth?
Head?
How cleaned?
Color of water?
Sediment in water?
Quantity of water handled?
Working periods of filters?
Reduction in bacteria?

Costs:
  Installation?
  Operation?
  Renewals?
  Increase in tax rate?
Cost per million gallons?

MECHANICAL FILTERS

Rate?
Quantity of coagulant used?
Is it necessary to add lime?
Per cent reduction of bacteria?
Effect of plankton. Is it a helpful variety?
Mud?
Time of subsidence?
Cleaning, method?
Costs:
  Installation?
  Operation?
  Renewals?
  Increase in tax rate?
Cost per million gallons of purification?

We have a ratio between speed, quantity, and required purification governed first by quality. The principle is the same, but details vary.

Chemical action takes time and can be accomplished only in a filter sand carrying plenty of oxygen, that is, one in which the voids are 40 per cent of the whole space.

Hurry filters such as Hyatt, Jewell, Warren, etc., gain time by omitting all real chemical action in the filter process, confining it to the reactions which produce the right kind of coagulant to enmesh the undesirable particles. Therefore soluble substances in the water for the most part go through after the coagulation unchanged. Thus a water previously high in free ammonia continues so after this process, because this substance does not enter into the changes; while calcium carbonate is lowered because it combines with the SO_3 in the alum, etc.

EXAMPLE FROM WORCESTER, OCTOBER, 1899

	Albuminoid ammonia.	Dissolved.	Suspended.	Free ammonia.	Oxygen consumed in filtered water
Sewage	.652	.315	.337	1.777	4.96
Effluent	.277	.269	.008	1.589	3.71
Per cent removed by Filtration	57.5	14.6	97.6	10.4	25.2
Sewage	.373	.186	.187	1.191	2.91
Effluent	.032	.032	.000	1.279	1.26
Per cent removed	91.7	82.8	100.000	.74	56.7

Among the many problems having a distinctly chemical basis, that of iron in the water is perhaps the most troublesome. Soil usually contains iron, both as sulphide or oxide derived from the slow decay of sulphide and as an organic compound. Chlorophyll, the basis of green vegetation, always carries iron, as does the blood of animals. The sulphide may give rise to soluble sulphate and thus enter the water, or the oxide may be dissolved and enter the water as carbonate chiefly, or as the original organic compound, yellow "humic acid," which holds the ferric oxide in solution, as the young analyst finds to his dismay in the laboratory determination of ferric oxide.

Water in percolating through the soils that are free from lime brings to the surface considerable quantities of iron, a most objectionable constituent for domestic use.

If this is in the form of ferrous carbonate, aeration will permit the escape of the carbon dioxide, and sedimentation or filtration will remove the solid oxide, as at Far Rockaway, L. I., Red Bank and Asbury Park, N. J. If the iron is in combination with organic acids, filtration through marble chips or some other addition of alkaline reagent will break up the rather loose union and set the iron free. This has the disadvantage of greatly increasing the hardness of the water. Another way is to break up the organic matter. One way of securing this is by oxidation of the humic or carbohydrate compounds by potassium permanganates, as in the laboratory test for organic matter. See Nichols, Water Supply, 1883, as used by English Army, also Report of the Mass. State Board of Health, 1899, p. 549. This was tested on Provincetown water. Fifty to seventy-five pounds of potassium permanganate to 1,000,000 gallons in laboratory experiments proved efficient after three hours' aeration.

At Reading, Mass., among other experiments that of a growth of crenothrix artificially cultivated has been tried. The plant takes the ammonia as food and probably the dissolved carbonaceous matter, and sets free the iron, which then may be filtered out.

The cure by the hair of the dog that bites is used to remove dissolved lime from water, namely, the addition of more lime to take up the dissolving agent, CO_2; so with some forms of iron solution (the Anderson process in modification), metallic iron is successful.

The trouble sometimes increases as the water table is lowered and swampy places are drained into hitherto clear waters.

If the soil receives additions of rich fertilizers or some acid trade wastes, the leaching of the iron increases, and not infrequently ground water supplies have to be abandoned, such as wells 25 or 30 feet deep draining from low land. Such a case occurred at Watertown, Mass.

CHAPTER XI

II. THE ULTIMATE DISPOSAL OF WASTES LIABLE TO CONTAMINATE WATER SUPPLIES

Cremation, of garbage, animal waste.

Dilution, by soil, by good water.

Utilization, land absorption of water and nitrogen.

The modern waterworks not only extends its feeders back into the mountains fifty to two hundred miles, lays pipe lines, establishes large storage reservoirs, and probably purification plants, but also installs a system of watershed inspection, intending to exclude that pollution of the soil now recognized as a dangerous factor. To maintain purity of soil both solid and liquid wastes must be disposed of effectively. This extension of the idea of prevention to include all waste disposal is one of the strongest arguments for municipal control and a unity of plan to be laid out and maintained only by engineering skill.

City wastes, other than sewage proper carried in pipes, are (1) ashes, (2) metals, (3) glass, (4) rubbish of all sorts, — trimmings of trees and shrubs, refuse of building, paper, and (5) dirty liquids carelessly thrown on the ground.

The first four are a menace only as they may be vehicles for carrying the last. Ashes may be coated with foul liquids, empty cans and glass may be breeding places for mosquitoes and other vermin. Rubbish heaps harbor rats and mice. The city dump is an unsanitary as well as an unsightly spot and should be abolished. Hand sorting of the freshly collected material under cover by trained workers whose hands and faces are properly protected would doubtless go far toward paying for collection if the householder did his part in original sorting. With the increased use of gas, ashes are being eliminated, but furnace ash still pays for screening. The disposal of the wastes of human life in a manner at once satisfactory, innocuous, and economical is still a burning question.

The completeness of the disposal of wastes of all kinds, used material of no value until the form is changed, marks the stage of civilization that a community has reached. It may be objected that it is possible to be supersensitive; that dead leaves and rotting wood are not as dangerous as a garbage heap or a dead carcass. Nevertheless we are finding influenza in the pretty litter of fallen leaves and carriers of disease in the insect-inhabited wood.

The more deeply one probes into the byways of life, the more it appears true that the first law of sanitation is quick and complete disposal of all wastes. Complete disposal means a return to usefulness, to those forms which may begin again the cycle of value.

The sanitarian, therefore, will endeavor to accomplish this result with as little offense as possible. Alas, to-day the hampering clause is added, with as little cost as possible — without reference to the cost, in human life and health, of *not* doing it.

Manufacturing wastes and city sewage carry much which does not belong to polluted water in the sense in which we have taken it. Cabbage leaves, butchers' paper, orange peel, banana skins, grease, soap, hair, hoofs and horns, matches, lint and rags, paper, cotton, wool, and what not, go into the city sewer.

If the sewer empties in one place this soon becomes clogged. Constant raking and burying are needed; or, if artificially clarified, the " sludge " is a burden, a terrible incubus on the works.

Nature never has so much to handle in one spot. The refuse of one dishwashing or one Monday's wash lies on the surface and becomes inoffensive by drying and sun. Colonel Waring used nature's way, by exposing this gelatinous sludge to aeration and drying it to nothing.

In some stage of civilization, when man began to be neighborly, so that his sink drain and *cabbage patch* began to be too close to his neighbor's windows and to offend his neighbor's nose, he devised a hole in the ground with loose walls and cover, a leaching cesspool, into which everything went — beef bones and corn husks. Usually this took care of itself and was no nuisance; here was neither air nor green plants, nor even nitrifying organisms, but the sort of enzymes which "rett" flax, which act on the buried leaves and overturned sod, the barnyard manure, etc., together with the ordinary putrefying bacteria, so that *in time* the solids all disappeared with the liquids. Into the cesspool came fresh portions of liquids day by day and hour by hour, and the effluent spread slowly into the earth and eventually found its way into the watercourses, for the most part below the nitrifying layer. Hence, Colonel Waring conceived the idea of having an elongated instead of a deepened tank, and so devised the subsurface drainage which goes by his name. A foot was rather deep and the time was not always sufficient for solution, so it has not been universally successful but is gaining favor.

The cesspool is reappearing under the name of the residential septic tank, and it is important to understand the reactions as far as possible, so as to foresee the consequences.

The use of wells in a village after a town supply was put in was the straw which broke up the habit of universal use of cesspools. The amount of water a family would pump was not so much as to oversaturate the ground of an ordinary village lot, but, given a tap with good pressure, the quantity rose so that the cesspool fed the well, which, because it was cold, was still used for drinking by one's self or his neighbors.

We have reached a further stage now, so that wells are no longer tolerated in a village with water supply, and cesspools may come back if we are sure that somebody else is not going to suffer.

CREMATION

A return to the sanitary practice of early times in the cremation of all useless solid substances which are combustible is a doctrine to be promulgated among all intelligent peoples.

A large proportion of city wastes might be thus disposed of if the citizens would coöperate, in ways at present non-existent or non-effective. Garbage is much larger in bulk than it need be or should be, because so much rotten fruit, uneatable vegetables and unused meat, and general waste goes into the city receptacles. When furnaces and coal stoves are used each householder may lessen his quota, but with gas stoves and water or steam heat from a central plant the remedy for half the food waste is in the market, from which the refuse may be disposed of while it is fresh and not offensive. Most city waste is either innocent bottles, cans, bricks, mortar, ashes, etc., or combustibles, as paper, coal, sticks, grease, etc.

The mechanical difficulties of cremation may be overcome just as soon as the sanitary importance of this disposal is conceded.

Crematories in place of cemeteries will add to the safety of the living, and all sanitarians should unite in this effort to keep the soil clean; even the farmer will find profit in cremating instead of burying or leaving exposed many waste products. On a farm there is always enough woody refuse to burn the rest. The one exception, perhaps, may be dead leaves, cornstalks, etc., that form of mulch carrying organic carbon in combination with nitrogen in such form as to be available quite quickly for the next year's plant life. Such organic substances are usually free from disease germs, although in certain cases fungus epidemics have to be stopped by burning all stalks and leaves.

Many trade wastes could be improved by suitable screening as the stream leaves the plant and by a treatment for recovering grease for combustion of refuse. To-day many establishments attempt recovery only on a basis of commercial profit. In future, sanitary economy will be more largely considered on this line. There is a great field for reorganization of sentiment as well as of practice. The whole subject is in its infancy and is a promising field for the inventive engineer.

Bottles and tins have some value. The enormous waste of paper should be separated at the house and for the most part collected by itself, but enough goes with the rubbish and garbage to furnish fuel for the cremation of the latter.

All sanitary principles point to the cremation of decomposable organic matter at once to save the soil and the sea from pollution.

The establishment of the fact of the possible production of nitrates from that inexhaustible storehouse of nitrogen, the air, whether by plant nodules or by electricity, has taken away all valid objection to cremation of bodies or food wastes. The soil must be protected. This indiscriminate throwing of dirty liquids into alleys and unpaved places in the city is now prohibited by ordinance, but the dwellers on the watershed are not so careful.

This branch of conservation must be considerably extended and enlarged; hand in hand with it must go the education of the people.

Rural sanitation for the protection of the watershed is a new branch and not yet developed.

Dilution: "Drains and sewers have been in use for thousands of years, but it is only within the present century that they have been made carriers of excrement. Their use, however, for this purpose has increased of late in all civilized countries; and it seems probable that this will soon be the universal method employed in cities and crowded towns. We have already referred to some of its manifest advantages. The saving of labor is one which must specially commend it to all American communities. It is almost automatic in its operation. It sweeps away from our sight the most offensive things. It is capable of entirely relieving a city or town of the presence of such foul collections of putridity as are always disclosed in an ordinary privy vault. When a great fire destroys the houses and uncovers the earth in an old town, we can see how numerous and how vile are these places. Would not everybody desire to have such filth removed and the site of the town thoroughly aired and purified before the houses were rebuilt?"[1]

This most common waste, sewage as it flows away from cities, is not merely 75 per cent water as an animal carcass is,

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[1] Fourth Massachusetts Report, 1873.

not 90 per cent as vegetable garbage tests show, but 99.8 per cent of water. It is already so dilute that the addition of more water seems the natural order of disposal. Most streams receive only 20 parts in a million of polluting material, the resulting mixture giving frequently no indication to taste, smell, or laboratory tests of its character. It was only when the bacterial count became possible and one cubic centimeter of the water showed fifty to five hundred million colonies that men's imagination began to be affected. This " scare head " was so effectual that now it is difficult to convince some people that all of the millions are not deadly.

Dilution decreases the risk not merely in proportion to the dilution but after the discharge into cold media, the pathogenic germs are exposed to sunlight and to the destructive action of hosts of hostile organisms, protozoa, etc. The greater part succumb and the few left are in effect distributed over a million times more water. Some such theory explains the general immunity from disease following dilution of polluted water, but this immunity is rudely interrupted by any unusual disturbance.

Dr. Charles Ferguson, city sanitarian of Indianapolis, recently reported that the water supply showed signs of fecal contamination and that a very large proportion of the 45 sufferers from typhoid fever during the year were either directly or indirectly users of city water. As the water supply of Indianapolis has been considered exceptionally good, Dr. Ferguson's report created some comment, until an investigation by the county health officer developed the fact that a small village about six miles above the Indianapolis intake had undertaken a wholesale cleaning of its privy vaults and that the contractor had dumped the contents of these into or along the river.

The many cases on record like the college epidemics in New Haven and Ithaca, the Cambridge case of Italian laborers, the famous Chelmsford patient who in one day started typhoid in three cities and did a service to sanitation in putting the final weapon in Mr. Hiram F. Mills's hand for the Lawrence filter, —

all go to show that dilution cannot be relied on as a final disposal in all circumstances.

The case of wells and springs is even worse, for although the water is colder, the absence of combating organisms gives freer play. The well contaminated by a freshet with melting snow giving thirty cases of typhoid is an instance which might be multiplied.

In a way the dilution is advantageous, as it allows the chemical and biological processes to go on freely. There has been less danger from water carriage than from cesspools, but the garbage and increased trade wastes which the sewers are made to carry under conditions of modern luxury, as well as the denser population, makes the problem a somewhat difficult one.

The subject of the self-purification of rivers admits of being considered from two perfectly distinct points of view, as, indeed, do almost all other questions relating to the purity of water, viz., the chemical and the biological aspect.

Until recently the subject has been discussed only from a chemical point of view, in consequence of the impossibility which formerly existed of obtaining any precise or accurate information on such matters of biology.

All engineers are acquainted with streams which are visibly polluted at one spot and apparently pure a few miles lower down. When such cases are further submitted to analytical tests, the latter, of course, fully confirm the previous ocular impressions. In fact, that such disappearance of organic matter does take place is beyond a shadow of a doubt, and it is mere waste of time to contest it. A bagful of feathers shaken into the air at one spot would similarly be imperceptible a few hundred yards away. That the polluting matter has been destroyed, however, in the course of a few miles' flow is almost as improbable as that the feathers should have been decomposed in their short flight through the air. In fact, when these cases of supposed self-purification come to be carefully investigated, it becomes very doubtful as to whether the phenomenon is due to anything beyond dilution and sedimentation.

ILLINOIS RIVER
Parts per 1,000,000

Locality.	Date, 1900.	Color.	Solids.		Albuminoid ammonia.		Free am.	Nitrites.	Ni-trates.	Oxygen Cons.	Cl.	Bacteria per c.c.
			Total.	Dis.	Total.	Dis.						
Chicago................	June 18	.10	179	154	.328	.256	.680	.044	.056	6.3	6.9	2,060,000
Lockport, end of Canal....	" 19	muddy	692	625	1.680	.860	20.000	.000	.000	23.3	219.0	180,000
Joliet, Des Plaines River...	" 18	.15	198	188	.264	.152	1.640	.070	.000	5.6	14.0	540,000
Morris................	" 19	.20	219	214	.264	.200	2.040	.368	.000	6.3	8.6	88,000
Ottawa................	" 19	.20	258	214	.232	.208	1.360	.300	.300	6.6	21.0	12,000
La Salle...............	" 19	.20	260	225	.224	.208	.728	.300	1.050	6.5	16.6	11,000
Henry................	" 18	.20	380	272	.238	.208	1.280	.320	.730	8.6	19.0	1,900
Averyville..............	" 19	.20	329	274	.264	.240	.120	.240	1.160	7.5	16.0	800
Havana................	" 20	.20	310	244	.344	.208	.344	.130	.420	8.3	14.0	7,400
Kampsville..............	" 22	.35	336	222	.264	.160	.026	.060	1.140	7.6	9.8	5,800
Grafton, Illinois River.....	" 22	.35	274	234	.232	.160	.012	.017	1.300	6.6	9.6	11,500
Mississippi River at Alton, midstream.	" 20	.20	286	178	.272	.160	.046	.007	.300	8.5	4.6	4,000
Mississippi River, 400 ft. from Illinois shore.....	" 21	.30	906	203	.442	.096	.014	.005	.000	13.0	6.6	8,500
St. Louis Water Co., tap. water at St. Louis......	....	......	374	216	.112	.112	.016	.000	.350	6.0	8.2	2,400

Copied from report of E. O. Jordan, Report of Streams Examination.

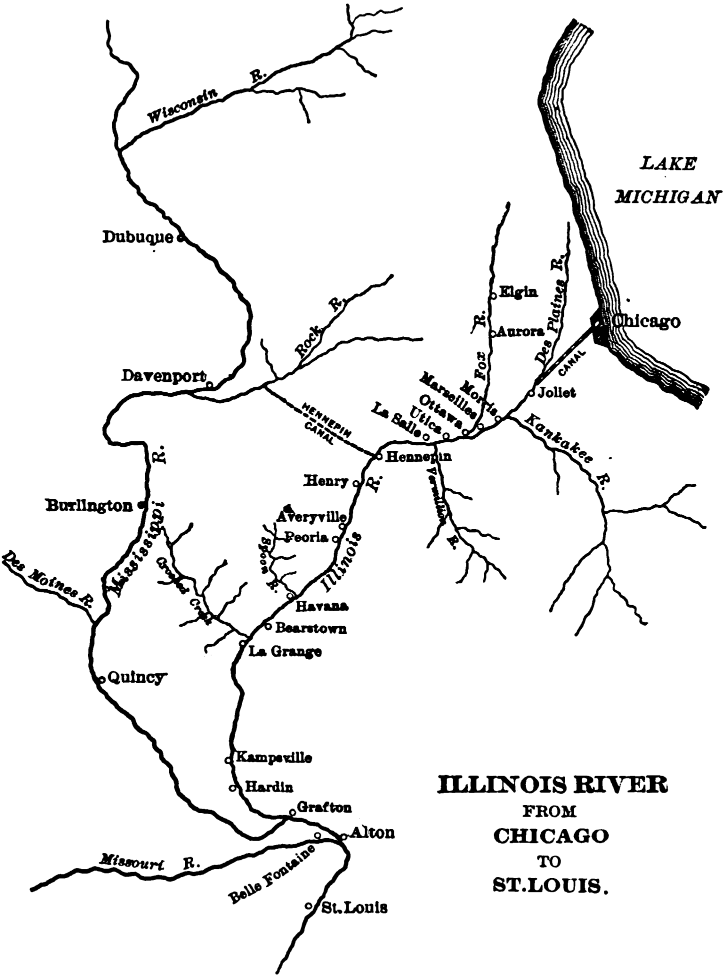
Persistency of Individual Characteristics of Rivers after Confluence

Parts per 1,000,000

Locality.	Date, 1900.	Total solids.	Total albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Cl.	Bacteria per c.c.
Illinois at Grafton	June 29	410	.272	.040	.040	.600	10.4	13,700
Mississippi at Grafton	" 29	560	.560	.032	.003	.300	3.4	4,000
Mississippi at Alton, 100 ft. from Illinois shore	" 27	499	.376	.034	.034	.450	6.6	7,600
One-quarter distance from Illinois shore	" 27	519	.376	.044	.026	.450	6.0	4,000
Midstream	" 27	530	.456	.028	.019	.450	4.6	13,900
One-quarter distance from Mo. shore	" 27	572	.480	.052	.019	.450	3.2	20,000
100 ft. from Mo. shore	" 27	494	.408	.030	.024	.350	3.4	5,800
Missouri River at W. Alton	" 27	3716	1.520	.020	.004	.650	8.4	25,000
Mississippi river, 400 ft. from Ill. shore	" 28	1235	.656	.048	.003	.350	4.6	15,000
Midstream	" 28	2123	.960	.046	.003	.450	6.6	9,500
Inlet Tower Water Co.	" 28	2756	1.120	.046	.002	.350	6.6	9,000
400 ft. from Miss. shore	" 28	3429	1.344	.056	.001	.600	7.6	11,400

See map for relative positions of rivers and cities to illustrate above data.

The most notable case in recent times is that of the Chicago Drainage Canal, where foul water is washed out with lake water and diluted with a dozen tributaries of more or less good water until it mingles with the Mississippi, whose great volume has absorbed the drainage of twenty cities, and with the great Missouri, a fouler stream, but so muddy that the sedimentation is a powerful purifying agent.



ILLINOIS RIVER
FROM
CHICAGO
TO
ST.LOUIS.

Dilution is a great safeguard and so long as it is a million to one, will as a rule — to which there will always be exceptions — answer.

Dilution as well as soil filtration — general seepage and percolation of small wastes, farmyards, factories, gas washers — are helpful.

"Much inconvenience and ill health caused by impurities in the drinking water originate primarily from the alimentary tract, and are due to gastric and intestinal disturbances. The ingestion of contaminating materials may be a cause of dyspepsia or diarrhea, and probably also renders the system receptive to the invasion of the bacillus coli, the bacillus of Shiga, and other pathogenic organisms, and this quite independently of any pollution of the drinking water by the disease-producing germs themselves."[1]

Contaminated waters are not necessarily dangerous at the moment or ever, but bear the marks of previous pollution. They are suspected and the expert must determine the source and character of this previous pollution before he can be sure if it is safe to go on using them. Most cases of domestic wells come under this head.

Water cannot be restored to its pristine purity. It can only be cleansed so as to be passable and not dangerous.

The Psychological effect of appearance is worth much — because of tradition.

Science not infrequently meets a setback from a well of obtuseness due to inherited ideas. The English Commission furnishes instructive history — as the following extracts show.

INSTRUCTIONS TO THE COMMISSIONERS

Gentlemen: WHITEHALL, May 30, 1865.

Her Majesty having been pleased to appoint you to be Commissioners for Inquiry into the Pollution of Rivers, I am directed by Secretary Sir George Grey to send you the following instructions for your guidance in the proposed inquiry.

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[1] American Medicine, March 29, 1902.

Although it may be taken as proved generally that there is a widespread and serious pollution of rivers both from town sewage and the refuse of mines and manufactories, and that town sewage may be turned to profitable account as a manure, there is not sufficient evidence to show that any measure absolutely prohibiting the discharge of such refuse into rivers, or absolutely compelling town authorities to carry it on the lands, might not be remedying one evil at the cost of an evil still more serious, in the shape of injury to health and damage to manufactures. It is, therefore, suggested that your inquiry should include selected river basins, illustrating different classes of employment and population; that these river basins might be:

First. The Thames Valley — both as an example of an agricultural river basin, with many navigation works, such as locks and weirs and mills affecting the flow of water, and many towns and some manufactories discharging their sewage and refuse into the stream from which is mainly derived the water supply of the metropolis.

Second. The Mersey Valley — including its feeders, particularly the Irwell, as an example of the river basin most extensively polluted by all forms of manufacturing refuse, particularly that arising from the cotton manufacture and processes connected therewith.

Third. The Aire and Calder Basin, as an additional example of the same class, particularly in connection with the woolen and iron manufactories.

Fourth. The Severn Basin, for the same reason, but in particular connection with the great seats of the iron trade.

Fifth. The Taff Valley, in connection with mining and industry applied to metals.

Sixth. A river basin comprising a mining district in Cornwall.

Your special points of inquiry should, it is conceived, be in the Thames Valley. (1) The condition of the river as affected by mills, weirs, and locks, and as affecting the drainage of towns and villages and adjacent lands. (2) The condition of the river, as affected both by the drainage of sewage from towns and villages, and the refuse of manufactories, paper mills, etc., and the possibility of intercepting and rendering useful or innocuous these sources of pollution.

As to the other rivers mentioned, the main object of the inquiry should be how far the use or abuse of the rivers is, under present circumstances, essential to the carrying on the industry of these districts, how far by new arrangements the refuse arising from industrial processes in these districts can be kept out of the streams, or rendered harmless before it reaches them, or utilized or got rid of otherwise than by discharge into running waters. In the course of these investigations you will make inquiry into the effect on health and comfort of the existing system of sewage of towns and populous places in the districts examined, and into the best mode of protecting individual and public interests in the purity of running water.

Secondary questions will, no doubt, arise contingent on these leading points, in which case you will include them, as far as it is necessary, within the scope of your inquiry.

I am, etc.,
(Signed) H. WADDINGTON.

R. Rawlinson, Esq.,
J. T. Harrison, Esq.,
J. T. Way, Esq.,
Commissioners to inquire into the Pollution of Rivers.

RECOMMENDATIONS

We also humbly submit the following Recommendations to Your Majesty:

That the whole river be placed under the superintendence of one governing body.

That this body be the existing Conservancy Board, provided that the Board receive an addition of an adequate number of representatives of the local interests of the Upper Thames; and such representatives to be elected by the persons who now constitute the Thames Commissioners.

That, after the lapse of a period to be allowed for the alteration of existing arrangements, it be made unlawful for any Sewage, unless the same has been passed over land so as to become purified, or for any injurious refuse from paper-mills, tanneries, and other works, to be cast into the Thames between Cricklade and the commencement of the Metropolitan sewerage system, and that any person offending in this respect be made liable to penalties to be recovered summarily.

That it be made incumbent upon the Conservators to see to the enforcement of the above prohibitions against pollution of the river, and that for this purpose power be given to them to visit and inspect works and, after due notice, to close the outlets of sewers, drains, and discharge-pipes into the river within the limits described in the last preceding recommendation.

That, subject to proper safeguards to prevent abuse, powers be given to local authorities to take land compulsorily for the purpose of sewage irrigation, to an extent not exceeding one acre for every fifty persons whose sewage is to be applied.

That the Upper Navigation from Lechlade to Staines be put into good working order, and so maintained.

That the rights of private persons to take tolls at locks no longer used for the navigation be abolished, and that the property in all weirs on the Thames now belonging to private persons, together with the liability to maintain the same weirs, be transferred to the Conservators.

That all fishing rights which interfere with the level or free flow of the river be abolished, with such compensation as may be settled by Parliament.

That the Conservators be empowered to levy upon all Waterworks, taking water for domestic or trade purposes from the River Thames, a rental in proportion to the volume abstracted; the maximum of such rental to be named by Parliament.

That the Conservators be empowered to borrow the necessary money for the restoration and maintenance of the Upper Thames. That in order to provide adequate security for money so to be borrowed, the Conservators be authorized to give a first charge upon the future revenue of the Upper Navigation to the postponement of the existing bonds, and to pledge, as collateral securities, the rental above mentioned upon the Waterworks and also the revenue of the Lower Navigation.

That upon the aforesaid security the Public Works Loan Commissioners be authorized to make advances to the Conservators.

That powers be given to the Conservators to compound with the holders of existing bonds on the Upper Navigation.

That powers be given to the Conservators to make Embankments throughout the valley of the Thames, and carry out arterial drainage operations, the cost of such improvements to be met by a tax upon the properties so improved.

All which we humbly certify to Your Majesty, under our hands and seals.

(Signed)

ROBERT RAWLINSON.
JOHN THORNHILL HARRISON.
J. THOMAS WAY.

GODFREY LUSHINGTON,
Secretary.

March 29, 1866.[1]

From a chemical standpoint, any discussion of pure water, or of water of sufficient purity to be used for a town supply, almost of necessity involves, first, a discussion of the pollution to which water is liable and the means of prevention of such pollution.

The most immediately dangerous wastes of human life, as is conceded by present-day sanitary theory, are those included in the term *sewage*. " Straight," or domestic, sewage, the outflow of sink, laundry tub, bath tub, and water-closet is a water carrying only about 1 per cent of extraneous matter, but many millions of bacteria, some of them probably harmful along with products of decomposition that *may* be deleterious. At least,

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[1] From First Report of the Commissioners appointed to inquire into The Best Means of Preventing the Pollution of Rivers (River Thames), Vol. I, pages 4 and 32–33.

having passed through the body once, they are not desirable for a second drinking.

On the 6th of April, 1872, the State Board of Health of Massachusetts was instructed by an order of the legislature to collect information concerning sewage and the possibility of utilizing it; the pollution of streams and the water supply of towns, and to make report at the next session. Dr. Henry I. Bowditch, the Chairman of the Board, writes in the next year: "There is no single subject that is attracting more attention in England, and which excites more heated partisanship, than the vast question looming up under the various names of 'earth-closet,' 'water-closet,' 'sewage,' 'its dangers to health,' 'its utilization as a manure,' etc. In other words, the great sanitary question of the day, 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."[1]

He goes on to describe the excitement caused by these discussions at the meeting of the British Association of that year, at Liverpool, under the presidency of Huxley, and remarks that "they had to be *repressed* in the various sections." Also, "The chemist kept the discussion simply to the chemical aspects of the question, and all engineering or simply sanitary ideas were sedulously kept away. They had, strictly speaking, no right in the laboratory." His description of the "partisan violence" and the "language worthy of Billingsgate" which he heard on this occasion is very amusing. However much sanitarians differ to-day they do not vilify each other to such an extent.

Only farmhouses, country estates, and institutions furnish the simple problem of domestic sewage disposal. All factory villages, towns, and cities add another or several other elements in the shape of what are technically known as trade wastes; that is, water used in washing wool, acid pickling liquor for iron, paper-mill and silk-mill washing water, wastes

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[1] Second Report, 1871, p. 233.

from gas works, and a thousand other industries each adding its quota to a modern city sewage and increasing one hundredfold the difficulty of treatment. City sewage is this mixed liquid with its ½ per cent of house sewage and 1 or more per cent of trade wastes. There is borne along by the water at times considerable solid material which should be screened out by somewhat finer screens than those commonly used and the collection burned.

The disposal of the remaining liquid is the great sanitary problem of the day, not merely for the present but for the future protection of the soil and the sea.

A study of any tables of sewage analysis will show that, in America at least, the flow is one of dirty water only, carrying putrescible organic matter to a less extent, as a rule, than it carries products already in a state of decomposition as indicated by both the chemical results and the bacterial count.

Thus a sewage carries 100 to 200 parts per million of combustible organic substances, of which albuminoid ammonia is 5 to 10 parts, free ammonia 15 to 30 parts, while the chlorine also is 5 to 10 parts.

The activity of the changes is indicated by the large number of bacteria, one to two million per cubic centimeter being common. If these were all pathogenic bacteria, the test would be easy, but most of them are simple scavengers doing their work like orderly citizens. They work on carbonaceous as well as nitrogenous matter, but the decomposition of the latter is held to give rise to the more objectionable feature.

Sewage carries both soluble and insoluble substances. A portion of the insoluble may become soluble through decomposition in a few hours, while the rest is of more permanent character. It is usually held to be sufficient to secure the decomposition of the ready material and the removal of the rest by sedimentation or straining.

This decomposition may be materially hastened by a temperature favorable to the growth of the agents, *i.e.* incubation.

The removal of the insoluble may be hastened by straining, and this may be facilitated by coagulation, which acts like a fine drag-net to collect and hold together the suspended particles which are to be disposed of.

Purification of this dirty water means, therefore, the removal of the contamination or conversion of possibly dangerous into harmless substances.

Removal of substances in suspension in any liquid may be accomplished by filtration through mediums sufficiently impervious. Any substances which can be made insoluble by chemical interchange may be removed, but other substances are usually left in solution to replace those taken out.

The permanently soluble substances may be changed into others by various processes. Thus sugar, by the process of fermentation, may be decomposed into alcohol and carbon dioxide, the alcohol into water and carbon dioxide.

If a manufacturer should come to a carpenter's office and ask to have a tank of certain dimensions built for him and should specify just a wooden tank, no matter what it is to be used for, the carpenter would be put in a dilemma approaching that which confronts the chemical or sanitary engineer when he is asked to plan a treatment for sewage — just sewage. As there are 100 kinds of woods on the market, all varying in resistance to decay, to acids, etc., so there are a thousand varieties of sewage (dirty water), and no two alike, especially in America, where so diverse habits and conditions rule.

The chemist has been very meek and has allowed himself to be browbeaten into pacifying the public demand with barren results for the most part. Instead of studying one problem at one place (which was the secret of the success at Lawrence) each new commission sent a man to Europe to see how the problem was solved there, but he came home more muddled than enlightened because he did not go back of the sewage to the elements, especially to the *water* used in the original supply.

The so-called putrescibility tests serve to distinguish between the most unstable agents of decomposition. The plants or enzymes that attack cellulose and woody tissues require different conditions for work from those that break up unstable nitrogenous substances; hence, real purification goes on in stages, the cleavage indicated in the reactions as taking place with little oxygen in the presence of water.

Oxidation follows, with elimination of odors, and slow "retting," as in the case of flax, goes on wherever the solids may be, — in the interstices of the filter, or on the side or bottom of the stream, or in the soil of the filter bed.

There is no mystery about it. The work in each case is a balancing of many factors; the trouble is that the operator may not have all the facts at hand. The smaller the purification plant the more effect, if all the housewives chance to wash their blankets the same day or the bakeries get a lot of bad bread sponge and send it down the sewer. Yeast is a constant in city sewage.

In a large city there is less variation. Treatment to avoid nuisance may be made to run very regularly, but slack water will occur downstream, and the works must expect to watch for times of trouble.

If the treatment is on land, there must be no miniature settling basins at the outflow where the slowly changing solid particles may set up unpleasant fermentations. It is in little points like these that care is needed to obviate prejudice against sewage treatment.

In the case of hospital sewage and in times of epidemic when many disinfectants are used some trouble may be experienced, some interference with regular working. It is probable that most of these can be overcome by dilution, but an extra intercepting tank may be put into commission for a time and the solid contents passed through fire. This would be a profitable sanitary measure.

For details see Reports of Experts and current literature. In so active a topic any special process is out of date before the ink describing it is dry.

In common law each owner of land is held to own certain property rights to any water flowing through his land. He may use the water in any manner and for any purpose he chooses, providing he does not so alter its quality or decrease its quantity as to damage the interests of the man lower down the stream, a man with similar rights.

An appeal to the right of eminent domain has of late years, since the rise of large cities, been successfully made. Some decisions are in direct contradiction, since rights are taken from the few for the benefit of thousands.

Statutory law covering water rights is usually based upon the premise of nuisance, although in some states the sanitary interests of the people downstream are made the basis.[1]

It is usually held that underground water goes with the soil, and that rights may be bought and sold; that even if a neighbor's supply is cut off he has no redress unless it was so nominated in the bond; but, on the other hand, a man's neighbor is not permitted to place anything on his own land which by percolation shall injure the potability of the other man's well.

For a compilation of decisions in common law and of the state statutes, see U. S. Geol. Survey, Water-Supply and Irrigation, Paper No. 103, 1904. For later records of many decisions of eminent jurists, see files of engineering publications. More than half the states now have some legal basis for water users.

The Blackstone River and its tributaries offer one of the best examples of improvement of streams by dilution and sedimentation.

The accompanying sketch map with the drainage areas much compressed, but in relative position, taken together with the table of analyses, shows the influence of mixture of waters.

In 1872 the State Board of Health reported, "The day may not be in very remote future when the legitimate use of the river in manufacturing operations may call for an injunction upon its use as a carrier of sewage." It was then suggested that the city of Worcester should attempt land treatment. It

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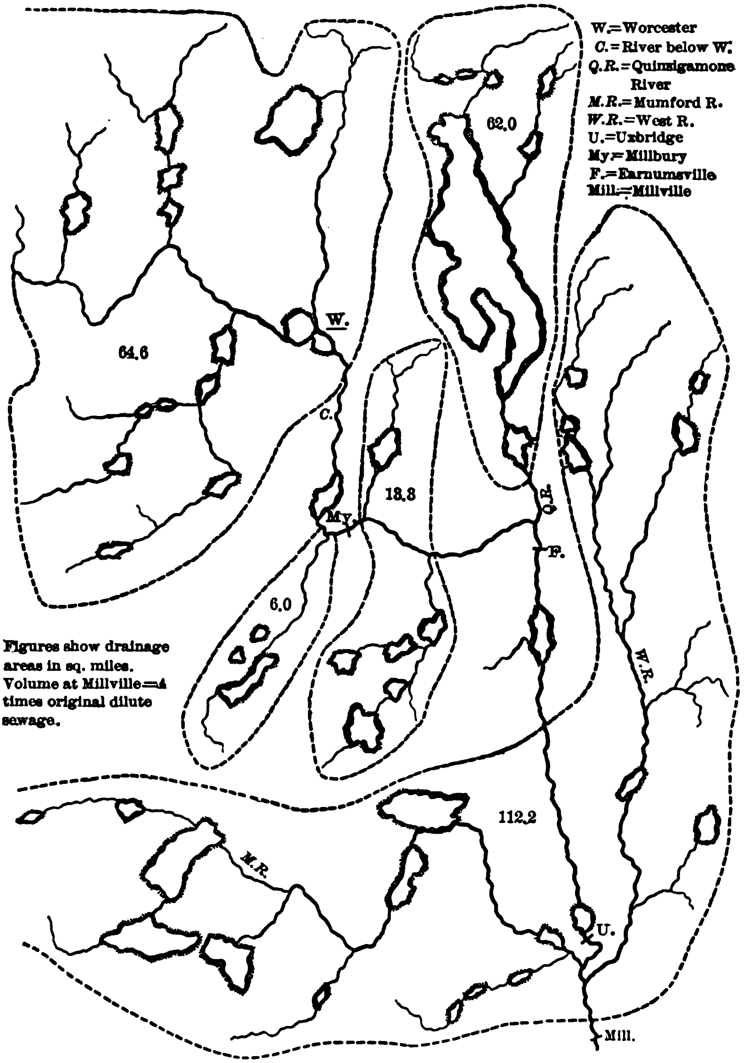
[1] Page 199, Montana River pollution law. Untreated sewage cannot be discharged into Yellowstone River within four miles of a potable water intake.

would however require 1000 acres at a rate of 3300 persons to the acre and the estimated value was only .861 of a cent per ton.

MAP OF BLACKSTONE VALLEY.



Until about 1890 the river water at Blackstone was readily drunk by horses, and the stablemen noticed little change except in the very dry year of 1871, when the horses refused to drink.

In 1886 the Legislature directed the city to purify its sewage before discharging it into the river. This they began to do in 1890, by treating a portion with chemicals.

In 1891 the State Board of Health made a series of tests to determine the extent of the purification. The results are given in the table. Only about 50 per cent of the organic matter was removed and the results were not satisfactory. The problem was made more difficult by the rapid increase of the city in both population and manufacturing establishments so that the precipitation works were outgrown as soon as built. Not until land treatment was added to the plant did anything like a satisfactory condition of the river in its lower reaches exist because the organic matter was continually carried farther and farther down the stream and the precipitated sludge which accumulated was liable to be disturbed and cause nuisance. The forty years' experience on the problem of sewage disposal of a growing city into a small inland stream is very instructive and well worth a careful study.

Haste in introducing new schemes without full knowledge of previous results sometimes leads to needless expense in rectifying mistakes.

The modern method of moving this waste from house to stream is by the use of abundant water, so that the resulting liquid contains about .5 per cent of substance other than water.

In one way it is this very dilution, which allows the chemical processes to go on freely, which has saved us so far, for there has heretofore been less danger from water carriage than from cesspools. But now the danger is increasing, due to the greater luxury of life, the loading of the sewers with garbage, etc., and the denser population.

Therefore, the *scientific* interest in this side of the question is largely centered on the *purification* of this dirty water, and the *economical* interest in the *utilization* of the valuable material now going for the most part into the sea.

ANALYSIS BLACKSTONE VALLEY WATER

Average of Special 7-day Examples. Parts per 1,000,000

Locality.	Turbidity.	Odor.	Albuminoid ammonia.		Free ammonia.	Nitrites.	Cl.	Fe_2O_3.	CaO.	SO_3.	Total solids.
			Total.	In solution.							
C (1891)	......	......	1.869	0.780	6.223	.052	24.8	35.2	43.3	76.2	359.0
(1895)	rusty, milky	offensive	2.128	1.670	7.574	.105	35.2	20.5	20.5	118.0	394.1
[1] (1903)	......	......	1.080	0.545	3.880	.062	29.7	......	......	......	310.8
F (1891)	decided	musty	.325	.230	5.410	.003	9.4	2.3	18.2	30.0	90.0
(1895)	distinct	musty	.475	.400	6.150	.081	24.5	0.9	55.4	78.2	227.0
Q. R. (1895)	slight	vegetable	.232	.210	.012	.002	3.6	0.3	6.9	3.7	48.5
U (1891)	slight	vegetable	.345	.271	2.506	.004	8.7	1.7	19.9	34.3	110.7
(1895)	slight	musty	.223	.181	6.947	.064	17.5	0.7	34.4	40.7	165.0
[1] (1903)	......	......	.262	.215	3.030	.024	17.4	......	......	......	131.6
W. R. (1895)	distinct	vegetable	.235	.198	.016	.003	2.5	1.5	5.5	3.1	37.4
Mill (1891)	slight	vegetable	.214	.163	.873	.002	5.2	1.2	11.2	17.5	73.9
(1895)	slight	vegetable	.205	.178	.298	.018	11.3	0.8	20.6	24.1	107.9
[1] (1903)	......	......	.233	.189	1.397	.013	11.0	......	......	......	84.6

[1] Average of 6 months.

Letters denoting localities refer to map.

This represents a value of possibly $2 an individual a year, or for a town of 30,000, some $60,000.

What is it, then, that we wish to get rid of before we allow this fluid to go into the streams?

First. Insoluble matter, earthy material from the soil and streets, fragments of cotton, woody fiber, leather, and débris of life generally. This can be taken out by various means: (*a*) by sedimentation; this class of matter largely subsides if left to itself, but it takes too long; (*b*) by rough filtration, or screening, but besides the greasiness, the filter or screen has a tendency to clog up, due to the growth of organisms. A thick felt, like mother of vinegar, soon clogs up the spaces, and all such filters and screens need close attention. If they can be left to themselves to dry in the air[1] this will disappear and the filter can be used again. This takes room and time, and we wish to get rid of these things as soon as possible, so we add something which will form a clot at once.

Alum, which gives up its sulphuric acid to the other minerals, liberates a gelatinous mass which entangles all suspended matter, clay, bacteria, etc., and gives a clean, brilliant filtrate. Expense is one objection; the addition of so much sulphuric acid to water which may be needed for boilers and other manufacturing purposes is another. Alum is valuable in that it does take out and hold some of the ammonia, providing it is used without lime or soda.

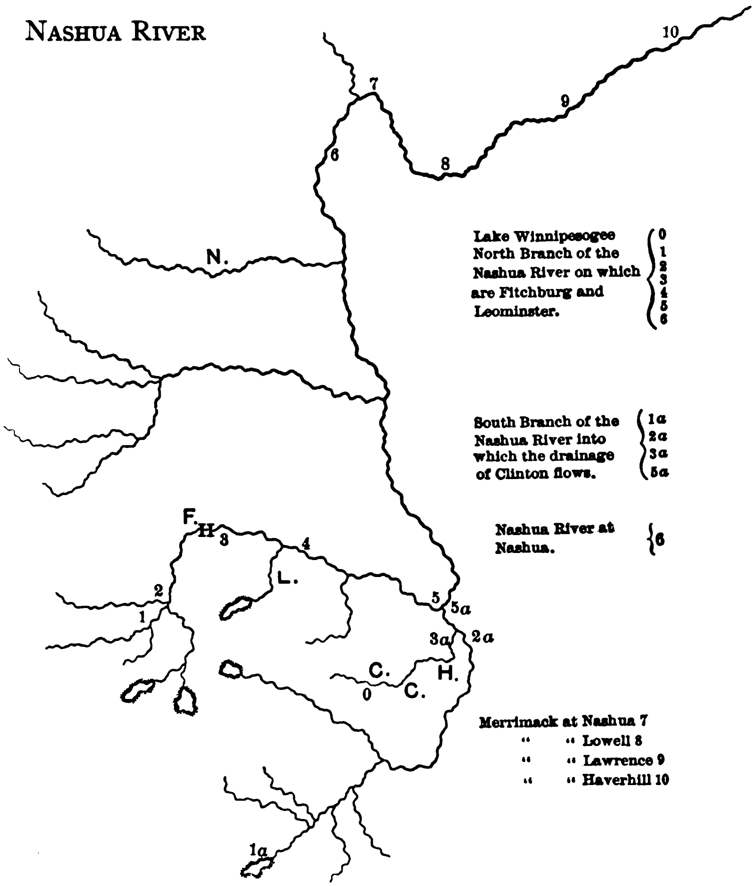
Caustic lime unites with the carbonic acid and precipitates out. Lime always increases the odor and ammonia and makes a most objectionable filtrate. Even just lime enough to neutralize the liberated acid from alum and to precipitate the aluminum hydrate is objectionable for boilers. The A B C method, using alum, blood, clay, and charcoal, proposed about 1870, was one of the earliest attempts at purification.

Intermittent, downward filtration was even then considered as the best process, and an opinion was given that this would be the best plan for Worcester.

[1] Waring, Newport Experiment above.

Neither from an engineering nor from a sanitary standpoint does it seem necessary to spend much time discussing chemical purification of sewage, since we know no practical means of rendering insoluble the ammonia, the chlorine, the nitrites, or the nitrates, and therefore we will leave that to the future chemist.

NASHUA RIVER



The possibility of taking nature's way of purification is admirably illustrated at Lawrence and at Framingham. The chemical side is very simple. Given the living organism, and the right amount of air and food, the operation is complete, but like all life processes, there is danger of over-feeding and under-aeration; one of the chief troubles with human beings. The manipulation requires the engineer as well as the chemist, or better, the engineer-chemist. Therefore the more carefully the methods and the principles illustrated in these fields are studied the better.

ILLUSTRATION OF POLLUTION AND PURIFICATION OF STREAMS
Average for 1887, 1888, and 1889

	Color.	Total solids.	Albuminoid ammonia.		Free ammonia.	Nitrites.	Nitrates.	Chlorine.
			Total.	In solution.				
0	0.1	2.12	.0092	.0085	.0003	.0000	.0038	.12
1	0.40	3.55	.0168	....	.0016	.0002	.0070	.17
2	0.10	6.65	.0168	....	.0004	.0001	.0050	.39
3	1.00	10.09	.0580	.0419	.0326	.0014	.0125	.83
4	0.60	8.50	.0340	.0257	.0243	.0014	.0125	.76
5	0.56	7.47	.0287	.0261	.0118	.0002	.0251	.72
1*a*	0.15	3.95	.0202	.0138	.0020	.0003	.0070	.28
2*a*	0.20	3.87	.0188	.0147	.0013	.0003	.0075	.30
3*a*	0.29	9.75	.0659	.0187	.1955	.0083	.0190	.98
5*a*	0.20	4.91	.0230	.0173	.0264	.0008	.0192	.38
N.	0.50	3.95	.0120	.0108	.0000	.0001	.0030	.17
6	0.50	5.50	.0300	.0254	.0096	.0007	.0120	.40
7	0.34	5.01	.0153	.0131	.0014	.0002	.0074	.15
8	0.32	5.40	.0171	.0128	.0014	.0002	.0078	.16
9	0.33	4.75	.0180	.0139	.0023	.0003	.0091	.18
10	0.34	5.99	.0201	.0158	.0025	.0003	.0094	.19

NASHUA RIVER. (See Map.)

It is of consequence at this stage of our inquiry to examine the claims that there is no need of all this trouble and expense; that the flowing river or stream purifies itself in a few miles, and that this is manifestly nature's way of getting rid of objectionable matter.

One of the best pieces of work done in the way of investigating dilutions as to time and flow, was the investigation of the branches of the Nashua River in 1891, October 12–15. The sketch and figures are shown. Unfortunately, rain interfered with further work and there are gaps.

Volume of the Merrimac at Nashua is forty times the Nashua.
Velocity, 86 cu. feet per second, N. Branch.
55 cu. feet per second, S. Branch.

Tributaries add about 150 feet per second at Nashua.
The Merrimac yields 6000 feet per second at Lowell.

As is natural in a manufacturing region where soda ash, alum, sulphuric acid, etc., are so largely used, the total solids increase more than the chlorine, which comes largely from population, and such is the effect of coagulation and precipitation that they are really less at Lawrence.

Examine the two indications of *recent* pollution, ammonia and nitrites. 1, 2, 1a and 2a are very low in both, while 3, 4 and 3a are very high in both; 5 and 5a both show the effect of pollution more than any other. Compare them with 2, for instance, which has more chlorine than 5a, and with 2a, which has nearly as much.

And now comes the crucial test. Can one tell at 6 if there *has been* pollution after these many tributaries of comparatively good water have mingled and after the many miles of flow?

Number 6 will bear a critical study, for we see here the relative value of the tests for nitrites and ammonia. Both indicate, without question, contamination with chlorine far above normal. The total albuminoid ammonia is higher than in the contributing streams, colored water coming in and suspended matters being carried along.

The problem of waste is quite as serious in water supply as in other things. Like all organic wastes liable to putrefaction, water-borne wastes are hastened beyond reach by as great a flow as possible. If each town or city was a question by itself, there would be as little sanitary problem as there was when the savage moved his tent, or the early settler dwelt alone.

To-day there is always some one *below*, *beyond*, another city to be considered, other interests to be adjusted. This is one of the places where the kind of social sense of the sanitary engineer spoken of on page 290 comes to the front. The larger problem of the number of communities affected must come into the discussion of any one community's needs.

A large part of water trouble has come into existence since water carriage of house and city wastes.

The wastes are quickly taken from the place of origin, but are only too often distributed over a wide area and allowed to become offensive as well as dangerous.

To-day the problem is the bringing state and federal law into action to prevent selfish interests from interfering with the rights of others.

Standards for discharge in potable waters must include organic matter as food as well as present vegetable bacteria. No practicable treatment pretends to remove all the spores.

For immediate use this does not particularly matter, but for traveling a distance and for mingling with other waters these latent organisms have to be dealt with.

For this reason, simple filtration fails and sterilization is resorted to. These bodies are very resistent, however, as the preservation of the species demands, and the process of complete sterilization is an expensive one.

So that it is economically indicated that wastes be kept out of potable waters, or at least that they be forced to undergo the long, slow treatment where time takes the place of elaborate machinery.

Some of the most vital conservation problems are right here. The disposal of wastes without nuisance is a possibility, but also an expense, much of which is to be overcome by engineering skill. Some chemical problems are to be worked out in each case, but the methods of handling are of great importance.

The largest problems of the immediate future are those of the large cities on the seashore. While they were small and the volume per capita moderate, it went without saying that the ocean was the place for their wastes; but to-day they are a serious menace to all the shores — a nuisance, if not a menace, to health.

A city like New York must undoubtedly treat its wastes. The sands of Long Island offer opportunities, if utilized soon.

The sands of Cape Cod lie ready for Boston's wastes.

UTILIZATION

That man who thinks at all, who is a student and an observer, is at heart an economist. He believes, knows, that there is only so much material of a certain sort available on the earth, under the earth, over the earth, and he believes, if he thinks at all, that man's brain and inventive power have a duty in making the most of these materials. In so many directions wastes have proved immensely profitable when recovered that it is quite *en rapport* that the value of wastes, of human activity, should have been closely calculated, and now that intensive farming is talked of and beginning to be practiced, the utilization of all this water as water obtained at such cost comes into view with greater force than when the nitrogen value only was considered. All sanitarians have agreed that utilization is desirable, but few have been willing to say that it is practicable. A few opinions are interesting to show the progress of the sanitary idea.

"The utilization or '*beworthing*' of waste material of every sort is of equal interest to the political economist and to the sanitarian. To one it is a direct saving of money; to the other a saving of health and of life, both of which have a true money value.

. . . . . .

"We must never despair of success in the search for the means of converting our waste into useful and harmless products, however great may be the difficulties in the way.

"Obstacles which now seem well-nigh insuperable may be expected to become less formidable and at last to disappear before the advance of science and of skill. It is no exaggeration to say that this problem of the conversion of the excremental waste of towns and people, and the refuse of factories, into useful materials, is now engaging as much of the attention of intelligent minds throughout the world as any social question.

"Sewage irrigation is no novelty. In Italy, in the neighborhood of Milan, sewage has long been used for purposes of irrigation, and the Craigentinny meadows, in the neighborhood of Edinburgh, have been treated with sewage for many years. At Milan the liquid refuse of the city is collected in large sewers which join one another and meet in a canal called the 'Vettabbia.' This is made to ramify and serve for the irrigation of about four thousand acres of land, after which it falls into the river Lambro, about ten miles below the city. The amount of sewage supplied to the land is at about the rate of the liquid refuse of forty persons to the acre. The land irrigated with sewage is devoted mainly to the cultivation of grass, and the crops are superior to those raised upon neighboring lands which are irrigated with water simply."[1]

Although eastern nations far back in history made use of wastes in the cultivation of crops, the English-speaking peoples, from a variety of causes, partly psychological, seem to have been prejudiced against such use.

In the revival of altruism which has been noticed (Chap. V), the students of waste disposal spoke in no uncertain terms of the use of the land as the logical and scientific measure.

But in England the introduction of water carriage and the attempt to utilize the waste water in land cultivation failed for two chief reasons — too much return was expected, and the soil tried was most unsuitable. In America a Puritan prudery, together with the ease with which running water could be made serviceable, kept the experiments in the background. If there was no profit in sewage farming why undertake it — at least until forced to do so. The early students in Massachusetts spoke with no uncertain sound. In the chemical experiments of the Massachusetts Board of Health at Lawrence, the firm belief of Mr. Hiram F. Mills that Nature's processes were worthy of imitation led to the practical application of principles of purification which showed why the English failed and what

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[1] From Fourth Annual Report, Massachusetts State Board of Health, January, 1873, "Sewerage; Sewage; The Pollution of Streams; The Water Supply of Towns."

were the elements of success. They only pointed the way, however. Few trials have been made, and those mostly unsuccessful. The cities of Paris and Berlin partly use the sewage on cultivated lands, but they are not recovering more than half the value.

In an address quoted in *Science*, August 1, 1902, by a distinguished chemist, occurs this statement: "Sewage farming and chemical treatment are now considered as methods of the past."

Intermittent filtration without utilization is held as the only practicable means of sewage disposal. This theory takes no account of the nitrates which escape to be used as food lower down the stream and which may cause serious trouble, and therefore it is well to emphasize the fact that utilization is possible under favoring conditions and that, given the belief in its element of conservation, a way will be found to make it more practicable.

As an example of what is possible under favoring conditions may be cited the broad irrigation plan in use for fifteen years at Vassar College, Poughkeepsie, N.Y. The whole scheme was worked up as a method of disposal, not of profitable farming. That it has been profitable is due to the excellent quality of the soil and to the favoring topography of a plot of available ground. Natural drainage gullies existed on either side of the field of ten acres.

The four essentials are:

1. The soil.
2. The topography.
3. The plant.
4. The results.

VASSAR COLLEGE SEWAGE FARM

The soil is a rich brown color and, with the exception of a few stones, passes through a 30-mesh sieve. It holds 52.8 per cent moisture. The fine holds 75.6 per cent.

Eleven acres can be irrigated by radial ditches from the pipe outlets.

ANALYSIS OF THE SOIL

Parts per 1,000,000

Sieve mesh.	Per cent passing through.	Humic acid, per cent.	Color ammonia solution.	Parts per 1,000,000.	
				Loss on ignition.	Oxygen consumed.
30	100	1.51	18.5	55	69.7
40	12.1	1.03	18.5	60	70.9
60	28.8	1.60	13.9	53	....
80	12.6	1.78	12.5	....	59.8
100	17.7	....	11.7	48	....
120	8.5	....	13.5	....	....
170	16.6	2.66	25.0	84	116.6

The filter beds are used only at planting time, and in winter if necessary because of frozen ground.

About 56,000 gallons of sewage daily were pumped during February and March of the first winter, 1896.

Total cost of the works, including engineering expenses and preliminary reports upon system of disposal to adopt, was $7500.

About 100,000 gallons of sewage are pumped daily from September 10 to June 10, approximately, with no offense when properly cared for.

ANALYSIS OF STEAM RECEIVING EFFLUENT FROM BEDS

Parts per 1,000,000

Date	Solids	Alb. Amm.	Free Amm.	Nitrites	Nitrates	Chlorine
September 30, 1895	142.0	.122	.094	.010	.300	5.0
October 14, 1895	198.0	.276	.192	.033	1.000	8.0
December 17, 1895	123.0	.082	.090	.006	.530	2.4
April 16, 1896	150.0	.122	.014	.004	.500	4.0
May 28, 1896	141.5	.112	.048	.011	.400	6.8
September 16, 1896	153.0	.940	.148	.030	.400	6.2
November 21, 1896	177.0	.094	.030	.002	.800	10.6
April 14, 1897	—	.072	.014	.006	.400	6.0
November 12, 1897	210.0	.102	.042	.005	.850	11.1
September 30, 1898	235.0	.182	.018	.010	2.000	15.6
December 3, 1904	—	.064	.060	.007	2.650	13.8
October 13, 1905	210.0	.216	.034	.008	1.000	8.2
December 26, 1905	231.0	.042	.092	.003	8.000	11.0
December 12, 1908	—	.053	.054	.0012	3.000	2.80

The crop is silo corn, giving a yield of fifty tons to the acre at the end of ten years, double that from the field the first two years. The slow effect on the water of the stream receiving the drainage is seen in the preceding table selected from the records of the whole time.

Not every city has the right soil and other conditions. Massachusetts has many square miles of sandy areas admirably adapted for intensive farming when treated with the now wasted water of its metropolitan sewage. In time this economy will replace the almost unbearable condition of its harbor water. New York may have more difficulty, but probably land will be found when the requirements are studied more sympathetically.

All methods of land disposal are liable to the accusation of polluting underground supplies. There is a vigorous protest being made against the new sewage farms near Paris. All the local wells are infected, and there is an epidemic of intestinal troubles. The sewage seems to escape between fissures in the soil into subterranean sources of supply to the wells (*Scientific American*, Feb. 17, 1900). It would seem wiser to take out as much of the food value as possible.

This saturation of the soil by inland farms and towns can hardly be prevented unless the used water is diverted to another watershed and so taken to the sea. This is not often practicable.

There is also, in the near future, to be a common agreement to combine in the use of public supplies, abandoning the private wells to their fate. It would seem to be the wise solution of many problems. Much opposition to sanitary reforms comes from the clinging to traditional habits under new conditions.

The ancestral well is reverenced as devotedly as grandmother's china. The pasture spring bubbling up from white sand *must* be pure.

The argument for cropping the sewage field is that so long as water carries food it will feed plants the moment conditions are favorable. The air is supplied with spores of the plankton or rootless plants, etc.; the earth is full of seeds, and as soon as the nitrate and carbonate-bearing water comes to the light, green growth begins. This may clog the watercourse and may be of such a nature as to cause offensive odors, or only to become a nuisance.

An effluent is not *purified*, restored to its pristine condition, so long as it is capable of causing a nuisance. It is no argument to say that most wells and many bottled waters are in this condition. They are not let loose on the land.

Management of arable land may be safe, even though the effluent always shows chlorine and high solids.

CHAPTER XII

TREATMENT OF VARIOUS WASTES

A. DILUTION AND SCREENING MAY BE SUFFICIENT FOR ÆSTHETIC REASONS. B. CHEMICAL TREATMENT MAY BE NEEDED FOR SANITARY REASONS. C. BIOLOGIC TREATMENT AND SAND FILTRATION FOR DIRECT POTABILITY

CIVILIZED man demands some kind of treatment for his waste of daily living. Nomad tribes simply tossed the bones over the shoulder and moved off when the refuse heap was too high. Nature's process and the dry air of the regions frequented by such tribes in tropic or arctic latitudes in time took care of residues.

But when man settled into permanent habitation, the disposal of waste became another matter. The rural dweller has still so much space that he leaves wagons and plows, bones and refuse piles, an unsightly ring around his habitation. He allows sink and barnyard waste to cross his daily path. As a matter of course, it is not offensive to him, for it does not mean either indecency or disease.

Both the crowding of his neighbors and his education in propriety and value of order and tidiness have so developed the sensibility of civilized man to dirt and refuse that he removes them from sight for æsthetic reasons. It has happened more than once that as far as health was concerned the dirt would have been less harmful if left exposed.

A TREATMENT FOR ÆSTHETIC REASONS

The farmhouse drain, the surface gutter of the city, the foul brook from a starch factory or creamery, have been hidden or cleaned because of this æsthetic sense rather than from a belief in the danger to animals and children from wading in them. The suggestion of unpleasant processes had more effect than fear of danger.

As refinement of language and living increases, city streets become cleaner, back yards blossom, and beaches and harbors are relieved of their burden of wastes.

What this treatment (of waste waters) shall consist of is governed largely by the prominence of one of the three chief reasons for improvement — æsthetic, sanitary (nuisance), and potable — of the mixed water.

The waste from a starch factory may be white, milky, soon fermenting to a bubbly froth, or a water offensive to the eye, that from dye works may discharge a red or blue liquor equally unsatisfying to the eye.

The waste from glue works or a canning factory, even in small amounts, may collect on the bank, forming a mass repulsive to the eye and yielding vile odors offensive to the nose, polluting air as well as water; or a small drain from a house may carry imperceptible wastes into a large body of water and on occasion infect a large area.

On a known principle of psychology, the nose is most quickly offended by disagreeable influences, — a deeply implanted inheritance of a pre-scientific race.

After experience with refuse piles, one soon becomes convinced that the disposal by fire should have been resorted to. If even the dry refuse were burned, it would lessen the amount now unnecessarily soaked in water only to be dried out again.

For all these reasons, the *Inspection Service* is to be largely increased in the future — a real inspection backed up by laboratory and testing works.

Pipe lines are no longer experiments; distribution, drainage, and all the paraphernalia of irrigation are more or less understood. The one error will be in assuming without trial that wastes can be made to pay for themselves.

The experience in England in 1869–70 shows that failure is easy. On the other hand, if the sanitary side is taken as the object, the rest is clear gain.

No interference with Nature's processes is made without a penalty. The diversion of flowing water to do man's work for him lays upon him the obligation to return that water in good condition.

A very great difficulty in treatment of wastes is their volume.

The work of the immediate future will lie in the direction of treatment before dilution, that is, of the wastes at their source instead of miles away, after many other elements have complicated the problem. To be sure, other wastes may enter the stream to neutralize the effect of the first. Self-purification has been a familiar battle ground, but with newer chemicals and more changeable processes these conditions are too unstable to be relied upon.

A record book should be kept, where past experiences may suggest reasons for inexplicable conditions. In such complicated matters underground, out of sight out of mind, the real causes are often difficult to ferret out. A detective mind must be included in the outfit.

Hence the engineer must have at hand a laboratory outfit. This need not be as elaborate as the chemist's. As has been said, it is water *assay* rather than water *analysis* in the old sense that the sanitary engineer needs. He should, however, be trained to make the most of simple apparatus in the shortest time, since time is to-day the dearest commodity known to man.

For a more permanent laboratory, the writer has always advocated one at a university where special problems, either chemical or bacteriological or engineering, can be submitted to experts.

The sanitary engineer of the immediate future will have the broad oversight of all contributing applications of science.

Water carriage increased the unæsthetic character of watercourses, and as demands increased and standards rose, many streams became, to modern eyes, offensive in fact or by suggestion.

To-day such refuse must be kept out of streams by such means as were indicated in the previous chapter, — cremation and earth filtration, — or by some chemical or hastening process.

City sewage is, as we have seen, so dilute that it is only when the body of water is small or refuse other than sewage proper — garbage — is mixed with it, that it becomes a nuisance.

The great group of objectionable wastes from the æsthetic point of view is composed of those from the trades. These wastes often give rise to odors more or less disagreeable because suggestive. Man is affected most quickly through his sense of smell. The educated nose is the best detector of uncleanness or of leaking fixture, gas or sewer.

Such wastes, therefore, as give rise to odors, even if harmless, are the first to be disposed of. It is for that reason that dilution above referred to is so popular, and for that reason also that many treatments are barred, for the peculiar odors developed are held by the neighbors to be a menace to health because they are peculiar. Cremation of refuse was long delayed because of the occasional accompanying odors. But the public is now awake to the beauty of tidiness and order, and is beginning to recognize the dangers from loose papers in the streets and floating refuse in the brooks. It is ready to keep out of watercourses all that is possible, and for such as are now loaded, to use the process of screening and subsequent cremation, coagulation, fine screening, cremation, as a remedy for most of these troubles.

B. Treatment for Sanitary Reasons

Some of the trades wastes are objectionable from a sanitary point of view, that is, they foul the air, and the result is lessened well-being, whether from direct effect or by taking away appetite. There are strong objections to sewage mixed with garbage and refuse of all sorts. A new term is needed to indicate this unholy mixture which never ought to exist. Not only is any treatment difficult, but the danger from sewage is intensified by its coating over orange peel and its enclosure in grease; the germs are thus spread out and carried on.

Prevention should be applied at the source, that is, separation of wastes, but until it is, screening, coarse filtration, by coke, spongy iron, etc., may precede other treatment. For filtration, too much "jelly," whether zoöglœa or grease, is a hindrance. The straining is delayed until decomposition sets in, and the "sludge" is an elusive mass to filter. Rapidity of the various stages of treatment is rather more favored than "septic tank" processes.

Colonel Waring's plan of hastening decomposition without offense, by forced aeration, has not found as much favor as the idea deserves. The sprinkling filter adopts much the same idea, but does not give the effective drying of the sludge which the strong air current accomplished in the Waring filter. In his own words describing the experiment at Newport, R.I., in 1895:

" The process by which the impurities of the sewage are removed is the purely natural one on which depends the ultimate destruction of all organic matter. When sewage is spread over the surface of the ground, as in irrigation, it is exposed to the atmosphere in thin broad sheets, and the bacteria which reduce its putrescible matters are active because air is abundant. The process in the aerating tank is essentially the same, but in this case the earth is massed in cubical form, and the atmosphere is made to pervade the mass, so that every conceivable plane within it presents — so far as bacterial activity is concerned — the conditions of a natural surface.

" The same is true with regard to the straining tanks. While the sewage is passing through them, the action is merely mechanical sedimentation. When the liquid has been drained off and the aeration has begun, the process and the result are the same as they would be if the accumulated sludge were spread in extremely thin sheets over the surface of a large area of soil.

"The rate of application was an average of 7,574,400 and a maximum of 17,900,388 gallons per acre.

"The average percentage of purification, as represented by the removal of organic nitrogenous matter, accomplished by the strainers alone, was 51.3, and by the strainers and aerators together, 92.5. At one time a purification of 99.08 per cent was reached.

"After screening, these results demonstrate that:

"1. The suspended matters of sewage (sludge) can be mechanically withheld by straining slowly through suitable material.

"2. The filth accumulated by this straining material can be destroyed and the straining medium restored to a clean condition by mere aeration.

"3. The successive alternate operations of fouling and cleansing can be carried on indefinitely, without renewal of the straining material.

"4. The purification obtained by this straining process practically equals that accomplished by chemical precipitation, and is sufficient to admit of discharge into any considerable body of water not used as a source of domestic supply or for manufacturing purposes requiring great purity."

By whatever mechanical device the screening, straining, and aeration are supplied, the result to be attained is the oxidation of the decomposed products to a condition of inoffensiveness. The devices will vary with the conditions and with the inventive power of the engineer.

C. Treatment for Direct Potability

Involves complete decomposition, oxidation, and fine sand filtration, or well-managed coagulation and then mechanical filtration or sterilization. These steps are necessary to prevent the entrance of any pathogenic germs into the domestic supply. It is assumed that minute spores will not develop under conditions so unfavorable. These last treatments are usually applied as a precaution, just before the water intake, while sprinkling filters, slate beds, etc., come at the source of the pollution 20 or 50 miles upstream, for nearly all these modern processes are in connection with streams in which the dangerous material has nearly all disappeared from sight by dilution.

Mr. Elliott A. Kimberly suggests the following general rules to govern the needed degree of purification of domestic sewage:

"1. Where the sewage effluent is to be discharged into running streams subject to floods and with a water containing considerable turbidity at all seasons of the year, the degree of purity required need not be more than that of an effluent which, undiluted, will no longer putrefy under summer conditions.

"2. In streams, the water of which is clear except at times of flood, the purification of the sewage should be such as to remove from it the largest practicable quantity of suspended matter, so that the visible purity of the stream will not be affected, the non-putrefaction of the effluent being taken as coincident with a degree of purification which will afford an absence of all but small amounts of turbidity.

"3. In drinking-water streams, and in certain cases of sea discharge where shellfish layings must be protected from contamination, the purification of the sewage must needs be carried out to its fullest extent, and besides the production of a chemically stable effluent, the problem practically reduces itself to the destruction of all the disease-producing bacteria present in the raw sewage, by subjecting the well-purified effluent to some form of sterilization process."[1]

Anaerobic filters. "A modification of the septic tank is the anaerobic filter, which is operated continuously and is at all times full of sewage. The air is therefore excluded, and action is caused principally by the anaerobic bacteria.

Complete Sewage Treatment. "The complete treatment of sewage would involve its passage through, first, a grit trap and screening chamber; second, a septic tank; third, a coarse filter; fourth, a fine filter.[2]

"A contact bed, as suggested by John W. Alvord, resembles nothing else so much as a huge lung. The emptying and filling of the liquid in the contact bed correspond to the inhaling and exhaling of a breath, and as the indrawn air in the lung oxidizes

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[1] Bulletin University of Wisconsin, No. 331.

[2] Ibid.

the impurities of the blood through the thin walls of its tissues, so do the entrained air and bacteria in the contact bed do their work upon the dissolved impurities in the sewage.

Percolating Filters. "Percolating filters are made of a fine-grained material, such as sand or screened cinders, and the sewage is applied to the top, as in a sewage farm, and allowed to seep through to the underdrains below. In this type of filter a straining action takes place on account of the small size of the passages between the grains of filtering material, and large amounts of solids are retained on or very near the surface, the passages being too small to allow the solids to penetrate far into the body of the filter.[1]

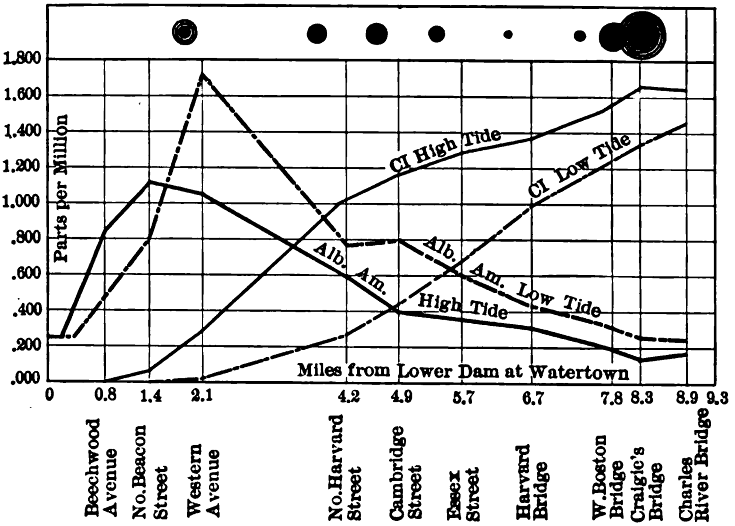
Contact Beds. "The filtering material of contact beds is contained in a water-tight reservoir, in which the sewage is retained for some hours by closing the outlet valves. In this type of filter the solid matter is not strained out of the sewage, for the passages between the grains of the filter are usually much larger than the particles of solid matter in the sewage, and furthermore the sewage is often let into the contact bed at the bottom, sometimes through the same pipes through which it is again drained out, thus precluding any true straining action. A large part of the solids of the sewage is nevertheless filtered out of the sewage by the contact beds. The action is brought about by the solids of the sewage settling onto or adhering to the grains of filtering material with which they come in contact. As the reservoir is emptied of sewage, the solid matter is retained in the filter, but air is drawn down into the filtering material by the removal of the liquid, and this thorough aeration enables the bacteria, which swarm in the filter, to consume a large part of the retained solid matter. Also when the next dose of sewage comes into the contact bed, the bacteria which have so recently been thoroughly aerated are able to oxidize large amounts of the impure matters which are dissolved in the sewage."[2]

[1] Bulletin University of Wisconsin, No. 331.

[2] Ibid.

This side of the treatment of sewage for drinking water is in process of experimentation; some of it is costly in lives, but each step adds to our knowledge. Retention of the larger part of waste substance at its source will render the later stages more effective.

Need of Treatment. The mixture of certain untreated trade wastes of slow decomposition with sewage and their discharge into tide water is illustrated in the case of the Charles River, which in 1896 received the waste from the Brighton Abattoir as well as considerable sewage. The wastes from slaughter-houses while highly nitrogenous are slowly decomposed and prolong the nuisance liable to result.



The above chart, prepared from results of an investigation by the State Board of Health, shows this very clearly. The bringing back by the tide of the yet undecomposed slaughter-house waste is shown by the curve of pollution.

Abattoir situated above Western Avenue.

Pork-packing establishment at Craigie Bridge.

CHARLES RIVER TIDEWATER. DISTANCE OF RISE OF SEA WATER AND ITS EFFECT ON DILUTION OF SEWAGE.

Parts per 1,000,000.

Locality.	High Tide.					Low Tide.				
	Free ammonia.	Albuminoid ammonia.	Free plus albuminoid.	Free after 7 days.	Cl.	Free ammonia.	Albuminoid ammonia.	Free plus albuminoid.	Free after 7 days.	Cl.
Beechwood Ave......	.752	.856	1.608	.784	10	.160	.468	.528	.192	10
North Beacon St.....	.400	1.124	1.524	1.600	580	.176	.772	.948	.208	12
Western Ave........	.608	1.060	1.668	1.920	2,800	.384	1.740	2.124	1.920	238
North Harvard St....	.832	.604	1.436	1.280	10,300	.480	.772	1.252	1.120	2,690
Cambridge St........	.784	.396	1.180	.929	11,750	.592	.800	1.392	1.280	4,400
Essex St............	.832	.364	1.196	.960	12,920	.768	.628	1.396	1.040	6,800
Harvard Bridge......	.768	.328	1.096	1.040	13,800	.800	.444	1.244	1.120	10,000
West Boston Bridge..	.720	.204	.924	.768	15,390	.608	.340	.948	.992	12,550
Craigie Bridge.......	.816	.152	.968	.400	16,580	.400	.276	.676	.800	13,500
Charles River Bridge.	.144	.188	.332	.384	16,530	.400	.260	.660	.832	14,730

Circles represent quantity of polluting material, — black, sewage; light, manufacturing wastes.

N.B. Analyses also show change from albuminoid to free ammonia upon standing seven days.

The sewage purification works at the plant of the Allis-Chalmers Company at Milwaukee consists of four concrete septic tanks, four anaerobic filters and trickling filters. Below the tanks the sewage is aerated by fall over weirs and some steps, and enters the anaerobic filter from the bottom. From here the sewage passes to the siphon chambers, which discharge it onto the trickling filter below.

This disposal plant is interesting, as the effluent is used again in the shops for sanitary purposes, boilers, and for washing after being purified. Such use has an advantage in that the purified sewage is not nearly so hard as is the city water, and therefore there is little trouble with boiler scale.[1]

In The Travis Hydrolytic Tanks at Norwich, England, the theory is that sewage matters become colloid and dissolved (more or less) as they mix and flow with the water supply, and that purification is a process or desolution, a physical rather than chemical process and more active than the vital processes.

Collins has installed four tanks each with three compartments, and splines of jarrah wood to attract the fine suspended solids and change the colloids. The reduction chamber has cones for settling and withdrawal. The hydrolyzing chamber flows upward and has scum channels and sludge removers.

A Review of Twenty-one Years' Experiments upon the Purification of Sewage at the Lawrence Experiment Station

" 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

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[1] Bulletin University of Wisconsin, No. 331.

State Board of Health, and has been carried on under his general supervision.

" The report for 1891 took up the subject of the permanency of filters. 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 aeration of the filter; in fact, this was a true trickling filter, as is now known.

" 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.

" 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 aerating 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 aerated a portion of the time by means of a current of air was first shown at this period.

" 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 aerated generally only from one to two and one-half hours daily.

" From the first, studies looking to the removal of the matters in suspension in sewage sedimentation, chemical precipitation and coke straining were made.

" Early in 1899 there was put into operation a trickling filter 10½ feet in depth, constructed of broken stone and operated at the rate of 2,000,000 gallons per acre daily.

" 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,' and the tank was so arranged that the sewage passed upward through this stone.

" 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.

" 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 1901, the slate filters being similar to those operated in more recent years in England by Dibdin.

" 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.

" 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.

" 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.

" 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, woolen mills, wool-scouring works, dye works, shoddy mills, creameries, yeast factories, glue works, gas works, etc."

H. W. CLARK, 1908.

CHAPTER XIII

THE COMMUNITY AND THE INDIVIDUAL

THE EDUCATION AND THE POSITION OF THE SANITARY ENGINEER IN THE PROGRESS OF MODERN SANITATION

OUT of the chaos of conflicting ideas and interests brought about by the rapid development of material resources there will come some controlling factors to preserve the race of man from degradation and extinction. All ages have had this thread of prophecy, which the succeeding age felt to be as far from fulfillment as the last. But yet the forward look brought a vision to some seer.

According to Mr. H. G. Wells, as expressed in "Anticipations," a study of the reaction of mechanical and scientific progress upon human life and thought, the saving element is coming through the engineering and medical professions. These essays were written before the rise to prominence of the sanitary engineer as at present understood, and it is to this group of engineers concerned with the preventive side of what the past century knew as medicine that the world now looks for that new influence which shall leaven the mass of sordid living whether of excess or poverty. By virtue of their studies and training there may be formed a new ideal of rational living.

Prof. Dugald C. Jackson in a lecture before the *Stevens Institute Eng. Soc.*, Nov. 23, 1909, said:

"The profession of the engineer demands a creative imagination cultivated to the sober clear sight which sees things as they are — political and social sciences must be added to the list. The existence of civilization as we know it, and to a large degree its advancement, depend upon transportation and intercommunication, which are fundamentally engineering industries. Are the engineers then to allow those important political and civic activities which cling around civilized life to fall under the sole direction of others?

"However well a man knows the physical and mathematical sciences he cannot make the most of his abilities as an engineer unless he also understands the human character and the trend of human progress.

"There is a failure to impress on the mind of the student that the economic subjects are intimately related with the work of his profession."

How much more is this true of that one whose whole training should be toward community welfare! The very name implies the direction in which his talents must be used, engineering applied to health or human welfare.

That person or thing must be *understood* before it can be helped or modified.

As the successful physician needs to understand his case in all its bearings, so the sanitary engineer who is to deal with problems of air and water, dust and food transportation, habits and idiosyncrasies of the multitude, needs the wide knowledge of which Professor Jackson speaks. His education must include an appreciation of the elements which go to make up this complex life.

Since life is short and the days of preparation shorter still, the engineer must not be fed with chopped food but stimulated to exert his full powers of assimilation. Foundational principles of related sciences must be added to the engineering training and these principles must be stated in a digestible form. There is not time nor is there need of the technique of chemistry, physics, and biology. Trained workers may be employed in these lines, but the *understanding* of the meaning of these sciences and their relation to the results the engineer is aiming for is essential to the successful carrying out of the projects for human betterment.

It is true that an engineer need not be a chemist, but he does need chemistry — a very different matter. He needs an understanding of chemical language if he is not to be at the mercy of ignorant or fraudulent dealers and promoters. In science it is *knowledge*, not *belief*, that is needed. Just how to present this foundational knowledge without being superficial is the present problem.

There will probably be found a certain combination most available for opening the safe. It must come through a co-operation of the teachers and experienced engineers. It will probably be an engineer who has had a varied training, having changed his school and his course two or three times, and then changed his occupation, who will have just the inspiration to make an effective "short cut." Meanwhile the general phrases "sanitary chemistry" and "sanitary biology" must cover such endeavors as may be made to give the most in the shortest time and to give it in an assimilable condition. The engineering student is apt to suffer from indigestion from this concentrated food, it is true, hence he is given that for which he declares he has not and never shall have use.

There are not wanting indications that the extreme of specializing has been reached and that the coming leader will have a broader foundation as well as a sounder community spirit.

The civic sense is just now being aroused to the problems of crowded living brought about by the inventions so readily adopted and by the apparent gain in combined effort, a gain in material advance offset by a loss in human well-being. The warring elements of industrial life need study and enlightenment of both sides. A balance sheet must be drawn by experts. Adjustment is needed in nearly every department of business and manufacture which touches human living and working conditions.

Dr. Luther Halsey Gulick in an address before the College of Physicians and Surgeons, New York, April 14, 1909, said:

"People need to be taught how to manage *efficiently* the machinery of life. This is the problem of the biological engineer."

In the exceedingly complex life of to-day it is evident that there is needed a strong force to weld the heterogeneous elements into a working combination, a force which has the confidence of the community as the minister, the doctor, and the lawyer had in the early colonial days. The age has developed by mechanical progress to such an extent that a new force in sympathy with this kind of progress is needed for guidance into a safe channel. Conditions have reached that point at which wise use of the limitless resources science has provided is the essential element in human welfare. There must be economy in securing health and comfort for the people in order that there may be means for more health and comfort for more people.

For this new work the new profession, engineering, is taking the place in public confidence occupied by the so-called learned professions of earlier times, not because the world has no longer need of leaders but because its leaders must have that insight into conditions which intimate knowledge alone gives and because they must be in sympathy with *change*. The modern world is in a state of flux, and will no longer accept as final "Thus the fathers did."

This is perhaps the reason why the minister, the doctor, and the lawyer have no longer the authority they once had over the minds and actions of the people. They go too far back in the centuries for their precedents.

Of the engineer there have been evolved many sorts in the course of the conquest of the world's forces. The civil engineer is essential to the strong network of railroads; a very important person he is in the general scheme of things, but his business is to serve the railroads. The mechanical engineer furnishes the working combination of materials which the mining engineer brings from the depths of the earth; his work is to displace human labor by machinery. The electrical engineer handles the earth's forces at the behest of great combinations of capital, as does the chemical engineer, for the public good undoubtedly, but nevertheless these men are not free agents, as the purely scientific investigator has always claimed to be.

Dr. Leo H. Baekeland in an address as president of the American Electrochemical Society, Pittsburgh, May, 1910, said:

"Modern human dynamics have reached an intensity never witnessed before. . . .

"Let me assert it emphatically: the two most powerful men of our generation are the scientist and the engineer. . . . The masses are unaware of the immense power of the scientist and the engineer because both of them modestly play the rôle of 'the servant in the house.' . . .

"To put it tersely, I dare say that the last hundred years under the influence of the modern engineer and the scientist have done more for the betterment of the race than all the art, all the civilizing efforts, all the so-called classical literature, of past ages, for which some respectable people want us to have such an exaggerated respect."

Since 1890 there has been slowly developing the sanitary engineer, trained to consider public service affairs, water supply and waste disposal, questions of public health caused by bad living and working conditions, questions of disinfection, of transportation and distribution, and of the effect of large industries on human welfare. This engineer has begun to serve on public commissions as the agent of the philanthropic element in the community which has the will but not the knowledge.

There are not wanting signs that from a mere employee this engineer is emerging as a leader of thought, a shaper of public opinion. His support will come from the community as a whole, not from any one special interest. He will become so important as to be outside political control, especially when the welfare of the whole group becomes paramount even in political thought. It will become increasingly clear that control of some sort is needed, and that instead of all striving to make more money to spend, some must learn how to make a given sum go farther and bring more reward in health and happiness.

The sanitary engineer has to-day the best prospect of becoming that leader. He has thus trenched on the ground hitherto held by the medical profession, and has usurped the moral standpoint of the preacher and insisted upon a new basis for law, the people's right to health as well as right of way.

Prof. Henry S. Carhart, in an address at Throop Institute, Pasadena, California, June 8, 1910, said:

"The engineer is now more than ever an essential factor in affairs. He is (rather) the masterful man who unites oceans and revises the paths of commerce; who levels hills and removes mountains if they chance to be in his way; who changes the course of rivers or sends them through tunnels to generate electric light and power and to convert deserts into fruitful fields.

"If we inquire somewhat more minutely into the qualities that make for leadership in engineering, we shall find that thoroughness, originality, and the habit of making all mental acquirements one's own are essential. Originality is a gift, but it may be cultivated: the two other qualities are certainly within the reach of every young man with normal mental endowments. . . . Thoroughness is associated with sincerity in the conduct of public works. . . . There is still another (quality) which is a supreme test of fitness for public service. It is the moral quality of honesty. Failing in this there is no compensation — especially so in these days of uncovered bribery and graft. The honest engineer's opinions are not for sale to the highest bidder. He is entitled to compensation for his judgment and his decisions, but they cannot be purchased, a distinction with a marked difference.

"The great civic and economic facts of the larger world should be a part of the engineer's outfit. His part in the world's work has close connection with those social and economic movements that are conditioned on future development."

This new sort of engineering person needs a new designation.

Community engineer might serve as a term descriptive of the man who serves the whole community and considers its welfare in general.

Civic engineer is a shorter descriptive term, and if civic is kept broadly to mean any small community as well as a large city, is perhaps satisfactory.

Municipal engineer has been adopted in a few places, but must be supplemented by *rural engineer* to be fully adequate.

Public-service engineer comes nearest to giving a full explanation in the title, for the trained person is likely to come up from the employee to be the guiding force in public-service organizations.

The endeavor of medicine to adapt itself to modern conditions has been more noteworthy than the efforts of either law or theology. Its high moral code of disinterested service to all has kept the ideals of medicine much more in touch with progress.

Preventive medicine was an admirable watchword, public health doctor an expressive title. Nevertheless the profession has been hampered by tradition, bound by authority, and not wholly free to branch out into new fields. But to-day research in the lines of preventive medicine, the use of all scientific resources to find the reasons why, is absorbing the energies of the medical profession. All honor to it.

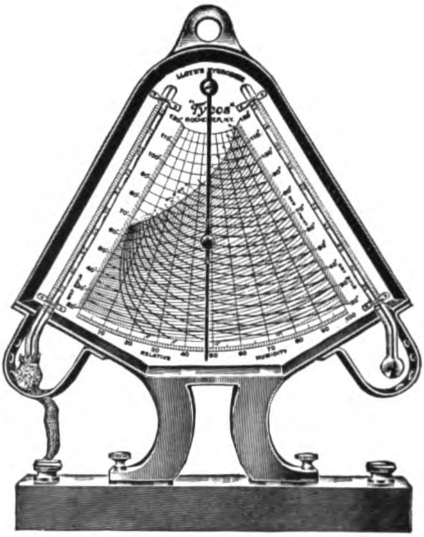
There is, however, another element in the successful *control* and application of the knowledge thus gained, in the determining *efficiency* of health measures.

The mechanical basis of modern life must come to the aid of moral and personal influence. It is not enough to tell men to do the right thing; they must be fenced in from the wrong thing.

For all these reasons it would seem that the *civic* or *public-service engineer* is the emerging leader in community welfare.

PART II

LABORATORY NOTES



Convenient Hygrodeik for Inspection of Humidity at Regular Intervals

Form of Recording Thermometer Useful in Test of Ventilation

PART II

A LABORATORY EXERCISE ON THE INSPECTION OF VENTILATION

Air Supply Tests and the Instruments Available

There is needed a more frequent asking of the question "Is this air safe to breathe?" as it is becoming a common question "Is this water safe to drink?" There are indications that there will be in the future a wider use of recording instruments or hourly readings of standard instruments for temperature and humidity to govern the circulation of air in the space.

For a quick indicator, the estimation of carbon dioxide is to be recommended. If expense is no object the laboratory should have two Petterson testers, in order that one may be always in commission and available for carrying on inspection trips.

For many approximate estimations, as for instance in a series of schoolhouse tests, the automatic pipette with the steam vacuum bottles serves the inspector well.

VENTILATION TEST

Report by..
Date...................................Room......................
Sketch of room with dimensions, air ducts, doors, windows, transoms, gas lights, steam radiators.
Samples where taken.
Change of temperature during test.
Change of humidity during test.
Change of CO_2 during test.
Use of room during test, occupant's light.
Usual use of room.
Form of heating, lighting, ventilation.

REPORT OF THE COMMITTEE ON STANDARD METHODS FOR THE EXAMINATION OF AIR. — AMERICAN PUBLIC HEALTH ASSOCIATION

1. *Laboratory Methods for Determining Carbon Dioxide with a High Degree of Accuracy*

"Numerous efforts have been made to develop methods of analyzing air for carbon dioxide, applicable to the varying conditions under which the chemist, sanitary engineer, or inspector must work. The chemist is called upon to make exceedingly accurate, careful analyses for scientific purposes, while the inspector and engineer are called upon to make estimates and comparisons. It is plain that no one system or method will satisfactorily meet the requirements of all these conditions, and therefore in preparing a description of the most satisfactory processes for use as standard methods the available methods have been classed either as accurate methods or as general tests.

"For accurate, scientific work, say when accuracy to one-tenth of a part per ten thousand is required, the committee recommends as the standard the Petterson apparatus as modified by Sondén, one form of which has been used by Dr. F. G. Benedict of the Carnegie Nutrition Laboratory for over a year with the greatest satisfaction.[1]

"This apparatus measures a given volume of air, and absorbs the contained carbon dioxide in potassium hydroxide, afterward accurately measuring the remainder, thus giving the carbon dioxide present by volume. The air is measured in all cases at the same pressure and temperature and is measured accurately by means of the readings on a very finely graduated capillary. The principle is simple, but accurate operation requires considerable technique.

"The apparatus may be had by applying to Sondén in Stockholm, at a cost of something less than one hundred dollars.

"For accurate inspection work, say one-quarter of a part per ten thousand, the Eimer and Amend form of the Petterson

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[1] This apparatus will shortly be described in print by Dr. Benedict.

Palmquist apparatus is recommended. This is very similar to the Sondén form but not as delicate. Its cost is about fifty-five dollars.

2. *Practical Methods of Determining Carbon Dioxide for Sanitary Purposes*

"The time method of Cohen and Appleyard (1894) is recommended as combining practicability and reasonable accuracy in a degree suitable for practical sanitary work.

"**Standard Method for Carbon Dioxide.** If a dilute solution of lime water, slightly colored with phenolphthalein, is brought in contact with air containing more than enough CO_2 to combine with all the lime present, the solution will be gradually decolorized, the length of time required depending upon the amount of CO_2 present. The quantity of lime water and volume of air remaining the same, the rate of decolorization varies inversely with the amount of carbon dioxide. The method is scientific in principle because it recognizes the fact that the absorption of CO_2 by calcium or barium hydroxide solution is a *time reaction.*

"Collect samples of air in one-half-liter glass-stoppered bottles by any of the methods of collection. Run in 10 cc. standard lime water, replace stopper, and note time. Shake bottle vigorously with both hands until color disappears. Note time required, and ascertain corresponding amount of CO_2 from table.

Time in minutes to decolorize solution.	CO_2 per 10,000.	Times in minutes to decolorize solution.	CO_2 per 10,000.
1¼	16.0	3½	6.0
1⅓	13.8	4	5.3
1½	12.8	4¼	5.1
2	12.0	5	4.6
2¼	11.5	5¼	4.4
2¾	8.6	6¼	4.2
3¼	7.7	7½	3.5

"**Standard Lime Water for General Tests.** To a liter of distilled water add 2.5 cc. of phenolphthalein (made by dissolving .7 gram of phenolphthalein in 50 cc. of alcohol and adding an equal volume of water). Stand the bottle of water on a piece of white paper and add drop by drop saturated lime water until a faint color persists for a full minute. Now add 6.3 cc. of saturated lime water and quickly cork the bottle, or connect the pipette.

3. *Methods of Collection*

" In the case of the Cohen and Appleyard Method particularly, the method of collecting the sample is fully as important as the actual test. For this the committee recommends as standard for accurate work the method of collection by water siphon.

" **Standard Method of Collection.** The Water Siphon Method. Two bottles (diameter one-third the height), volume about one-half liter, of nearly equal capacity should be fitted with rubber stoppers carrying small glass tubing connected by several feet of rubber connector, with clamps. Fill one bottle completely with water nearly free from carbon dioxide.

" The pair of bottles is taken to the place from which the air is to be collected. The inlet tube may be long enough to reach to near the ceiling, or short; if long, the first siphoning should be rejected, to secure filling the inlet tube with the air desired, the stoppers exchanged, and the sample taken. The air-filled bottle should be stoppered and taken to the laboratory; or the test solution at once added, and the bottle stoppered and shaken, noting minutes and seconds. One bottle of water with a small reserve will serve for a number of takings before absorbing a deleterious amount of CO_2.

" The Steam Vacuum Method may be used as an alternative in less accurate work. The steam is supplied by a 500-cc. flask serving as a boiler, with a Bunsen burner to apply the heat. The flask should be fitted with a rubber stopper carrying a No. 6 glass tube so arranged that one end extends within one-half inch of the bottom of the bottle when placed in position on the stand. The bottles should be of about 500 cc. capacity, made for a ground-glass stopper but fitted with a rubber stopper.

" To prepare the jet, the water in the flask should boil for five minutes in order to expel completely the air in the water and the flask. The pressure should be sufficient to throw the vaporized steam at least 1 foot above the exposed end of the tube.

"Place the empty bottle on the stand in an inverted position and allow to remain for three minutes. In the meantime apply a thin coating of vaseline halfway up the sides of the stopper. The vaseline acts as an unguent, reducing the coefficient of friction to such an extent that the principal resistance is due to the reaction of the stopper against compression. This enables one to force the stopper in far enough to bring the glass and rubber into intimate contact, which is essential. The vaseline also fills the interstices between the rubber and the glass, so as to make leakage impossible.

"Protecting the hand with a cloth, raise the bottle from the stand, and the instant it clears the end of the tube insert the stopper while the bottle is still inverted. The stopper may be pushed in more securely by pushing it against the table with a few pounds' pressure while the bottle is still in the inverted position. Keep the stopper in under this pressure for a few minutes until the vacuum begins to form, after which the atmospheric pressure will keep it in place.

"All the bottles required are treated in the same way. The rubber stopper should be at least one size larger than would ordinarily be used for the bottle, and should project three-eighths of an inch or more so as to be easily removed when the sample is to be taken.

"Sample bottles may be tested for completeness of vacuum by holding them in an inverted position under water at 70° F. and removing the stopper. After the water has replaced the vacuum, the stopper is inserted and the bottle removed.

4. *Bacteriological Determinations*

"The determination of the number of bacteria in air seems to the committee to have less importance than was once believed. Disease spread through air is probably due most often to direct pollution with spray from the mouth; and it does not seem possible to measure such pollution in a quantitative way. The total number of saprophytic bacteria often corresponds with the amount of dust present. This is especially true when the dust is not of metallic or other industrial origin. In the examination of the air of barns, dairies, theaters, factories, and streets bacterial data may prove of value."

C.-E. A. WINSLOW, Chairman.
ELLEN H. RICHARDS,
G. A. SOPER,
J. BOSLEY THOMAS,
JOHN WEINZIRL.

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TWELVE CLASS EXERCISES FOR FOURTH YEAR SANITARY ENGINEERING STUDENTS

IN EXAMINATION OF WATER AND WASTES. TO BE SUPPLEMENTED BY THREE OR FOUR FIELD TRIPS

LABORATORY PRECAUTIONS

Although the student knows in a general way, from his experience in the bacteriological laboratory, the need for clean handling of apparatus, yet when he comes into the water assay room he needs reminding that only clean hands will keep apparatus clean and that exact and delicate work cannot be done with unclean dishes and tubes. Approximate results are valuable only when obtained by rigid compliance with exact requirements. The following notice posted over the sink provided with hot water, soap, and towels has proved an effective reminder.

CLEAN HANDS THE FIRST ESSENTIAL FOR THE WATER ANALYST

Not merely free from ordinary dirt, but freshly cleansed from the constantly accumulating ammonia, chlorine, nitrites, etc., constantly being excreted.

During the progress of the work not more than half an hour should elapse between complete rinsings of the hands. Each student will rinse out all used apparatus and will carefully dispose of all sewage residues lest a neighbor may unwittingly handle them.

Iron rust stains may be removed from dishes and glassware by dilute 1 to 3 hydrochloric acid. Manganese stains in distilling flasks, for example, require the acid hot. Unless there is, as there should be, a separate room for all such severe cleaning operations, care must be taken not to vitiate the air of the laboratory with acid or ammonia fumes.

An excellent cleaning acid for organic matter stains is potassium bichromate dissolved in concentrated sulphuric acid. It is hard on sinks and fixtures, and flushing should be conscientiously carried out. Potassium or sodium hydrate is to be at hand for cleaning greasy and acid dishes; also alcohol and ether for cleaning and drying measuring flasks. But the laboratory cleanser *par excellence* is hot soapsuds, and for hands a nailbrush in addition to plenty of clean towels. It is as disgraceful to find finger marks on water beakers in the laboratory as on water tumblers on the dining table.

Although each student will in the main have his own apparatus, yet some flasks, dishes, etc., will be in common use. Duty to one's neighbor demands that these dishes should be left in good condition after use.

Not only must the air of the water laboratory be free from fumes but from dust, which, settling on the apparatus, contaminates the hands, even if bottle, flasks, etc., are closed.

With these precautions made a habit, the analyst may permit himself to judge many things by approximate results.

As in any other professional occupation, each establishment will have its own peculiar methods, so that the student can profitably learn only general principles which may be modified to suit his employer or the peculiar circumstances in which he may find himself in his profession.

Certain preliminary qualitative tests are as saving of time and productive of information for a classification of the samples as are the tests applied to samples of steel for reinforcement. Such may be roughly classified by a few physical tests, as appearance of fracture, bending, action under a drop of acid, etc.

EXERCISE I

PRELIMINARY TESTS, RESULTS GOVERNING THE QUANTITIES TO BE TAKEN FOR CERTAIN DETERMINATIONS

From each sample of water half fill two 50-cc. Nessler tubes, to the one set add two or three drops of Nessler reagent, watching for the heavy reddish precipitate which indicates sewage, the less heavy lighter-colored precipitate which indicates polluted water or effluents, the deep yellow color without precipitate which shows the presence of too much ammonia for a good water, or the absence of any color, which is favorable as far as it goes. Waters with brown color will turn darker on the addition of the alkaline reagent. Waters containing iron may give a precipitate, but several things are learned by this test, and not infrequently half a day's time is saved.

To the other set of 50-cc. tubes a few drops of silver nitrate are added; if a heavy precipitate is formed, two or three cubic centimeters may be required. If no perceptible cloudiness appears, the water is to be concentrated, as it probably is nearly normal in chlorine, 1 to 2 parts per million. Unless there is a distinct tendency to precipitate it is advisable to concentrate, since results between 20 parts per million for a direct titration of 25 cc. of the sample are liable to be too high. A very heavy precipitate remaining after acidifying by nitric acid shows that the estimation will be more accurately made in a measured volume of 5 cc. made up to 25 cc. with chlorine-free distilled water.

Having in this manner classified the two or three samples assigned to him the student proceeds to make the tests and record the results on the blank form provided for the purpose.

SANITARY WATER ANALYSIS No......
Parts per 1,000,000

Address for report
Locality
Date
Description of Wafer

PHYSICAL EXAMINATION	Turbidity		
	Sediment		
	Color		
	Odor	Cold	
		Hot	
CHEMICAL EXAMINATION	Free Ammonia		
	Albuminoid Ammonia		
	Nitrites		
	Nitrates		
	Hardness		
	Chlorine		
	Oxygen consumed		

REMARKS

For determination of turbidity of sewage samples Mr. H. W. Clark of the Lawrence Experiment Station has successfully used a standard the basis of which is the actual material passing down through contact or intermittent-continuous sewage filters collected from the effluent of a filter in good working order and kept moist and sterilized by two or three cubic centimeters of formaldehyde. The set so prepared will last without clotting for two or three months. Standard sets are made up from a strong mixture in which the solid matter in a given number of cubic centimeters has been determined. 0.01 gram per liter means 1.0 turbidity, 0.10 gram means 10.0 turbidity in parts per 100,000.[1]

TESTS

General Appearance.

First. Note general appearance, which in many instances will suffice for an experienced investigator to determine to which class the sample probably belongs. Therefore the student should begin the practice at once.

Observe turbidity, sediment, color, sizable organisms, and any special characters, as sand, iron rust, etc.

APPARATUS. For a simple observation it is sufficient to note the extent of both turbidity and sediment, in words, as "clear," "none," "slight," " considerable," etc., but for an exact determination various instruments are employed, such as platinum wire, turbidimeters, etc. Some analysts prefer to shake the sample and mix the sediment with the suspended matter and call it all turbidity. As the removal of the readily settling particles presents comparatively little difficulty, it would seem more logical to know the quantity remaining suspended after twelve hours. For the muddy river water the method of the turbidimeter is most used.

If desired, the amount of sediment may be estimated by the separator centrifuge.

At times, further examination of the suspended matter or sediment with a microscope is desirable.

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[1] Thirty-sixth Report Massachusetts State Board of Health, 1904.

Odor, Hot and Cold.

Second. Although to the experienced observer only is odor an argument of value, yet since with experience it becomes of distinct importance, the student's attention should be directed to the technique of its determination.

Just as one can be sure of alcohol in a man's breath, so one can be sure of the presence of certain organisms in water or of certain chemical products of decomposition — odors which accompany pollution. To the initiated, odor is one of the most enlightening tests to be applied to water.

APPARATUS. A tall, slender beaker without a lip and with a rim so even that a watch glass will rest closely enough not to allow the warmed vapor to escape easily. This watch glass should be just a little larger than the rim.

The capacity of the beaker is conveniently about 300 cc.

PROCEDURE. The beakers are placed on an iron plate previously heated by gas or electricity, and allowed to come just to the point of giving off steam bubbles, but not hot enough to allow the liberated gases to escape from under the still cool watch glass. The freed gases will be condensed in the vapor in the upper part of the beaker, and on cooling five minutes, not more, a rotary motion and quick sliding of the watch glass will permit plunging the nose into the beaker without scalding. The judgment must be ready for a quick decision, since the odor is usually very evanescent. The increase or the change in odor on heating, often noticed, is due to one or more of several causes,— splitting of substances, developing of new ones, like the roasting of coffee; the collection of the diffused odor into a smaller space, or the liberation by heat of ready-formed oil globules, for instance, from enveloping cells.

The cold odor is determined by agitation of a considerable sample (2 to 4 quarts) in a bottle with a neck not less than one inch wide. A narrow-necked bottle will not serve.

Third. The chemical test for *ammonia* by means of the well-known Nessler reagent. In many cases this test alone is decisive, for sewage is always high in ammonia and polluted waters carry a large portion for long distances. It is only when the sewage passes through seeded ground (nitrifying) that the ammonia quickly disappears. And it is only in contaminated and imperfectly filtered waters that high ammonia does not mean sewage. The one exception (besides leakage of a neighboring ammonia plant or in distilled water) where the presence of ammonia is without sanitary significance is in deep wells in the coal measures, or in sandstones above the oil, where "prehistoric ammonia" remains, because those geological formations do not apparently carry the nitrifying organism. Other tests do not, in these cases, confirm the inference of pollution.

APPARATUS. A set of test tubes all of the same size, depending upon the quantity of water at hand. They may contain 10, 50, or 100 cc. 50-cc. Nessler tubes 9 inches high to the mark are most convenient. The one essential is that they shall be comparable in diameter and in the color of the glass.

REAGENTS. Nessler's reagent is the standard.

PROCEDURE. Fill the tubes to the mark with the waters to be compared. Add from a glass tube about 1 cc. of the reagent. A quick release allows the heavy liquid to drop to the bottom without assistance.

Sewage gives a heavy brick-red precipitate, color and quantity modified by the presence of other things, but unmistakable.

Polluted waters give a less precipitate, or a deep red-orange color. Waters contaminated with trade wastes vary and may not give a decisive test, but other indications will differentiate them from the clear colorless natural spring waters which give not a trace of ammonia. If iron is present in a solution, it is possible to be deceived by its color, but the characteristic red precipitate reveals itself on standing half an hour.

Distillation is resorted to in all doubtful cases and in most cases where small quantities do have sanitary significance, since it leaves no room for doubt.

Fourth. The chemical test for *nitrites*, which are a nearly constant accompaniment of ammonia in stale sewage and polluted waters, and which seem to indicate sewage pollution in a comparatively recent past when found in surface waters, shallow wells, etc.

In deep wells nitrites are sometimes found reduced from nitrates. The two, ammonia and nitrites, present in the same sample at the same time, are, in the great majority of cases, sure proof of a degree of contamination which renders the water unsafe to drink if not for any domestic use. In the case of suspicious samples a confirmatory test by platting for bacteria may add conclusiveness, since both these chemical substances are the product of bacterial activity and presume upon the immediate presence of the organisms themselves, except in rare cases of rapid and perfect filtration.

Apparatus. Any uniform glass tubes, usually in the field of 10 cc., in the laboratory of 100 cc. capacity, 5 inches high to the mark, flat bottom.

Reagents. Most commonly, sulphanilic acid in acetic acid and naphthylamine acetate.

Procedure. Fill the tubes to the mark with clear water (decolorized if perceptibly colored, or if turbid. This is accomplished by shaking up with milk of alumina, and filtering). Add to 100 cc. 10 cc. of each of the two reagents; the order is immaterial. The color develops in five or ten minutes and must be observed within twenty, since any room in which gas is burned gives an atmosphere carrying nitrites which may vitiate the test. Compare the color developed with the two standard papers.

The need for treatment in this test brings the student naturally to the consideration of the need for *clarification* or *straining* in other cases, especially before any quantitative estimation by depth of color is attempted.

The class will find that some of the samples need to be treated and will now prepare such samples for the next day's examination. Although clarification may be effected in a few minutes, it is more in accordance with actual practice to allow the treated sample to stand several hours in order that the work of sedimentation shall make less difficult the subsequent filtration.

Apparatus. Tubes or bottles of any convenient size, but tall and narrow in shape.

REAGENTS. Coagulants: any substance which will act as a dragnet to enclose the large and small particles, clay, and organisms, and by the agglomeration cause a subsidence of the whole. Such substances are: prepared aluminum hydrate, or the same set free in the solution from alum or alum cake, or from aluminum electrodes; ferric sulphate; manganese sulphate; copper sulphate, etc.

These flocculent, gelatinous substances act like the white of egg in clearing coffee, agglomerating the finest particles with the coarse and dragging the whole to the bottom (unless buoyed up by air bubbles).

Since the changes are very rapid and the temperature of the laboratory is above that of a commercial filtration plant, it may be necessary to keep the samples in the ice chest or to sterilize by chloroform.

Changes in composition may be hastened by incubating at a higher temperature. Preliminary observations and all decisions as to clarification and incubation should be made during these first two hours exercise in order that the results may have a definite meaning.

Too often the untrained investigator neglects these small precautions and finds himself quite at sea in interpreting his results, which may seem to be at variance with those of others.

It is wisest to determine, as near the source as possible, the free ammonia by direct Nesslerization, and perhaps by distillation, to see what is in an unstable condition, — probably to determine the total organic nitrogen, and in some cases the suspended matter, by the Gooch crucible or by filtration through paper, — then to incubate at 37° C. for 48 hours and repeat the above determinations and add what others the case calls for.

Then the manager may have some idea of what will happen as the fluid warms up and passes along through the purification system. Samples from a continuously running plant are taken at the entrance to see what the machines have to do, as well as at the end to see what they have done. Comparability is of the utmost importance.

Direct Nesslerization of sewage is often desirable. The worker needs to experiment with the particular combination he is dealing with. In a testing laboratory to which fifty kinds of sewage are brought no one combination of precipitants has been found to work on all, and not only is time lost in the experiment, but the composition has been changing; therefore for quick work on uncertain or unknown samples distillation is recommended, while the samples are being otherwise treated. With steam, fifteen minutes should suffice for a determination.

For routine work on a uniform mixture including many samples a day the information desired may be more readily gained with fewer hands once the details of the direct method have been worked out. It must be borne in mind that only in incubated or old sewage are the two results nearly comparable. They need not be to give valuable information.

Since treatment takes place usually some hours after collection, a second test for change during the interval is most desirable. It is a mistake to run a testing laboratory short-handed. During the installation and regulating time no variation should escape the plotting sheet. After the establishment of the routine, fewer hands will serve.

Careful notes are to be set down of each step as to quantity, time, temperature, etc. It is always well to state in the report of the day's work, also, what the next steps are to be. For in the interim of a day or two days the student will have many different things to occupy his mind and it will waste time to bring back to memory details of procedure.

EXERCISE II

TESTING OF STRAINED AND SEDIMENTED PRODUCTS

First. Note appearances of the cold or chloroformed as well as of the incubated samples.

Record the completeness of sedimentation.

Second. Determine the quantity of ammonia by direct reading. Compare the results obtained from the cold and the incubated.

Apparatus. Nessler tubes and racks.

Standards, glasses, platinum-cobalt or ammonium chloride, 1 cc. = .00001 gram N.

Reagents. Nessler reagent, copper sulphate, potassium hydrate.

Procedure. There are certain precautions to be taken in making the color test for ammonia. Some of the most important of these should be observed by the student at this point:

Only the same dilutions give comparable colors.

Only the same temperatures give comparable colors.

The lighter shades are those of pure color and most perfect solution.

The depth of column may be taken as nearly proportional in the tints given by 6 cc. or less of the standard solution.

Since the color is one produced by a reaction in the solution with a tendency to precipitation, the once Nesslerized portion cannot be diluted, as can a color formed by merely neutralizing the acid solvent.

"Ammonia" may exist, in polluted waters at least, in several kinds of combination. One set will give the reaction if treated in the cold, another will be broken up by heat, and still another by heat and alkali. It is sometimes desirable to know each quantity separately.

FROM REPORT ON STANDARD METHODS

Free Ammonia by Direct Nesslerization

Reagents. — 1. A 10 per cent solution of copper sulphate.
2. A 10 per cent solution of lead acetate.
3. A 50 per cent solution of sodium or potassium hydrate.
4. A 10 per cent solution of magnesium chloride.

Procedure (1) for Sewage. Fifty cc. of the sample to be tested are mixed with an equal volume of water, placed in a short Nessler tube and a few drops of copper sulphate solution added. After a thorough mixing, one cc. of the potassium hydrate solution is added and the contents are again thoroughly mixed. The tube is then allowed to stand for a few moments, when a heavy precipitate should fall to the bottom, leaving a colorless supernatant liquid. Nesslerize an aliquot portion of this clear liquid.

PROCEDURE (2) FOR SEWAGE. In place of adding copper sulphate to sewages of high magnesium content, it has been found that satisfactory clarification and also softening of the sample may be obtained by heating it to 40° C. after mixing with the caustic alkali The heat causes the bicarbonate of lime to be precipitated and the magnesium to separate as a gelatinous precipitate (hydrate). During cooling, the bottle containing 100 cc. of the sample should be shaken several times to facilitate the subsidence of the precipitate. Where samples are low in magnesium content this treatment may be accomplished by adding a small quantity of magnesium chloride. (Note that both heat and alkali are used.

Many samples containing hydrogen sulphide require the use of lead acetate in addition to the copper, and others require a few trials before the right combination of the three solutions to bring about the best results can be made. In view of the fact that flocculent precipitates absorb varying amounts of ammonia from solution under certain conditions, it is recommended that the smallest practicable amounts of precipitants be used.

The amount of nitrogen as free ammonia is computed after comparisons with standards in the same manner as in the distillation procedure.

EXERCISE III

POLLUTED WATERS WHICH MAY OR MAY NOT NEED TO BE TREATED

Definition of
Characteristics of
Methods of purification?
Laboratory tests concerning
Limits of dilution, how determined?

There will be so much variation in the samples that this exercise will test the individuality of the student in devising the best means of applying what he has learned, supplemented by common sense and ingenuity in making the materials at hand serve.

This problem is one which confronts the young engineer who goes to a small town, perhaps, or is employed by a manufacturing firm. A report must be made, intelligible to such employers, somewhat after the following order:

MESSRS. A. B. & CO.

Gentlemen: I have examined the sample of water from the stream above your factory and which is liable to be used as a domestic supply by the operatives. I find it a soft, colored water, clear at this season, free from perceptible iron and thus eminently suited for laundry use. The sample gave a distinct test for free ammonia and nitrites. The presence of several thousand bacteria, variety B. coli, confirms the indication of contamination with intestinal excreta not far from the place of collection; therefore I would recommend........(treatment).

Or if the water is from a well:

"I have examined the sample of water from the well or 'spring' used by the families of your employees. It is clear, colorless, and cold, with no sediment. It carries, however, ten times the normal chlorine of the region and eight times the usual nitrates. This, taken with the excess hardness, indicates cesspool pollution somewhere along the course of the water flow. Just where this occurs is a point to be ascertained, since the safe use of the water depends upon the filter between the source of pollution and the well. Unless you can give me a topographical sketch of the surroundings I must visit the locality before giving an opinion."

Or the problem is often put in this form:

MR. X of Y., VT.

Dear Sir: I have examined the three samples sent from your country estate. I enclose the results with suggestions. A more complete analysis, which you may keep for future reference, may be desirable for the sample you choose.

If the sample is brought to the laboratory by the collector, the preliminary tests and some of the physical observation, possibly a microscopic examination, may be made to save time, but the rule will be to begin the tests with the next exercise.

EXERCISE IV

Collection and Transportation of Water Samples

If possible this should be a field excursion, either singly or as a class. The proper collection of samples in sterilized bottles for bacterial counts should be emphasized. The watchword is cleanness. Avoid contact with hands. Collect a fair sample in a clean glass vessel. Use a *new* cork stopper if glass is not available. Do not collect in a fruit jar, even if a new one; the rubber ring affects the odor. Do not use a milk jar, even if sterilized; the food is possibly still in some corner. A stone jug is liable to be porous and the earthy odor is apt to persist, masking any other.

The notebook is to record more in detail than there is room for on the blank. The slightest observation may prove the important link in the chain of evidence.

Information demanded.

Method of collection prescribed.

Time and date of collection noted; time elapsing since.

Surrounding conditions described, if sample is not collected by the analyst.

In shipping by express, the sealed string over the cloth is to insure against any tampering with the sample. Sealing wax or paraffine directly on the stopper is not to be tolerated. It requires much time and skill and is often impossible to remove it so that no tiny speck will drop into the bottle when opened.

If more than twenty-four hours must elapse between collection and examination the fact is to be noted. Polluted surface waters are those most affected.

Instructions for Collecting Samples of Water for Analysis.

First. From a Water Tap. The water should run freely from the tap or pump for a few minutes before it is collected. The bottle is then to be placed directly under the tap, and rinsed out with water three times, pouring out the water completely each time. It is then again to be placed under the tap and filled to overflowing, and then a small quantity poured out, so that there shall be left an air space under the stopper of about an inch. The stopper must be rinsed off with flowing water and inserted into the bottle while still wet, and secured by tying over it a clean piece of cotton cloth. The ends of string must be sealed on the top of the stopper. Under no circumstances must the inside of the neck of the bottle or the stem of the stopper be touched by the hand or wiped with a cloth.

Second. From a Spring, Stream, Pond, Reservoir, or Well. The bottle and stopper should be rinsed with the water, if this can be done without stirring up the sediment on the bottom. The bottle, with the stopper in place, should then be entirely submerged in the water and the stopper taken out at a distance of twelve inches or more below the surface. When the bottle is full, the stopper is replaced below the surface, if possible, and finally secured as above. It will be found convenient in taking samples from a well or from deep water to have the bottle weighted, so that it will sink below the surface. The stopper may be removed by a separate cord attached to it. It is important that the sample should be obtained free from the sediment on the bottom of a stream and from the scum on the surface. If a stream or spring should not be deep enough to admit of this method of taking a sample, the water must be dipped up with an absolutely clean vessel and poured into the bottle after it has been rinsed.

The sample of water should be collected immediately before shipping by express, so that as little time as possible shall intervene between the collection of the sample and its examination.

The accompanying "certificate" must be filled out carefully and enclosed in the envelope shipping tag.

Water must be collected in an absolutely clean *glass bottle* (not stone jug or fruit jar) of at least one quart capacity. The stopper, if not of glass, must be a *new* cork stopper.

CERTIFICATE

Accompanying a sample of water, to be enclosed in the addressed envelope tag.

SAMPLE OF WATER

From ....
Name of city or town.

Collected and sealed by ....
Name and address of collector.

....

Collected from ....
State whether the water is from a tap, or from stream, pond, well, or

....
other source.

....

....

Collected on..
Give day, date, and hour of day.

....

....

....

Give full information with regard to the source of the water, its location and surroundings.

EXERCISE V

EXAMINATION OF COLLECTED WATER SAMPLE, PRESUMABLY A COLORED OR TURBID SURFACE WATER

Rapid work is required, and the best possible dovetailing of measuring, distilling, testing, with times of standing for colors to develop, will be needed to make the necessary determination in two or three hours of exercise.

Preliminary observations. Note and record turbidity, organisms, color.

Rinse off mouth of bottle; avoid contact of hands.

Take care of hands.

Keep mixed, unless the sample is to be tested only after filtration or decantation, as in the case of extraneous sand or weeds.

Ammonia.

Since ammonia is the most sensitive of all the chemical tests and the most liable to change, its determination is usually begun immediately after the qualitative tests, page 235, which should never be omitted, if time is of value.

Most water samples, in distinction from sewage, contain so little ammonia, and at the same time so much other matter precipitable by alkaline reagents, that a sharp determination cannot be made in the direct test. It takes less time and gives surer results to separate the volatile compounds by distillation.

APPARATUS. Distilling flask 750 cc., round bottom, square shoulder, closed with perforated, treated rubber or cork stopper; condensing tank through which passes the block-tin pipe leading from distilling flask to collecting vessel; usually Nessler tubes with rack.

REAGENTS. Standard ammonium chloride, 1 cc. = .00001 gram N, Nessler reagent.

According to the preliminary test 100 to 500 cc. are placed in the distilling flask and heated. If the water is taken below an industrial plant, as wire works which deliver to the stream acid wastes, the ammonia will not be set free without the addition of an ammonia-free alkaline reagent, like ignited sodium carbonate.

A precaution to be noted is that the gas must be condensed in the water vapor. Therefore the condensing tube should be of small bore and good conducting power. Block tin is commonly employed.

The ammonia is read by comparison as before, with the exception that care must be taken to bring the condensed distillate to room temperature to insure accuracy.

CALCULATION. Standard = 1 cc. = 0.00001 gram N.

Example: 500 cc. water taken.

First distillate of 50 cc. gives 3. cc.
Second distillate of 50 cc. gives 1. cc.
Third distillate of 50 cc. gives 0.8 cc.
4.8

Then the water contains .096 part per million N as ammonia.

Albuminoid Ammonia.

By the term "albuminoid ammonia" is meant that portion of nitrogen in a given volume of water which may be obtained from the yet undecomposed organic substance. This is accomplished by digestion with a given qantity of "alkaline permanganate."

It was originally supposed to give that portion which is now more often based on the increase in putrescibility, that is, the unstable compounds. But peaty waters, which are almost always nonputrescible, yield large amounts. Therefore the old definition does not hold in such cases. In the absence of exact methods, it is still used, and if rightly understood, may give valuable indications to aid in the interpretation. Ground filtered waters should yield less than .050 per million, the best less than .010. Clear colored surface waters yield, according to the depth of color, .150 to .250. Turbid waters, or those containing organisms, may go as high as 1.000 without indicating danger. Sewage of a strength which gives 20 to 60 parts free ammonia yields, perhaps, 5,000 albuminoid ammonia. Trade wastes, on the other hand, may give 20 to 60, or more, albuminoid ammonia and very low free ammonia. That is, the *ratio* between the free and the albuminoid ammonia is far more instructive than the absolute amounts.

Just as in the case of carbonaceous matter in oxygen consumed, the test gives results of value *only* when carried on under identical conditions of volume, amount of reagent added, time of distillation, etc.

For ordinary, soft surface waters like those of the Appalachian region, the procedure given below yields very closely one-half the amount obtained in the "Total Nitrogen" or "Kjeldahl" test (see page 268).

APPARATUS. The flask containing the residue, 500 less 150 cc., after the distillation of free ammonia.

50-cc. graduate.

Funnel.

Bottle to serve as stand for funnel, so that the outside may not have a trace of the alkaline fluid.

REAGENTS. Alkaline permanganate, 40 cc. of which yields no ammonia on boiling with redistilled water.

NOTE. If the KOH is of first quality, this may be true. It is unwise to try to use a permanganate which requires a large correction.

PROCEDURE. Add 40 cc. through the long-stemmed funnel. The heavy liquid will sink to the bottom and unless mixed will be liable to start boiling explosively and ruin the determination. But since the decomposition begins at once in the still hot liquid, the flask must be instantly closed and connected with the collecting flask to avoid loss.

The electric heater is best, but if a gas flame is used, place the burner so close to the distilling flask as to spread the flame.

This beginning of boiling must be closely watched, as some waters froth excessively After once starting, the operation goes on quietly n all but very *hard* waters.

In sewage analysis, unless steam distilling is used, 10 cc. of the sample is diluted to 500 cc. with ammonia-free water and the procedure is as above.

While distillation is in progress the time may be utilized for the previously noted tests for nitrites, odor, color, etc.

In the majority of cases it is either necessary or desirable to know something of the past history of the water, the kind of ground it has passed over or through, the substances it has taken up in the course of its progress. Since water is the great solvent, it bears with it in all its after course the traces of its defilement, and frequently the proofs of its purification. What has once happened may happen again. Dr. Drown's classic phrase, "What is desired in a drinking water is innocence, not repentance," and the author's dictum of "chlorine once in the water always in the water," render the use of certain tests for the past of the water of more or less value, often more.

As has been elsewhere explained, the geological formation of the region is of the utmost value in interpretation.

Chlorine.

Chlorine being soluble in all its common compounds and not being set free by any known reaction when in the dilution of drinking waters, and, moreover, not being wanted by any plant growth, is the best index of the degree of previous pollution.

Sink drains, cesspool sewage, most wastes from manufactories, all carry into both streams and ground waters a greater or less, but determinable, quantity of chlorine. Barnyards, stable drains, and fertilized fields contribute less in proportion to the nitrogen per square mile.

Mr. F. P. Stearns's estimate of one-tenth part per million per 200 inhabitants has never been disproved. (Mass. S. B. H., Vol. I, Part 1, p. 680, 1890, special report.)

APPARATUS. Six-inch evaporating dishes are best, since the volume and conditions should always be the same. These dishes are most convenient, since the titration is made without transfer.

If the solid residue has caked on to the sides, it should be loosened by a feather end. Waters carrying 20 to 40 parts per million may be titrated directly in 25 cc.

REAGENTS. Neutral potassium chromate freed from chlorides.

Sodium chloride, 1 cc. = .001 Cl.

Silver nitrate; for routine work 1 cc. = .0005 is best.

For sewage, trade wastes or salt waters, a stronger solution may be desirable.

PROCEDURE. Most surface waters require decolorization and concentration before the test can be made with required accuracy. Wherever isochlors, lines of normal chlorine, have been established (see map) this determination has the utmost value. There are places where the presence of salt springs and the proximity of the sea (by a few yards) or the presence of old geological formations in deep deposits, mine drainage, etc., cause this determination to lose most of its value, but comparatively small areas are thus excluded.

Nitrates.

Nitrates, the other telltale of past misdemeanors, is less stable than chlorine because of its tendency to be decomposed by organisms and to be used as food by green plants. Its compounds are also soluble and are carried long distances.

In Archæan regions, the nitrate content of the soil (see p. 118) is that of the rain water minus the loss by decomposition.

As a result of many thousands of determinations, the residuum is not over .4, and usually not over .1 N per million. In such regions 1.0 part is proof of some sort of previous pollution.

In the waters seeping through the deep prairie soil the nitrates may be prehistoric and so without present sanitary significance, but all the same they do indicate past conditions of living animal activity just as do the guano deposits.

APPARATUS. 3-inch dishes, 10 to 100 cc. tubes, warm plate or water bath.

REAGENTS. Phenol disulphonic acid, KOH, standard nitrate solution .000001 gram N per cc.

PROCEDURE. Precaution: the presence of high chlorine vitiates the test; overcome this by removing the chlorine or by dilution.

See Standard Methods, Thresh, etc., for other tests.

Brucine, for field work, is sometimes made use of.

The test is not at present capable of as great accuracy as that for ammonia, for instance, because of loss on evaporation.

In some laboratories there is still used the old method of reducing the nitrates to ammonia. Metallic Zinc in acid solution yields nascent hydrogen, a powerful reducing agent. If nitrates are present, ammonia is formed. Zinc coated with freshly precipitated copper is an excellent and quickly acting agent (Thresh, p. 200–202). Sodium amalgam and aluminum zinc in alkali solution, also give hydrogen at slower rate.

The experience of this laboratory has been that there is little uniformity of action in every variety of liquids, so that one has no guarantee that the nitrogen existing as nitrates will in an unknown sample appear wholly as ammonia. Some may escape as N, as NO_2 or some other compound. Also some undecomposed organic matter may change and add to the result nitrogen which was not derived from nitrates. The Crum method of reduction to nitrogen gas appears the most scientific but the most costly in time and apparatus.

These methods are adapted to clear waters high in nitrates and free from organic matter.

Since the actual amount of nitrate varies in a changing fluid from hour to hour, it seems hardly a wise use of time to make attempts to gain great accuracy; only in certain cases is anything more than a close approximation desirable.

EXERCISE VI

Examination of Water Sample (*Continued*)

Oxygen Dissolved.

Limits of purification by dilution often require the determination of the air the fish breathes, in other words the free oxygen dissolved in the water. The samples for this test are collected in the field by any means which will insure complete replacement of the air in the collecting bottle, by carbon d'oxide for instance, or by water which may then be completely replaced by the sample desired.

From the laboratory tap from a large sample or tank the collection is made in an accurately calibrated, perfectly stoppered bottle of any convenient capacity (30 cc. is sufficient for field work) by passing the end of the delivery tube to the very bottom of the bottle, allowing the water to rise and overflow for two minutes until the volume has been changed six or eight times. For laboratory experiment as to the rapidity with which a given polluted water or waste robs a water of its oxygen, several mixtures may be made of varying dilution in two or three tall bottles. After standing the required time, twenty-four, thirty-six, or forty-eight hours as the case may be, a sample may be siphoned into the calibrated bottle as above described.

Apparatus. Two mounted burettes with long narrow delivery tubes, or for field work. Two pipettes, small bore, delivering 2 cc. One 5-cc. burette pipette.

Titrating flask, 400 cc. capacity.

Reagents. Manganese sulphate, 120 grams in a quarter liter.

Potassium hydrate, 90 grams; and sodium iodide, 25 grams, in a quarter liter.

Starch solution.

Procedure. Remove the stopper cautiously from the filled calibrated bottle, deliver 2 cc. approximately in the bottom layer of the manganese sulphate, withdrawing the delivery tube quickly so as not to leave any solution in the upper layer. This is an easy matter with the finger on the pipette tube.

With the other pipette or from the other burette add 2 cc. of the KI, KOH solution, also just above the bottom layer but not directly on the bottom of the bottle where the white manganous oxide is liable to form an adhesive layer. Close the bottle so as not to entangle the smallest bubble of air hold the stopper in firmly and invert the bottle, tip it back and forth until the precipitated spongy mass has swept the confined liquid free from the last particle of air. Allow to settle so that the removal of the stopper to admit the solvent sulphuric acid will not expose the manganese precipitate to air, add 4 or 5 cc. of H_2SO_4, stopper and mix. When solution is complete a few black particles may be disregarded. Transfer without loss to the titrating flask, add thiosulphate until a straw-yellow color only remains; only then add the starch solution to mark a sharp end point.

OXYGEN DISSOLVED — FROM REPORT ON STANDARD METHODS

3. Sulphuric acid. Specific gravity 1.4 (dilution 1 : 1).

4. Sodium thiosulphate solution. Dissolve 6.2 grams of chemically pure recrystallized sodium thiosulphate in one liter of distilled water. This gives an $\frac{N}{40}$ solution, each cubic centimeter of which is equivalent to .0002 gram of oxygen or 0.1395 cc. of oxygen at 0° C. and 760 mm. pressure. Inasmuch as this solution is not permanent, it should be standardized occasionally against an $\frac{N}{40}$ solution of potassium bichromate as described in almost any work on volumetric analysis. The keeping qualities of the thiosulphate solution are improved by adding to each liter 5 cc. of chloroform and 1.5 grams of ammonium carbonate before making up to the prescribed volume.

Calculation of Results. The standard method of expressing results shall be by parts per million of oxygen by weight.

It is sometimes convenient to know the number of cc. of the gas per liter at 0° C. temperature and 760 mm. pressure, and also to know what percentage the amount of gas present is of the maximum amount capable of being dissolved by distilled water at the same temperature and pressure. All three methods of calculation are therefore here given:

$$\text{Oxygen in parts per million} = \frac{0.0002\,N \times 1{,}000{,}000}{V} = \frac{200\,N}{V},$$

$$\text{Oxygen in cc. per liter} = \frac{0.1395\,N \times 1000}{V} = \frac{139.5\,N}{V},$$

$$\text{Oxygen in per cent of saturation} = \frac{200\,N \times 100}{V \times O} = \frac{20{,}000\,N}{VO},$$

where N = number of cc. of $\frac{N}{40}$ thiosulphate solution,

V = capacity of the bottle in cc. less the volume of the manganous sulphate and potassium iodide solution added (*i.e.*, less four cc.).

O = the amount of oxygen in parts per million in water saturated at the same temperature and pressure.

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

Temp. C.	Oxygen.	Temp. C.	Oxygen.	Temp. C.	Oxygen.	Temp. C.	Oxygen.
0	14.70	8	11.86	16	9.94	24	8.51
1	14.28	9	11.58	17	9.75	25	8.35
2	13.88	10	11.31	18	9.56	26	8.19
3	13.50	11	11.05	19	9.37	27	8.03
4	13.14	12	10.80	20	9.19	28	7.88
5	12.80	13	10.57	21	9.01	29	7.74
6	12.47	14	10.35	22	8.84	30	7.60
7	12.16	15	10.14	23	8.67	....	....

Free Carbonic Acid.

REAGENT. Standard $\frac{N}{22}$ solution of sodium carbonate. Dissolve 2.40 grams of dry sodium carbonate in one liter of distilled water which has been freed from carbonic acid by cautious addition of dilute solution of sodium carbonate. Add five cc. of phenolphthalein indicator (7 grams in a liter) to the distilled water before neutralizing and measuring. Preserve this solution in bottles of resistant glass, protected from the air by tubes filled with soda lime. One cc. equals 0.001 gram of CO_2.

PROCEDURE. Measure 100 cc. of the sample into a tall, narrow vessel, preferably a 100-cc. Nessler tube, and titrate rapidly with the $\frac{N}{22}$ sodium carbonate solution, stirring gently until a faint but permanent pink color is produced.

The number of cc. of $\frac{N}{22}$ sodium carbonate solution used in titrating 100 cc. of water, multiplied by 10, gives the parts per million of free carbonic acid as CO_2.

Owing to the ease with which free carbonic acid escapes from water, particularly when present in considerable quantities, it is highly desirable that a special sample should be collected for this determination, which should preferably be made on the spot. If the analysis cannot be made on the spot, approximate results from water not high in free carbonic acid may be obtained from samples collected in bottles which are completely filled so as to leave no air space under the stopper.

EXERCISE VII

EXAMINATION OF COLLECTED SAMPLE COMPLETED

Blank form to be filled out with all the tests that promise any help, however slight, in the completion of the diagnosis of the case for the prosecution; for it is the sum total and not any one special thing which determines the sentence in ninety out of one hundred examples.

SANITARY WATER ANALYSIS

Parts per 1,000,000

Address for report
Locality
Date
Description of Water

PHYSICAL EXAMINATION	Turbidity	
	Sediment	
	Color	
	Odor	Cold
		Hot
CHEMICAL EXAMINATION	Free Ammonia	
	Albuminoid Ammonia	
	Nitrites	
	Nitrates	
	Hardness	
	Chlorine	

REMARKS

SOLIDS

Amount taken
Weight of Dish and residue
Weight of Dish

Weight after ignition — Total

Sulphates — Loss
Oxygen Consumed
Iron

In cases where comparisons are to be made of the same water at different times, or of different waters for the same purpose, or of filter effluents for completeness of removal of organic matter, the carbonaceous content or "organic matter" is of consequence.

Oxygen Consumed.

Oxygen Consumed, or carbonaceous matter. This test of the quality of water dates back to the early efforts of chemists to account for the deleterious effects of some waters. At that time the ideal standard was the clear, cold, colorless, sparkling water from a bubbling spring. The greatest departure from that ideal was most suspicious. Therefore, color, turbidity, and organic matter in solution were looked upon with disfavor. Before means of distinguishing between harmful and harmless substances were known, the quantity of such substances as would burn out of the solid residue, or such as would take oxygen from potassium permanganate, was held to be a measure of the deleteriousness of the water. The habit of all primitive peoples has been to use streams as laundry tubs, following the practice of birds and beasts the world over.

All surface-flowing waters do carry organic, *i.e.* carbonaceous, substances in solution, and soft water, in wooded or cultivated regions, carries the brown coloring matter derived from leaves, peat, humus, etc. Streams may also carry refuse from manufactories, city sewage, etc.

The carbon in these extraneous substances is *partly* in such condition that it will unite with nascent oxygen set free from potassium permanganate in acid solution. If it were *all* in such state, the chemist's task would be easy. The quantity, however, varies with the substance, the degree of decomposition it has already reached, the concentration of the chemicals, and the temperature used.

So many variables are difficult of estimation, and as giving a decisive estimate of the quality of a single sample of water the test has little value. On the other hand, if a continuous series of tests is to be made on a given water or a comparison to be made of several waters for a considerable time, the determination may give most valuable results. For instance, a filter should reduce all organic content to a marked degree. Comparison of conditions before and after filtration is then most instructive, often conclusive.

The chemist may gain valuable confirmatory evidence from the quantity of oxygen consumed by a given water, but he may not rely upon it alone, as was at one time thought possible. Forchammer in 1849 proposed the process, but it was Dr. Tidy, chemist of the Rivers Pollution Commission, who in 1879 extended the scope, so that his name is most frequently connected with it.

APPARATUS. Flasks, 300 cc., flat bottom. Electric steam bath. Standard reagent burettes.

REAGENTS. H_2SO_4 (1:3); potassium permanganate; 1 cc. = .0001 gram oxygen; oxalate 1 cc. = .0001 oxygen.

PROCEDURE. The English custom was to put away a measured portion, with the reagents cold, for varying times, as one hour, four hours, twelve hours, or twenty-four hours.

The speed of reaction indicated the quality of the water. This plan has not been found of special value for American waters. The quicker methods appeal to our chemists, and the German modification, or Kubel hot acid process, has found most favor, the heating to continue 2 minutes, 5 minutes, 10 minutes, or half an hour according to circumstances. Little importance is attached to the actual figures, and it is as a control in continuous work — often a valuable one — that it is chiefly used.

Under these conditions each laboratory has its own practice, and standard methods for the whole country are hardly desirable, since colored waters and turbid waters give in any case non-comparable results.

For students' practice, the two-minute boiling serves as well as longer, more precise treatment requiring several precautions. These are discussed in " Standard Methods."

DIRECTIONS. Measure 100 cc. of the water into a 250-cc. flat-bottomed flask, add 10 cc. of sulphuric acid (1 : 3) and about

10 cc. of the potassium permanganate. Place the flask on wire gauze and heat it quickly to boiling. Boil the solution for exactly two minutes; remove it from the flame; let it cool one minute, and add 10 cc. of the ammonium oxalate. Titrate with the permanganate to a faint permanent pink color. Each cc. of the exact permanganate used in excess of the oxalate solution used represents 0.0001 gram of oxygen consumed by the sample.

NOTE. For highly colored surface waters 25 cc. are taken and diluted to 100 cc. with water free from organic matter; for sewage 10 cc. are diluted in the same way.

The oxygen given up by the permanganate combines with the carbon of the organic matter and perhaps to a certain extent with the hydrogen, but not with the nitrogen. The amount of oxygen consumed bears some relation, therefore, to the amount of organic carbon present in the water, but this relation certainly cannot be taken as a definite one in every case, the results varying even with the time of boiling. The method has its greatest value when it is used to compare waters of the same general character and having the same origin, for example in making periodical tests of the purity of the effluent from a filter. Furthermore, in order that the results shall have this comparative value, it is absolutely necessary that the process shal always be carried out in exactly the same way, even to the minutest detail of quantity, time, and temperature.

In some cases it may be found advantageous to heat the solution upon the water bath for half an hour instead of boiling it for five minutes. The results, however, will not be exactly comparable with those obtained by boiling.

Since the solution of permanganate does not hold its strength, especially if exposed to the light, it is necessary to determine its value not only when made up but every day or two. A "blank" determination is made by adding less than 10 cc., 7 or 8 cc., to 100 cc. of double-distilled water, using the same measure of acid and the same time of boiling as in the sample to be tested. Ten cc. of ammonium oxalate should decolorize to a colorless liquid, and titration to the faint pink color will give the value of the permanganate in terms of the correct oxalate.

This must not be relied on for many weeks, although it keeps its strength better than oxalic acid. If a brown precipitate appears before or after adding the oxalate it is probable that the measure of sulphuric acid has been omitted. The value given by the "blank" should serve for two or three days' work. The time may be prolonged by keeping the solutions in the dark.

Different kinds of organic matter behave differently with various oxidizing agents, so that a comparison of the results obtained with different oxidizing agents may throw light upon the character of the organic matter as well as its amount. In waters from the watersheds of eastern North America the color and the oxygen consumed have a certain though somewhat varying relation. See pp. 124–125.

Color.

Color in surface waters is due to vegetable extract, reddish brown to light straw yellow according to strength of solution and, in a degree, to age of leaves (early fall or late spring) and to kind of leaves; pine needles give very little color. This color is read as ammonia standard colors, as platinum standards, or with the colored glasses of the Lovibond Tintometer, and recorded on the blank.

Just as the engineer runs a base line to give datum lines for future operations, so the analyst sometimes needs to complete tests for reference in case of subsequent changes of conditions.

Total Solids.

In cases of the installation of a new supply for a town or a country residence the determination of total solid matter is of use.

For comparison of two or more waters, of the same water in different years, and especially for information regarding progressive pollution, the test may be important.

APPARATUS. Platinum dishes, 150 to 200 cc. capacity.

REAGENTS. None.

PROCEDURE. Ignite and weigh a platinum dish. Measure into it 100 cc. of the water (200 cc. in the case of surface waters) and evaporate to dryness on the water bath. When the water is all evaporated, heat the dish in the oven at the temperature of boiling water for two hours, then let it remain in a desiccator over sulphuric acid for several hours and weigh. The increase in weight gives the " total solids," or " residue on evaporation." If from a ground water, save the residue for the determination of the iron.

Loss on Ignition.

In the case of surface waters the residue should be ignited and the loss on ignition noted. Heat the dish in a " radiator," which consists of another platinum dish enough larger to allow an air space of about half an inch between the two dishes, the inner dish being supported by a triangle of platinum wire. Over the inner dish is suspended a disk of platinum foil to radiate back the heat into the dish. The larger platinum dish is heated to bright redness by a triple gas burner. Heat the dish in the radiator until the residue is white or nearly so. Note any blackening or charring of the residue and any peculiar " burnt odor " which may be given off. After the dish has cooled, slightly moisten the residue with a few drops of distilled water to secure weighing under the same conditions. Heat the residue in the oven for half an hour; cool in a desiccator and weigh. This gives the weight of "fixed solids," the difference being the "loss on ignition." Surface waters carrying much mud or other suspended matter are often filtered. The difference gives the suspended matter removed by passing through filter paper. For the use of the Gooch crucible see Exercise X, p. 267.

Before the introduction of modern methods of water analysis the determination of " loss on ignition " was the only method for the estimation of organic matter in water. In order, however, that the determination shall possess any real value, it is necessary to regulate carefully the heat during the ignition, so as to destroy the organic matter without decomposing calcium carbonate or volatilizing the alkali chlorides.

This is what the use of the radiator is intended to acccomplish, and in the case of surface waters with low mineral content and considerable organic matter the method gives generally satisfactory results. But in the case of ground waters having little or no organic matter and high mineral content the loss is often very great on account of the decomposition of nitrates and chlorides of the alkaline earths and the loss of water of crystallization. In waters of this class the determination of "loss on ignition" is, therefore, generally meaningless, although an approximation to the amount of organic matter can be obtained by the addition of sodium carbonate to the water before evaporating to dryness. By this means the alkaline earths are precipitated as carbonates, the chlorine and nitric acid are held by an alkaline base, and there is no water of crystallization in the residue. Even with this modification the loss is considerable when magnesium salts are present, owing to the loss of carbonic acid.

The *behavior* on ignition is oftentimes significant. On evaporation to dryness, swampy or peaty waters give a brownish residue which blackens or chars, and this black substance burns off quite slowly. The odor of the charring is like that of charring wood or grain; sometimes sweetish, but not at all offensive. Waters much polluted by sewage blacken slightly; the black particles burn off quickly and the odor is disagreeable. Any observations on this point should be recorded in the report under the heading "Change on Ignition."

The residue may be utilized for sulphates or iron.

Iron.

Iron, while not serious from a sanitary point of view, is of considerable consequence in considering a domestic supply which includes laundry.

Apparatus. Platinum dish from total solids determination, or No. 4 porcelain dish, 100-cc. Nessler tubes.

Reagents. HCl (1:1). Potassium sulphocyanate solution. Standard iron solution, 1 cc. = .00001 gram Fe. (This dilute standard is best for general use.)

Procedure. Evaporate 100 or 200 cc. of water to dryness in a platinum dish. (The weighed residue from the determination of total solids may be used if desired.) Treat the residue with 5 cc. of hydrochloric acid (1 : 1), being careful to carry the acid to the edge of the dish. In some cases it may be necessary to heat the dish gently on the water bath in order to bring all the iron into solution. When all is dissolved with the exception of silica, rinse the solution into a 100-cc. tube and make it up to about 50 cc. with distilled water. Add a solution of potassium permanganate drop by drop until the solution remains pink for ten minutes.

Meanwhile prepare a blank standard with 50 cc. of distilled water and about a cubic centimeter of hydrochloric acid. Add 15 cc. of potassium sulphocyanate solution to the water and to the blank standard. Add the standard iron solution, in small quantities, .02 cc. if necessary, from a capillary pipette, mixing thoroughly by pouring the solution back and forth from one tube to another after each addition, until the color of the standard matches that of the water.

In the case of some river waters it will be found necessary to add a few cubic centimeters of hydrochloric acid to the water while evaporating, in order to facilitate the solution of the iron. This should be done on a separate portion from that used for the determination of total solids.

The colors should be matched immediately after adding the sulphocyanate, since the color fades appreciably on standing. The highest standard should not contain more than 20 cc. of the iron solution, since the color then becomes too deep for accurate comparison.

EXERCISE VIII

GROUND AND SURFACE WATERS AND MIXTURE OF THE TWO. INTERPRETATION OF PUBLISHED RESULTS

It is not infrequently of importance to ascertain the character of a water, especially a lake, as to its probable behavior when used as a reservoir, probability of algæ growths, or of development of other organisms, many of which give disagreeable odors or clog pipes.

There is a technique of interpretation as of laboratory work, and the engineer is more often called upon to interpret the results of the chemist than to make his own determinations.

Some examples of interesting results are given for the student's practice in reading the figures and terms used by the technical chemist.

SANITARY WATER ANALYSIS
Parts in 1,000,000

Locality, state.	Physical.		Residue on Evaporation, total.	Nitrates as			
	Color.	Sediment.		Albuminoid ammonia, total.	Free Ammonia.	Nitrites.	Nitrates.
1 Unknown	......	......	110.0	.200	.040	....	....
2 R. I.	0	0	....	.010	.000	.000	....
3 N.Y.	0	0	....	.016	.010	.000	.850
4 Mass.	.25	cons. green	33.0	.478	.000	.000	.000
5 Mass.	.52	0	46.7	.194	.026	.001	.011

Oxygen Consumed.	Hardness.	Chlorine.	Iron.	Incrusting Constituents.	Alkalinity.	Bacteria per c.c.
1	....	20.	2.0	....	....	....
2 .100	71.0	30.	....	....	....	....
3 .300	109.0	....	....	....	....	....
4 6.000	11.0	1.1	....	....	....	....
5 5.300	4.0	11.9	....	....	....	....

No. 1 does not give data enough upon which to base an opinion. Number 2 cannot be rightly interpreted without nitrates, No. 3 without chlorine, etc.

In No. 4 the high albuminoid ammonia is explained only by the presence of the great amount of green algæ, which are harmless.

In No. 5 the chlorine by nearness to the sea.

In some complicated cases the whole 20 determinations taken together are necessary for a correct interpretation.

The expert has to interpret human nature as well as his results. Even if he visits a place, he may not find out at first all the conditions.

The water from a farm school well was found to be very offensive in odor and to give a high quantity of free ammonia but with normal chlorine, no nitrates, and little nitrites. The presumption was that something had fallen into the well which was blasted out of the ledge. Directions were given to have the well cleaned out. The laboratory force were astonished one day by the appearance of the caretaker and his wife bearing a wooden pail half full of dead angleworms. They seemed very incredulous when they were told that there was cause for an even worse condition of the water. They said, "That could not make any difference, could it?"

Sickness having broken out in the neighborhood of a mining town which was considered a model of such settlements, the wells were tested, and the only one showing evidence of previous pollution was that at the hospital. For weeks it remained a mystery, until one man recalled the fact that a few years before, an old cesspool had been filled in and a well dug within a few feet of the spot.

EXERCISE IX

EXAMINATION OF SAMPLE FROM THE STUDENT'S HOME TOWN OR FROM A SUMMER HOME TO SERVE AS A REVIEW AND FIXATION OF ROUTINE PROCEDURE

The very best possible training for the class will be for two or three to go out on an investigating trip and collect several samples under noted conditions representing several different qualities of water; for instance, a small lake with the streams tributary to it and the outlet, a well or two, or a drain from a barn or sewage field.

The rest of the class may make the tests and draw their own conclusions, and then in a round-table discussion bring out their various opinions and have them checked up by the observation of those who have been on the spot.

It may be necessary for a second squad to go out and complete the observations which the first are obliged to confess ignorance of.

In some way a close connection must be made between the laboratory and the field.

EXERCISE X

Sewage Analysis in a Water Laboratory

A testing laboratory is liable to be confronted with various problems. The methods to be used and the extent of the work to be done will depend upon the information desired.

These methods would be modified for a control station doing only sewage work.

If it is merely a comparison of the composition of the given sample with some other, then the tests must be as comparable as is possible.

If the engineer is to devise a method of treatment, then it depends upon the completeness of clarification or of purification demanded. Unnecessary work is not to be recommended, but neither should treatment fail because a few results are lacking.

Whatever the process, the fact that the fluid is extremely unstable is always to be borne in mind, and also that increase of temperature causes rapid change. Therefore the sample is to be tested for certain things at once or the fluid must be guarded from change. Or, if the process is to be applied to the stale material, the laboratory sample should be incubated to cause the hastening of the change.

Many a well-laid plan has failed of giving satisfaction because of the neglect of well-established chemical principles. Here is where the engineer may be glad of his chemistry.

There can hardly be an "average" sample, for the content of a sewer is of an extremely miscellaneous character, — orange peel to dishcloth, grease from the kitchen and acid from the laboratory, varying every hour and every day in the week.

Sewage Sampling. Just as in mining schemes trouble has come from willful or ignorant misrepresentation of the samples tested, so, all unwittingly, a purification process for dirty water may be devised on samples which may not represent the usual flow. Again, what is to be considered the usual sewage? On Mondays it carries more soap and grease; on Saturdays more yeast and starch; on Sundays more bathroom waste, *i.e.*, more dilute and less factory wastes.

The investigator needs close contact with the daily conditions, and the unpleasantness should not deter him from knowing the details. He needs a general knowledge of what he is liable to find. Specialized knowledge is not expected of the student.

The wide range in composition may be stated as follows: solid residue on evaporation, 150 to 1050 parts in a million. Of this there is lost on ignition (supposedly organic matter) 40 to 400 parts; carbonaceous matter, or oxygen consumed, will be 30 to 300 parts; albuminoid ammonia from 5 to 15 parts (except in trade wastes, where it may be 100 times as much).

The already broken up substances may give "free ammonia" 10 to 50 parts; nitrites, .0 to .300; nitrates, .0 to .900. The chlorine increment over the city supply may be 30 to 150 parts in town sewage. Trade wastes may give more or less. Where salt water is used for street watering and the street drains discharge into the sewers, the chlorine may be high.

I. *Kinds of Sewage. Analysis for Strength*

This test is often needed in order to determine the amount and character of the pollution of a stream to be investigated. It should be borne in mind that one sample is not sufficient to give a base line. Abnormal as well as diurnal variations are to be allowed for.

1. Determination of total solids or residue on evaporation. 10 to 100 cc., according to apparent strength, are evaporated in a previously weighed platinum dish, to which is added 5 cc. of sodium carbonate of known strength. This is used for the purpose of changing the probable calcium nitrates, or magnesium sulphates, or other substances containing water of crystallization, into anhydrous residues. The known weight of sodium carbonate is subtracted from the total.

The sampling of unfiltered sewage requires care. If time is not of prime importance, the larger sample is safer. 50 cc. as a rule gives good results. In measuring 10 cc., clots are apt to pass into one measure and not into another.

After thorough drying — one hour at least in the oven — weigh. Ignite in the radiator; weigh.

Record, also, the composition of the town supply.

The residue may be used for tests, *i.e.*, sulphates, phosphates, iron, etc.

Filtered samples are to be treated in the same manner, the difference being recorded as suspended matter. Or the latter may be determined directly in a Gooch crucible.

The Columbus, Ohio, Method for the Determination of the Total and Volatile Suspended Matter by the Gooch Crucible

Asbestos adapted for use in the Gooch crucible may be readily prepared from the granular commercial product by digestion on a water bath in strong hydrochloric acid for several hours.

Prepare a dilute cream of the washed asbestos, which must be free from coarse particles, attach the crucible to the filter flask in the usual manner, start the suction, and form a mat about $\frac{1}{16}$ inch thick upon the bottom of the crucible. After the asbestos has drained completely, apply to the crucible a small quantity of distilled water. If the mat is of the correct thickness, the distilled water will pass through the filter at the rate of about 50 drops per minute. Place the crucible in an oven at 110° to 120° C. for fifteen minutes; remove and ignite in a radiator for five minutes; cool in a desiccator and weigh.

From the well-mixed sample measure 50 to 100 cc., decanting into the crucible as great an amount as possible of the supernatant water before the main portion of the suspended matter is applied thereto; in this way the filtration will be more rapidly accomplished. When the filtration is completed, rinse out the flask with about 15 cc. of distilled water. To guard against imperfect filtration, it is advisable to apply the suction gradually. In case the filtrates are cloudy, they must be refiltered until clear.

The crucible is dried at 110° to 120° C. for one hour, cooled in a desiccator and weighed, the increase in weight representing the *total suspended matter* in the sample. To obtain the *volatile suspended matter*, the weighed crucible is ignited in the radiator at a low red heat for ten minutes, or to constant weight.

Removal of Mat. To prepare the crucibles for further use, remove the mat, rinse well in tap water, and finally with distilled water, making sure that the perforations in the bottom of the crucibles are not clogged."

2. Estimation of the nitrogenous organic matter remaining in the sample to be tested, whether unfiltered, filtered, or clarified, is an oftentimes useful test.

Total Nitrogen.

Total organic nitrogen by the Kjeldahl method. The simplest procedure, taking the least time, is necessary for a class exercise.

Measure 25 to 100 cc. into a round-bottomed flask. Add 250 cc. of ammonia-free distilled water; concentrate to half the volume; cool; add 10 cc. nitrogen free H_2SO_4 and digest under the hood until the white fumes begin to come off. Then place a small funnel in the mouth of the flask to condense the H_2SO_4. Digest until the liquid is colorless or has only a faint tinge of straw color.

It is more convenient (and some authorities hold the belief that more intelligible results are thus gained) to add the 10 cc. of H_2SO_4 directly to the sample as measured into the flask and digest as before. This method retains the "free ammonia," which must be found and subtracted from the result. It avoids the dilution and expulsion of ammonia in the sample and so hastens the operation. Some think it avoids the loss of some nitrogenous substances on boiling.

The colorless or straw-yellow acid liquid is now cautiously diluted with ammonia-free water, rinsed into a 250-cc. flask made up to the mark, mixed thoroughly, and an aliquot part, usually 25 cc. or .1 the amount, added to 250 cc. of ammonia-free water in the usual distilling flask. The ammonia formed from the organic nitrogen during the process is set free by the addition of 40 cc. of the alkaline permanganate solution, or of a specially prepared solution containing only enough permanganate to insure the absence from the reagent of any decomposable organic substance.

Quick work is required in this part of the process to prevent loss of the ammonia set free.

150 cc. are distilled from the volume into a 200-cc. flask and 50 cc. Nesslerized.

3. While the two long processes — evaporation for the solids and digestion for nitrogen — are going on, consumed oxygen may be determined. This is another indeterminate process (see previous notes), but one which may give valuable aid in the final summing up.

4. Chlorine may be determined by direct titration of 25 cc. Some samples may be acid and must be made neutral with dilute sodium carbonate solution. Some samples must be clarified by shaking up with milk of alumina.

II. *Kinds of Sewage. Analysis with Reference to Disposal*

Determine, in addition to the above,

1. Free and albuminoid ammonia,
2. Nitrites,
3. Nitrates,
4. Hardness.
5. H_2S.

Put away samples for putrescibility on incubation.

Tests with reference to
Removal of suspended matter.
Laws of settling particles.
Sedimentation.
Coagulation and subsequent sedimentation.
Agitation to remove adhering gas bubbles.
Shock to separate.
Electricity for dust and for suspended particles.

Time is usually essential, but if it is to be eliminated, then force is used. But force soon clogs the strainer, from the gelatinous nature of the substance to be removed.

The greater use of previous coagulation and sedimentation demands a closer study of the chemical changes consequent upon them.

Given a subsidence reservoir, which is two-thirds drawn off each day, in a month's time there will be a considerable collection of the coagulant and its precipitated ally.

How will the inevitable decay affect the supernatant liquid?

What substance will be added to the water?

Far more important than mere quantity is the character. Sand and chemical products take care of themselves. It is the gelatinous portion of slow decomposition that gives the most trouble.

III. *Kind of Sewage. Analysis with Reference to Treatment.*

Tests for

1. Acidity.
2. Starch and sugar content, which soon yields acidity.
3. Presence of antiseptics.
4. Clogging action
    - colloids on surface.
    - fine particles (clay) in sand.
5. Quantity and kind of coagulant.
6. Lowest safe limits of dilution.

Indication of the amount of suspended matter to be dealt with on the filter.

The test for putrescibility is made in different ways, two of which will be described. The first is called the odor test. In this method an average sample of the effluent, contained in a bottle which is completely filled and tightly stopped, is placed where the temperature can be maintained practically constant at 37° C. (or 98° F.).

At the end of forty-eight hours the stopper should be removed and a test made for odor. If the sample gives off no offensive odor, and is not blackened, a non-putrescible effluent is indicated.

If the odor is slight and disappears almost immediately upon removing the stopper the results are questionable. If the sample has blackened and gives off foul odors, the sample is putrescible and the degree of purification is unsatisfactory. In case it is not convenient to maintain a temperature of 98° F., the same result may be obtained by keeping the sample at a temperature of 68° F., but twice as long a time should be allowed before opening the bottle.

The second method is known as the methylene blue test. A small portion of an aqueous solution of the dye (1 cc. of a 1 per cent solution) is added to the effluent in a glass-stoppered bottle of 250 cc. capacity, and the sample is kept at either 98° or 68° F. During the period of observation the blue color of the solution remains practically unchanged until the available oxygen in the effluent is used up by the organic matter present and putrefactive conditions arise. At this point the dye is reduced and decolorized. The time required for decolorization is a quantitative measure of the degree of putrescibility of the sample, and the retention of the color for a period of four days or more at 68° or of two days at 98° may be taken as an indication of good stability. Instead of the periods mentioned, some use a period of one week at 68° and four days at 98° as the standard. A higher degree of purification is required to satisfy this test than the test with shorter periods. A note should be made, in the records of tests, of the standard used.

The trickling filter represents the latest method of sewage purification.

In a study of the treatment of wastes before they are allowed to enter running water certain facts are to be kept clearly in mind.

First. It is the changes occurring in matter high in nitrogen that cause most trouble from odor (the chief element causing *nuisance*).

Second. There are great differences in rate of decomposition of nitrogenous substances. Sewage wastes are already past the first stage; creamery wastes are readily putrescible; tannery wastes have both easily and slowly changing elements; most manufacturing wastes as they come from the mill contain both. The decomposition of unstable substances may be hastened by distribution in thin layers or in drops, also unsavory gases tend to disappear; oxygen being taken on in their place.

The more permanent substances await a favorable time. The relative amount of the two classes, unstable and stable, besides the decomposed material already in solution, is to be approximately known before a plan of treatment may be followed.

One way is to incubate the sample for twenty-four, thirty-six, or forty-eight hours at 30° to 40° C., and determine the change.

To ascertain the important fact whether the matter to be decomposed is already in solution, a portion may be treated with milk of alumina and filtered through paper.

The chief divergence from sewage, noticed in other wastes, is usually the higher oxygen consumed, and higher albuminoid ammonia in proportion to the free ammonia and consequent high loss on ignition.

Usually there is a higher mineral content and very often the kind of waste is betrayed by color or odor. Each case must be worked up on its merits.

In an earlier discussion of the cycle of nitrogen and its aid to interpretation of observed facts the differences in composition between animal and vegetable substances was noted. Recent investigation seems to show that it is not so much what has been called animal and vegetable, but that the distinction lies in the quantity of substances that enters into the living matter in each. To be alive is to be in a state of constant change or rearrangement of component parts, — atoms, ions, — or perhaps in the rapidity of motion of electrons.

In vegetables (fixed plant life) these changes are carried on with less protoplasm, that network of nitrogen, sulphur, and phosphorus about which and within which the chemical changes, building up in plants, tearing down, release of energy in animals, take place.

We may say that so far as our knowledge goes the forces of life and decay have to do with N, S, and P, and that carbon is the chief element with which these forces play in presence of water, H_2O, or at least HO, hydroxyl, or hydrol as some prefer.

In water examinations it is the products of decay which indicate danger. It is evident that a pound of leaves may give the same end products as a pound of lean meat, but that they will be in different proportions. The leaves will undergo the starch (see usual reaction) and cellulose fermentations, the latter yielding as end products CO_2 and H_2O with an intermediate CH_4, methane, marsh gas. Hoppe Seyler considers this the special business of the fission fungi and the probable reaction as:

$$C_6H_{10}O_5 + H_2O = C_6H_{12}O_6 = 3\ CO_2 + 3\ CH_4.$$

Others hold that the setting free of CH_4 is accompanied by the formation of acetic and butyric acids. In the absence of air, as at the bottom of ponds or of tanks, the butyric fermentation may be after this order:

$$C_6H_6O_6 \text{ gives } C_3H_7COOH + 2\ CO_4 + 4\ H.$$

But all life requires nitrogen, and leaves as well as all other vegetable tissues contain dead protoplasm to be disposed of. Rideal gives two possible reactions: hydrolysis, or breaking down by addition of water. A solution.

(1) $4\,C_8H_{13}N_2O_3 + 14\,H_2O \text{ gives gases } 4\,N + 19\,CH_4 + 13\,CO_2 + 2\,H_2.$

This is a typical decomposition without taking account of sulphur or phosphorus, or according to the species of bacteria at work the following may occur:

(2) $2\,C_8H_{13}M_2O_2 + 16\,H_2O \text{ gives } 4\,NH_3 + 16\,CO_2 + 33\,H_2.$

The greater activity of animal life seems to demand more S and P as well as N. S is a constant constituent of albumin; therefore the end products yield perceptible quantities of evil-smelling compounds of these elements, such as H_2S and mercaptans. The reactions are somewhat obscure, but the following have been suggested and will serve the purposes of illustration, even if they do not occur in just this manner:

$$\text{Albumin} \left\{ \begin{array}{l} C_{72}H_{112}N_{18}O_{22}S, \\ C_{728}H_{1171}N_{194}O_{214}S_3, \end{array} \right.$$

or is supposed to yield under some conditions at least such compounds as Argenin, $C_6H_{14}N_4O_2$; Lysin, $C_6H_{14}N_2O_2$; Histidin $C_6H_9N_3O$; Hæmatin, $C_{32}H_{32}N_4O_4Fe$.

The first three may break up according to the general formula

$$R-NH_2 + NOOH = 2\,N\ (\text{free nitrogen}) + H_2O + R - OH.$$

There is present in feces, Lucine, $C_6H_{13}O_2N$, which plus $2\ H_2O$ $= C_5H_{10} + CO_2 + 2\ H_2$ (free hydrogen) $+ NH_3$ (an example of hydrolysis).

There is also Tyrosine, $C_9H_{11}O_3N$, which in absence of air yields

$$C_8H_7N_1CO_2 + H_2O + H_2$$

$$4\,C_8H_{13}N_2O_3 + 14\,H_2O = \text{the gases} = 4\,N_2 + 19\,CH_4 + 13\,CO_2 + 2\,H_2.$$

This is another example of hydrolysis.

Also, Urea, $CON_2H_4 + 2\,H_2O = CO + (NH_3)_2 + H_2O$.

Nitrous acid *can decompose urea, but is itself at the same time decomposed.*

$$CO(NH_2)_2 + 2\,HMO_2 = CO_2 + 4\,N\ (\text{free nitrogen}) + 3\,H_2O.$$

Sulphur in albuminoids is very easily removed by organisms, some utilizing it for themselves, some causing it to be evolved as H_2S (a fission fungus has been grown in a pit water rich in $CaCO_4$ so successfully as to convert all the gypsum into CaS and FeS). Also $CaSO_4 + CH_4 = CaCO_3 + H_2S + H_2O$. Thus N, H, CO_2, CH_4, NH_3 are the end products of nitrogenous fermentations.

The usual sewage pollution which the engineer is called upon to recommend disposal for, is a mixture and a most indefinite mixture, varying not only every day in the week but every hour in the day. Discharged into a stream it is, moreover, more or less diluted; as the stream rises and falls it is pushed against the bank by the current and mingling with the colder water is often delayed by the friction of the banks.

After a short distance has been traversed the fluid has become so complex that any question of animal or vegetable origin of the organic matter is futile.

However obtained, the products include CO_2, CH_4, NH_3, N, H_2O, H, H_2S, SO_2 (?), sulphur, alcohols as mercaptan, C_2H_5SH, etc.

Although little is known of the decomposition of the phosphorous radicals, they doubtless add to the odors. Offense is given by the intermediate products only, and by those not food for organisms but produced by chemical *reduction* processes, enzymes, etc. Therefore it is the manager's task to keep the process going *forward* as fast and as far as is possible, and not backward.

The laboratory work of the class will depend upon the time available. The best exercise will be a test for sulphur products (either lead or zinc acetate — odor may be more delicate) or for organic acids as butyric, and for fats, soaps, etc.

The chief value of this exercise will be to draw attention to investigations now going on which may change all views. See Rideal, Sewage and the Bacterial Purification of Sewage; Lafar, Vols. I and II, Chemistry of the Proteids, Gustav Mann, etc.

EXERCISE XI

TRADE WASTES

If a field trip cannot be made for collection the instructor may procure a variety from different sources.

What was said of the extreme variation of sewer content is still more true of the discharge from manufacturing plants, the chemicals used in the processes, the materials themselves, often of putrescible substances, as in a tannery or a creamery;

of greasy character, as in wool scouring; of turbidity producing, as in the manufacture of glucose. Near the discharge it is comparatively easy to recognize the component parts, but after dilution with 10,000 parts of the water supply the determination of what has remained undecomposed and what has passed beyond need of consideration is often a case for considerable study.

No definite rules can be given.

The following trade wastes may be taken as typical.

AVERAGE ANALYSES OF WATER LIQUOR, FILTER EFFLUENT, AND PERCENTAGE REMOVAL OF ORGANIC MATTER OF WASTE FROM (A) WOOLEN MILL, NO. 2, (B) SHODDY MILL, AND (C) A MILL MAKING BINDER'S BOARDS[1]

Waste.	Total Residue.	Total loss on Ignition.	Ammonia.		Nitrogen as		Oxygen Consumed.
			Free.	Total Albuminoid.	Nitrates.	Nitrites.	
Raw (A)	162.3	62.4	.1000	.5330	....	.....	11.0
Applied	150.6	54.6	.0700	.3400	....	.....	8.7
Effluent	115.3	12.6	.0280	.0514	.01	.0023	0.97
Percentage removed by							
(*a*) Sedimentation	7	12	30	42	....	.....	22
(*b*) Sedimentation and filtration	29	30	72	91	....	.....	91
(*c*) Filtration	23	77	60	85	....	.....	89
Raw (B)	71.7	36.9	.6400	.4300	....	.....	4.30
Applied	53.6	10.1	.6225	.1298	....	.....	1.94
Effluent	61.1	9.4	.0176	.0534	1.01	.0419	0.67
Percentage removed by							
(*a*) Sedimentation	25	72	3	70	....	.....	56
(*b*) Sedimentation and filtration	15	75	97	88	....	.....	85
(*c*) Filtration	.....	7	97	59	....	.....	65
Raw (C)	67.9	29.4	.1800	.3550	....	.....	7.20
Applied	32.1	16.0	.1197	.1930	....	.....	3.72
Effluent	24.9	7.9	.0102	.0355	.11	.0002	0.70
Percentage removed by							
(*a*) Sedimentation	53	46	33	46	....	.....	48
(*b*) Sedimentation and filtration	63	73	94	90	....	.....	90
(*c*) Filtration	22	50	91	82	....	.....	81

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[1] Mass. State Board of Health, Report No. 38, pp. 298, 299, 300.

EXERCISE XII

STANDARD SOLUTIONS. PERMANENT STANDARDS

Outfit for general work. Outfit for field work. See Part I, page 101.

As to the manufacturer the phrase "time is money" has come to mean a real principle, so to the engineer the phrase "delay is fatal."

Many of the questions coming before the Boards of Control and before municipal and state laboratories need to be answered at once and with the least expenditure of time.

Permanent Standards in Water Analysis

Every chemist has noted with regret the hours that are consumed in preparing the various color standards for comparison now so universally used for the determination of the small amounts of ammonia, nitrites, nitrates, and other substances occurring in water.

Nearly every analyst has tried to minimize the time thus expended by some mineral solutions of his own or others' devising, which will keep indefinitely and be always ready.

There are two insurmountable obstacles to perfect success: first, that such pure or mixed solutions, frequently strongly acid, have a clearness and brilliancy of tone which the complex sample to be matched never possesses; and second, that the color produced in the solution to be tested depends upon a variety of conditions — temperature, quantity of reagent added, manner of making reagent, variable quantity of accompanying substances, time elapsing after preparation before comparison of color, and a score or two more, practically impossible to control perfectly. The determination of ammonia by the Nessler reagent is a familiar example.

These difficulties may be removed to a greater or less extent by careful preparation of the standards from solutions as nearly as practicable of the same order of variability.

Hence it is that permanent standards, made up to match a given set of conditions, *cannot be relied on under all other circumstances.* Nevertheless they have their uses; and for field work, where comparison within certain limits only is to be exacted, approximately permanent standards for all the common tests serve an admirable purpose.

In preparing a portable field apparatus for the Louisiana Purchase Exposition two or three combinations were devised which may prove useful. The Griess test for nitrites is one of the most valuable for field work, but in the conditions under which tests must be made — lack of pure rinsing water, dusty atmosphere, and hasty work — the very unstable nitrite standard is a source of anxiety, and therefore a set of permanent standards is much to be desired.

The most satisfactory approach to these are the two Milton Bradley standard papers. The violet-red VR tint 2 is an exact match for the color given by 5 cc. of the standard nitrite solution 1 cc. = 0.0000001 gram N in a cubic centimeter, when the test is made in a 100-cc. Nessler tube with a depth of 5 inches to the graduation mark. The VR tint 1 matches the color given by 10 cc. of the standard under the same conditions. For field work the proper corrections are made for differences in volume and size of tubes before leaving the laboratory.

Standards for the Grandval and Lajoux nitrate test were made from the neutral potassium chromate used for indicator in the chlorine test. For the deeper colors and ammonia, a solution made after Tidy's formula was found to be practicable for dilution to the desired tints. $K_2Cr_2O_7$, 0.25 gram $CoSO_4H_2O$, 9.05 grams per liter. This solution avoids the strong acidity so unpleasant in portable cases.

Aside from the acidity of the platinum standards they do not hold their color as well as does the Tidy solution in the stronger tints and under the conditions of field work.

Standards for oxygen dissolved may be made in the laboratory for field trips from the iodine and chromate standard solutions, which, if tightly stoppered and kept in the dark, will last some weeks. If clear glass flat bottles are used the per cent of saturation may be quite approximately determined.

The chemist has been trained to a degree of exactness which often makes him skeptical of the value of approximate results, while the engineer, more than a match for the chemist, knows that there is a large factor of safety in most calculations and that a wide margin for variations is to be allowed.

The use of standard paper for nitrites is a case in point. As was explained under Exercise I, numerical exactness is time thrown away in the usual preliminary tests of the laboratory.

Suppose a sample of water is brought in to find out if it has been contaminated from a hen yard; before going through a two-days' minute examination, the analyst may more profitably make the preliminary examination in an hour's time, and by the aid of permanent standards it may be possible to give an approximate quantitative analysis.

Such permanent standards must fulfill certain requirements, like actual permanence and good comparison.

Glass fulfills most requirements — Lovibond's Tintometer with its graded colored glasses, although costly, is a very satisfactory instrument.

In a number of cases the object is best reached by standard solutions which may be prepared in large quantities and the color developed as needed — nitrate standard, for instance.

In most such cases the colors are not permanent, but that is not of special consequence except for field work.

Field Work: Its Value in Survey Inspection

The student is now prepared to study the problem of field work. This can be satisfactorily carried out only by persons previously trained in the laboratory.

To put into the hands of an untrained assistant, however intelligent, tablets prepared by the wholesale weeks beforehand, with only printed directions and slight explanations, is much the same as to give similar directions with a case of medicine pellets to an engineer going to the Philippines hoping that he may dispense them without the aid of a trained physician.

The pellets so administered might ward off an attack of disease but they would be just as likely to cause some internal disturbance. On the other hand, carried by a trained person who understands their effect they might be of the greatest use.

A field kit should be prepared in the central laboratory and the results brought back to be checked up.

In this exercise the class will use both methods, *i.e.*, field processes and laboratory tests, on the same samples of water and compare the results obtained. Illustration, Part I, page 101.

Reagent. Nessler's. Dissolve 60 grams of KI (potassium iodide) in 250 cc. distilled water free from ammonia. Add to this, cautiously, a cold solution of $HgCl_2$ (mercuric chloride) which has been saturated by boiling an excess of the solid and allowing it to crystallize out. Mercuric iodide is a brilliant red precipitate. The small amount in solution gives only a yellowish tinge. The sensitiveness of the reagent is due to a nice balance at this point. If there is an excess of $HgCl_2$ the ammonia compound is too dark in color and precipitates too quickly; on the other hand, if not enough is added to give a few specks of red precipitate, the color will be too slight or even none. Practice will enable the operator to approximate the amount of red precipitate very closely. Either solution may be added subsequently as a corrective, but with some loss in clearness. The laboratory should always match the new solution to the old before it is quite out. Dissolve 150 grams of tested stick KOH in about 250 cc. of the ammonia-free water; when cool, add to the previously prepared mercuric iodide and allow to settle over night; decant and bottle. Keep a small bottle for the daily use. Some iron is liable to be present to cause a cloudiness.

The variations in ammonia determinations due to variations in Nessler sensitiveness may be as large as 25 per cent; therefore whatever shade is adopted it should be adhered to.

Reagent. Alkaline permanganate for albuminoid ammonia (may also be used to neutralize the Kjeldahl digestate).

Potassium hydrate (stick potash) may be had free from organic or reducing substances, and such only should be used. Find a satisfactory lot and then lay in a stock. Dissolve 230 grams in about 1200 cc. distilled water free from ammonia, add 8 grams of refined potassium permanganate crystals, sprinkling them in while stirring, watching for a green color which indicates impure reagents. There is usually a slight green with the first two or three crystals, due often to bits of paper from the KOH bottle. A deep purple color should persist after the first few crystals are added. Bring to boiling temperature as a matter of precaution for five or ten minutes, but no more than the extra 200 cc. should be evaporated; allow to cool and bottle for use. The first solution from a new lot of KOH should be tested to see if 40 cc. gives, with water freed from ammonia, any more on distilling 50 cc.

The Water Assay. Example of Routine Examination.

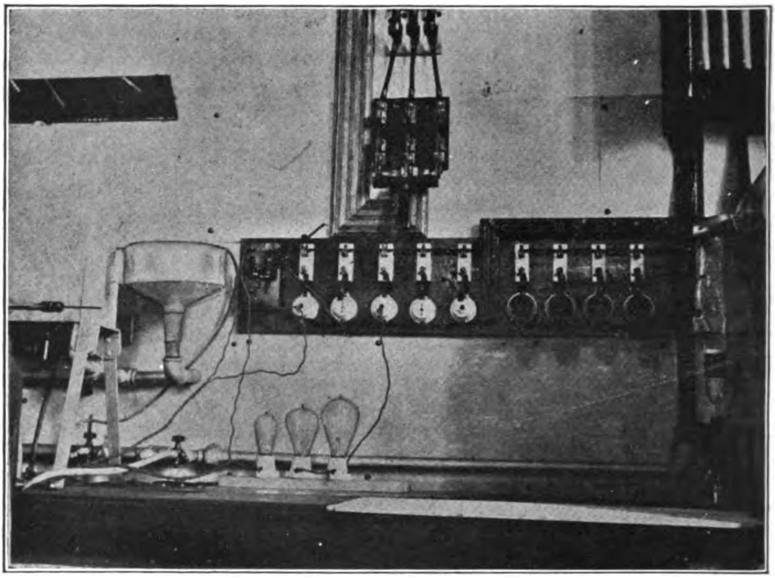
REQUIREMENTS AS TO OUTFIT, INTELLIGENCE, WORKERS.

Investigation must go hand in hand with routine work, for no outside search can compare with the questions which come to the expert in the course of daily variations. The mere routine worker does not catch the significance of the opportunity, does not see the explanation of observations extending over months perhaps.

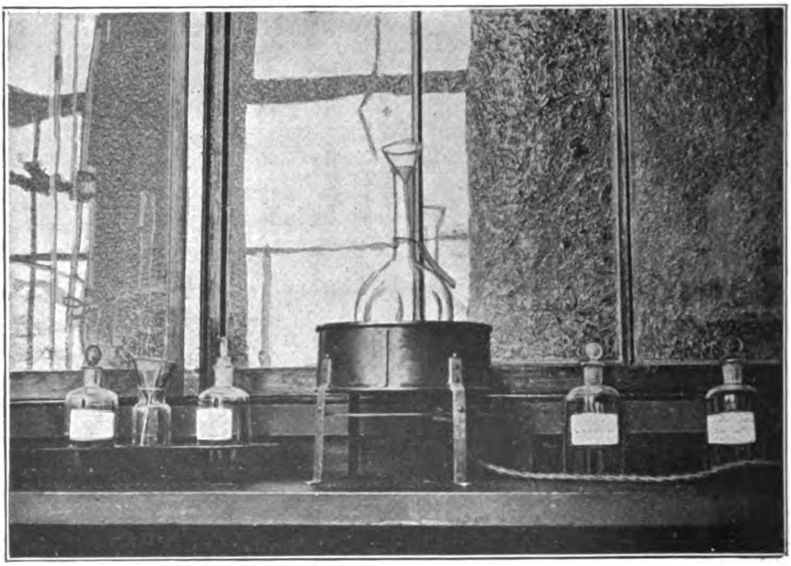
On the other hand, if the expert or manager has no idea of the possibilities of laboratory experiments, he will let slip many an opportunity.

From long experience, it is recommended that in a routine laboratory the workers be required to keep notes of each day's work, putting down all unusual appearances and any peculiar reactions, odors, etc. Such observation may prove the key to the interpretation.

Of importance it is that the worker should know the A B C of the business, the technique. If a horticulturist had never smelled violets, how would he know that they gave odors? So in the varied mixtures that are sent down rivers and into small



VIEW OF ELECTRICALLY EQUIPPED EXPERIMENT TABLE IN WATER LABORATORY



ELECTRIC FLASK HEATER IN USE IN LABORATORY FOR WATER ANALYSIS streams a knowledge of odors and of behavior of decomposing substances is of advantage. The peculiar odor of imperfect filtration, for instance, is a quicker and just as sure a test as a chemical one.

A skillful laboratory operator combines something of a business administrator, quick to seize an opportunity, combined with concentration of thought, something of a detective, watchful of any indication of the unusual, with the rapidity of working of a trained manipulator. The right test is to be made at the right time, not only to secure the right result but also to fit in best with the day's work. For instance, if the operator waits until noon to decide whether the sample must be concentrated, the whole day is lost, unless he works in the evening, so far as finishing the analysis is concerned. The half-evaporated sample must not be left exposed all night in the cleanest laboratory. All operations which require time are to be begun early. The tests which must be made on the freshly opened sample should come first—ammonia, nitrites, carbon dioxide, odors; such examinations as hardness, sulphates, etc., must await any convenient time.

A routine found to be generally practicable is as follows: 8.30 A.M., gas or electricity turned on, plates and stills started heating. Samples received the night before are examined, without shaking, for general appearance, turbidity, clayey milky sediment, flocculent organisms gathering toward the light, away from the light, at the top of the water or diffused, hydra fastened to the sides, leeches crawling on the bottom, cyclops active or dead, and daphnia, etc. When all observations are recorded, the stopper is rinsed off, also the mouth of the bottle with the contained water, and the bottle so placed that the successive samples shall be poured from the same clean side. The sample is then gently mixed. There is first taken the 500 cc. for ammonia distillation and the sample for carbon dioxide if it is required, then the 250 cc. for decolorization for nitrites and nitrates, and then and not till then is the bottle closed and shaken for half a minute so that the dissolved gases may be collected in the air space left by the abstraction of the various

SANITARY WATER ANALYSIS
Parts in 1,000,000 — 100,000

No.	Locality.	Date of		Physical.					Residue on Evaporation.			
		Collection.	Examination.	Color.	Turbidity.	Sediment.	Odor.		Total.	Loss on Ignition.	Fixed.	Change on Ignition.
							Cold.	Hot.				

SANITARY WATER ANALYSIS
Parts in 1,000,000

Nitrogen as							Oxygen Consumed.	Hardness.	Chlorine.	Iron.	Sulphates.	Remarks.
Total Organic.	Albuminoid Ammonia.			Free Ammonia.	Nitrites.	Nitrates.						(Organisms present; bacteria total count, B. coli present, etc.)
	Total.	Sol'tion.	Suspension.									

samples. The odor of the cold sample is now taken by inserting the nose into the inch-wide neck of the bottle and judging quickly by the first strong *sniff*. In the majority of cases the test is a delicate but decisive one if taken with experience and understanding. The odor of the heated sample may be confirmatory or may develop an entirely new lead.

By this time the stills are cleaned and ready for the already measured samples. In fine work it is best never to take anything for granted. All apparatus should be *proved clean* before using. With the electric still one may safely turn one's back for five minutes, as the rate is even. Nitrites may be filtered and tested, nitrates set to evaporate, chlorine put on the already hot water bath, on the whole a safer medium for chlorine than a hot plate. All the details of the work should be kept up sharply, especially the notebook; records *must* go down at the moment.

Six samples at one time are about the favorable limit for one person to handle in routine work for a complete series of tests. By 10 o'clock the record should show the physical character, the preliminary tests, the nitrites and the free ammonia in tubes ready to Nesslerize. If total solids are to be determined the dishes should now be weighed (unless they were weighed the night before and left in desiccators) and placed on the water bath protected by a ring of filter paper if silver-plated rings are not at hand. The least mark on the outside adds to the weight. Add the water after the dishes are placed, recording the numbers. The smaller the quantity of water to be evaporated the less danger of extraneous matter collected by it. The ammonia flasks are now cool enough for the dose of potassium permanganate, which must be added through a long-stemmed funnel to prevent a touch of alkali on the neck, whence it acts on the stopper if of rubber or cork, as on any organic matter, or if the stopper is of glass, helps to seal it in.

If a gas flame is used place it close enough to spread over a radius of an inch or more to prevent bumping, rotate the flask slightly to mix the heavy alkali liquid, watch until safely boiling. The electric still gives little or no trouble.

By 12 or 12.30 o'clock the racks of ammonia tubes should be set aside, covered to protect from stray dust,— there should be practically none in a water laboratory,— all the preliminary tests done, the records made up, chlorine and total solids evaporating, nitrates dry and covered ready for a convenient time to treat and read, Kjeldahl "cooking" if the test is to be made, and the operator can go to his luncheon with a good conscience; matters will be advancing in his absence.

Returning to the laboratory, the first thing is to Nesslerize and read the ammonia colors. They must be comparable and so stand the same length of time. If permanent standards are at hand the reading is simple and, with a tungsten-light apparatus, may be delayed until dark. If they are to be made up, *that* is to be done at the same time and the comparative readings taken in the strong midday light.

Although the chemist does not rely upon the amount of oxygen which a given sample of water will take from potassium permanganate as a decisive test, he finds it a useful comparison between two samples, before and after filtration, for example. He also finds in the relation between color, albuminoid ammonia, and oxygen consumed a valuable indication of the character of the dissolved organic matter as explained on page 124, Part I.

The potassium permanganate should be in excess even at the end of the boiling or half-hour digesting period; therefore if the sample bleaches it is better to throw it out and begin again. Taken in connection with this estimation of organic matter, the behavior on ignition of the weighed residue in the platinum dish is often most instructive, and in case of surface waters and filter effluents should not be omitted. The odors given off at the successive stages of heating are often characteristic. Sewage pollution not infrequently betrays itself by odor during heating more clearly than at any other stage of the examination. Practice and close attention are demanded of the operator to secure valuable results.

If a microscopical examination is to be made, it will be best to filter for it now and allow the total solids to stand overnight. It is usually best to leave them in the sulphuric acid desiccator several hours, since, because of its sugary or greasy nature, the residue needs long drying.

Hardness, iron, and other tests go over to the next day unless it is essential to get out a report. Then the cleaning up must be left and that is not advisable. In no class of operations is it so important to clean apparatus immediately after using. The Nessler tubes will keep clear for months if rinsed within the hour, but if the alkaline Nessler is allowed to dry on or to stand for hours the tubes soon become useless.

The distilling flasks are attacked by the strong alkaline permanganate left at the end of the distillation and unless washed without delay soon become so thin as to break while in use with disastrous results. If the operator has no trained helper he must look after this most conscientiously.

In making up the report the next day there may be discrepancies and doubts. Even the most careful person may take down a wrong burette reading or forget to record a volume used, especially if a caller intrudes on busy hours. The finishing up of all tests and records, the Kjeldahl if it is used, etc., will occupy most of the second day. If there is a helper, solutions may be kept up in intervals; some may be made up in large stock; some do not keep. The Nessler and permanganate require the most delicate manipulation.

The above assumes a general laboratory proceeding. In routine work where only two or three tests are demanded on a larger number of samples, there will be a system of running a bank of apparatus developed by the ingenuity of each laboratory force.

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TABLE I.

TABLE OF HARDNESS, SHOWING THE PARTS OF CALCIUM CARBONATE ($CaCO_3$) IN 1,000,000 FOR EACH TENTH OF A CUBIC CENTIMETER OF WEAK SOAP SOLUTION USED.

Using 50 cc. of the sample.

Soap Solution, cc.	0.0 cc.	0.1 cc.	0.2 cc.	0.3 cc.	0.4 cc.	0.5 cc.	0.6 cc.	0.7 cc.	0.8 cc.	0.9 cc.
0.0	......	......	......	......	......	......	......	0.0	1.6	3.2
1.0	4.8	6.3	7.9	9.5	11.1	12.7	14.3	15.6	16.9	18.2
2.0	19.5	20.8	22.1	23.4	24.7	26.0	27.3	28.6	29.9	31.2
3.0	32.5	33.8	35.1	36.4	37.7	39.0	40.3	41.6	42.9	44.3
4.0	45.7	47.1	48.6	50.0	51.4	52.9	54.3	55.7	57.1	58.6
5.0	60.0	61.4	62.9	64.3	65.7	67.1	68.6	70.0	71.4	72.9
6.0	74.3	75.7	77.1	78.6	80.0	81.4	82.9	84.3	85.7	87.1
7.0	88.6	90.0	91.4	92.9	94.3	95.7	97.1	98.6	100.0	101.5
8.0	103.0	104.5	106.0	107.5	109.0	110.5	112.0	113.5	115.0	116.5
9.0	118.0	119.5	121.1	122.6	124.1	125.6	127.1	128.6	130.1	131.6
10.0	133.1	134.6	136.1	137.6	139.1	140.6	142.1	143.7	145.2	146.8
11.0	148.4	150.0	151.6	153.2	154.8	156.3	157.9	159.5	161.1	162.7
12.0	164.3	165.9	167.5	169.0	170.6	172.2	173.8	175.4	177.0	178.6
13.0	180.2	181.7	183.3	184.9	186.	188.1	189.7	191.3	192.9	194.4
14.0	196.0	197.6	199.2	200.8	202.4	204.0	205.6	207.1	208.7	210.3
15.0	211.9	213.5	215.1	216.8	218.5	220.2	221.8	223.5	225.2	226.9

TABLE II.

TABLE OF HARDNESS, SHOWING THE PARTS OF $CaCO_3$ IN 1,000,000 FOR EACH TENTH OF A CUBIC CENTIMETER OF WEAK SOAP SOLUTION USED.

Using 10 cc. of sample of water plus 40 cc. distilled water.

Soap Solution, cc.	0.0 cc.	0.1 cc.	0.2 cc.	0.3 cc.	0.4 cc.	0.5 cc.	0.6 cc.	0.7 cc.	0.8 cc.	0.9 cc.
0.0	......	......	......	......	......	......	......	......	8.0	16.0
1.0	24.0	31.5	39.5	47.5	55.5	63.5	71.5	78.0	84.5	91.0
2.0	97.5	104.0	110.5	117.0	123.5	130.0	136.5	143.0	149.5	156.0
3.0	162.5	169.0	175.5	182.0	188.5	195.0	201.5	208.0	214.5	221.5
4.0	228.5	235.5	243.0	250.0	257.0	264.5	271.5	278.5	285.5	293.0
5.0	300.0	307.0	314.5	321.5	328.5	335.5	343.0	350.0	357.0	364.5
6.0	371.5	378.5	385.5	393.0	400.0	407.0	414.5	421.5	428.5	435.5
7.0	443.0	450.0	457.0	464.5	471.5	478.5	485.5	493.0	500.0	507.5
8.0	515.0	522.5	530.0	537.5	545.0	552.5	560.0	567.5	575.0	582.5
9.0	590.0	597.6	605.5	613.0	620.5	628.0	635.5	643.0	650.5	658.0
10.0	665.5	673.0	680.5	688.0	695.5	703.0	710.5	718.5	726.0	734.0
11.0	742.0	750.0	758.0	766.0	774.0	781.5	789.5	797.5	805.5	813.4
12.0	821.5	829.5	837.5	845.0	853.0	861.0	869.0	877.0	885.0	893.0
13.0	901.0	908.5	916.5	924.5	932.5	940.5	948.5	856.5	964.5	972.0
14.0	980.0	988.0	996.0	1004.0	1012.0	1020.0	1028.0	1035.5	1043.5	1051.5
15.0	1059.5	1067.5	1075.5	1084.0	1092.5	1101.0	1109.0	1117.5	1126.0	1134.5

Jour. Am. Chem. Soc., 1901, 799.

TABLE III.

TABLE FOR THE PHOTOMETRIC DETERMINATION OF SULPHURIC ACID.

Depth in cm.	SO_3 Parts per Million.	Depth in cm.	SO_3 Parts per Million.	Depth in cm.	SO_3 Parts per Million.	Depth in cm.	SO_3 Parts per Million.
1.0	522.	4.0	140.	7.0	81.	10.0	57.
1.1	478.	4.1	137.	7.1	80.	10.2	56.
1.2	442.	4.2	133.	7.2	79.	10.4	55.
1.3	410.	4.3	131.	7.3	78.	10.6	54.
1.4	383.	4.4	128.	7.4	77.	10.8	53.
1.5	359.	4.5	125.	7.5	76.	11.0	52.
1.6	338.	4.6	122.	7.6	75.	11.2	51.
1.7	319.	4.7	119.	7.7	74.	11.4	50.
1.8	302.	4.8	117.	7.8	73.	11.6	49.
1.9	287.	4.9	115.	7.9	72.	11.8	48.
2.0	273.	5.0	113.	8.0	71.	12.0	47.
2.1	261.	5.1	110.	8.1	70.	12.2	47.
2.2	250.	5.2	108.	8.2	69.	12.4	46.
2.3	239.	5.3	106.	8.3	68.	12.6	45.
2.4	230.	5.4	104.	8.4	68.	12.8	44.
2.5	221.	5.5	103.	8.5	67.	13.0	43.
2.6	213.	5.6	101.	8.6	66.	13.5	42.
2.7	205.	5.7	99.	8.7	65.	14.0	41.
2.8	198.	5.8	97.	8.8	64.	14.5	39.
2.9	191.	5.9	96.	8.9	64.	15.0	38.
3.0	185.	6.0	94.	9.0	63.	15.5	37.
3.1	179.	6.1	93.	9.1	62.	16.0	36.
3.2	173.	6.2	91.	9.2	62.	16.5	35.
3.3	168.	6.3	90.	9.3	61.	17.0	34.
3.4	164.	6.4	88.	9.4	60.	17.5	33.
3.5	159.	6.5	87.	9.5	60.	18.0	32.
3.6	155.	6.6	86.	9.6	59.	18.5	31.
3.7	151.	6.7	84.	9.7	59.	19.0	30.
3.8	147.	6.8	83.	9.8	58.	19.5	29.
3.9	144.	6.9	82.	9.9	57.	20.0	29.

J. I. D. Hinds. *Journal Am. Chem. Soc.*, 18, 661, and 22, 269.

TABLE IV.

FOR THE CONVERSION OF PARTS PER 1,000,000 INTO GRAINS PER GALLON, AND VICE VERSA: ALSO, FOR COMPARING DEGREES OF HARDNESS.

Parts in 1,000,000.	Grains in U. S. Standard Gallon.	Grains in Imperial Gallon.	Degrees of Hardness.		
			French: Parts $CaCO_3$ in 1,000,000.	English: Grains $CaCO_3$ in Imperial Gallon.	German: Parts CaO in 1,000,000.
1	.0584	.07	1	.07	0.6
2	.1167	.14	2	.14	1.1
3	.1751	.21	3	.21	1.7
4	.2335	.29	4	.28	2.2
5	.2919	.35	5	.35	2.8
6	.3502	.42	6	.42	3.4
7	.4086	.49	7	.49	3.9
8	.4670	.56	8	.56	4.5
9	.5254	.63	9	.63	5.0
17.131	1	1.1992	14.	1	08.
34.262	2	2.3893	29.	2	16.
51.393	3	3.5975	43.	3	24.
68.524	4	4.7967	67.	4	32.
85.655	5	5.9958	71.	5	40.
102.786	6	7.1950	86.	6	48.
119.917	7	8.3942	100.	7	56.
137.048	8	9.5934	114.	8	64.
154.179	9	10.7925	128.	9	72.
14.286	0.8339	1	1.8	.12	1
28.571	1.6678	2	3.6	.25	2
42.857	2.5017	3	5.4	.38	3
57.143	3.3356	4	7.1	.50	4
71.428	4.1695	5	9.0	.63	5
85.714	5.0033	6	10.7	.75	6
100.000	5.8372	7	12.6	.88	7
114.286	6.6711	8	14.3	1.00	8
128.571	7.5050	9	16.1	1.13	9

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