EIGHTH REPORT OF THE MICHIGAN ACADEMY OF SCIENCE

CONTAINING AN ACCOUNT OF THE ANNUAL MEETING

HELD AT

ANN ARBOR, MARCH 29, 30 AND 31, 1906.

PREPARED UNDER THE DIRECTION OF THE COUNCIL

BY
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SECRETARY

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BY AUTHORITY

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LETTER OF TRANSMITTAL

TO HONORABLE FRED M. WARNER, *Governor of the State of Michigan:*

SIR—I have the honor to submit herewith the Eighth Annual Report of the Michigan Academy of Science for publication in accordance with Section 14 of Act No. 44 of the Public Acts of the Legislature of 1899.

Respectfully,
E. E. BOGUE,
Secretary of The Michigan Academy of Science.
Agricultural College, May 1, 1906.

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RAISED BEACHES OF EASTERN WISCONSIN.

JAMES W.GOLDTHWAIT.

(*Abstract**)

A detailed study of the abandoned shore lines of eastern Wisconsin, carried on in the summer of 1905 for the Wisconsin Geological and Natural History Survey, makes it possible not only to identify the beaches and terraces of successive stages of Lakes Chicago, Algonquin, and Nipissing, but to reconstruct the extinct water planes with considerable accuracy.

Conspicuous step-like terraces on Washington island and the Door county peninsula mark three important stages of Lake Algonquin, and a twenty-foot water plane, believed to be the plane of the “Nipissing” shore. These shore lines were traced southward along the western side of Lake Michigan (and less easily along the east and west sides of Green Bay); and the profile of the whole series was measured in more than fifty localities, by means of the spirit or "wye" level. Assembling all of

this data, it is found that the water planes of Lake Algonquin stand in warped attitudes, the direction of steepest inclination being about N. 15° E. Each plane rises more steeply as it extends northward, and the higher planes slant more steeply than, the lower.

From ninety-five feet above Lake Michigan at Washington island, the highest Algonquin beach declines southward at an ever decreasing rate, until it seems to become horizontal at twenty-six feet near Two Rivers. South of that point it has been lost by more recent erosion, but seems to be correlated with the "Toleston" beach at Evanston, Illinois, which is twenty-four feet above the lake on the campus at Northwestern University.

The Nipissing shore line, everywhere a prominent feature, declines almost imperceptibly from an altitude of twenty to twenty-two feet at Washington island to fourteen feet at Centerville (near Manitowoc), becoming horizontal at that height, and thus encircling the southern end of Lake Michigan. In southeastern Wisconsin and northeastern Illinois (north of Waukegan) it has commonly cut back beyond the earlier Algonquin shore line. Stream terraces, however, and a few scraps of Algonquin shore terraces seem to fix the Algonquin plane at the twenty-four-foot level.

The Toleston-Algonquin shore line, horizontal at twenty-four feet, and the Nipissing shore line, horizontal at fourteen feet, in the southern part of the Michigan basin, correspond to the horizontal twenty-five-foot Algonquin beaches and the fourteen (?) foot Nipissing shore line in the southern part of the Huron basin. South of the vicinity of Manitowoc, there seems to have been no tilting since the beginning of Lake Algonquin.

This correlation of shore lines involves the use of the Chicago outlet as one of the outlets for Lake Algonquin at its highest stage.

Evanston, Ills.

*The full paper will be published by the Wisconsin Geological Survey.

SYMPOSIUM ON WATER SUPPLIES IN MICHIGAN.

GEOLOGICAL CONDITIONS OF MUNICIPAL AND INSTITUTIONAL WATER SUPPLIES IN MICHIGAN.*

FRANK LEVERETT.

SOURCES OF SUPPLY.

The details concerning the sources and geological conditions of the public water supplies of Michigan are found in the table presented below. From this table it appears that the Great Lakes and their connecting streams supply thirty-seven cities and villages with an aggregate population of about 500,000; the inland lakes seventeen towns with a population of 65,000; the inland streams forty towns with a population of about 200,000, while impounded water is used in seven towns with a population of 11,200. Springs are drawn upon wholly or in part by eighteen villages and three institutions with a population of about 30,000. Infiltration wells are drawn upon by five towns with a population of 39,000. Underground supplies are from the following sources: (a) Shallow drift wells, either excavated or driven, supplied from the surface part of the ground water, used in twenty-seven cities and villages, including Muskegon and South Haven which have pipes under the lake bed and are included also in the thirty-seven towns supplied from the Great Lakes, with a population of over 80,000; (b) wells carried deep into water bearing stratum but without passing through an impervious bed, in use by eighteen towns with a population of about 45,000; (c) wells from gravel or sand under clay in use by fifty-one towns and institutions with a population of 100,000; (d) shallow rock wells, less than 100 feet in depth, in use in four towns with a population of 5,765; (e) deep rock wells, 100 to 600 feet in depth, in use in twenty-five villages and five institutions with a population of about 100,000. Of this last class twenty towns with a population of 88,150 and the five institutions with 3,800 draw water from standstone, leaving only four supplied from limestone.

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CHARACTERISTICS OF SURFACE WATER.

Hardness. The waters of the Great Lakes and their connecting streams (St. Marys, St. Clair and Detroit Rivers) are found to contain a smaller amount of mineral matter and to be softer than the average waters of the inland lakes and streams, there being only one-third to two-thirds as much calcium and magnesium carbonate in the waters of the Great Lakes as in the inland rivers. This results naturally from the fact that a large part of the supply to the Great Lakes is by direct rainfall, the area of the lakes being nearly half that of their watersheds, while inland lakes and streams are supplied very largely through the drainage from their watersheds both surface and underground.

Of the Great Lakes, Superior has much softer water than Michigan, Huron and Erie, there being less than half the amounts of calcium and magnesium carbonates in its waters. Available analyses show for Lake Superior waters about forty parts per million of carbonates of calcium and magnesium, for Lake Michigan waters eighty to ninety-two parts, while those of inland surface waters of the Southern Peninsula run from 100 up to 300 parts per million. (See Lane Water Supply Paper, U. S. Geological Survey No. 31, also Annual Report of State Geologist for 1903, pp. 112-161.) This variation is readily accounted for by the geological conditions, limestone or other rock formations which give hardness to percolating water being poorly represented within the Lake Superior watershed compared with their occurrence within the watersheds of the three other lakes. The glacial deposits also being composed largely

of material of local derivation contain much less calcareous material within the Lake Superior watershed. Lake Superior is not only softer than the other Great Lakes, but its waters remain cooler through the summer months so that it is the most palatable of all the waters. The cities on its borders, therefore, have an unexcelled water supply so far as geological and geographical conditions are concerned. The waters of the other Great Lakes are also suitable for boiler use and are largely drawn upon to supply commercial and manufacturing needs.

The hardness of the inland lakes and streams like that of the underground waters is found to be generally above 140 parts per million, or the limit considered suitable for good boiler water, though there are a few notable exceptions where lakes have very small affluents.

Turbidity. The Michigan streams as a rule carry so little matter in suspension that so far as sediment is concerned they appear well adapted for domestic use and all other purposes where clear water is desired. The small amount of sediment carried by them is due to the fact that much of their supply comes through underground instead of surface runoff, the drift deposits being so porous that a large part of the rainfall is directly absorbed and then fed slowly to the streams by seepage. Since the slopes have been cleared and cultivated, and conditions made more favorable for surface runoff the streams are more frequently turbid than they were in the natural state of the country, but even now the condition of Michigan streams in this respect is better than any of the neighboring states. In some cases turbidity is caused by winds and the currents which they produce. The lake currents bring sand to the outlet of Lake Huron and this is carried through the St. Clair River to form the delta at the north edge of Lake St. Clair. Port Huron and other cities drawing supplies from St. Clair River thus have a somewhat turbid supply. At the head of Saginaw Bay the water is so shallow that storms disturb the sand and render it turbid for some miles from the shore but this condition is only occasional and is therefore of slight detriment to the Bay City supply. The waters of the lakes are very clear except in the shallows where waves and currents stir up the sand. The disturbing effect of waves on the shores has made it necessary at several points to extend intake pipes out into deep water.

The inland lakes are in some cases shallow and rendered turbid by storms, but a large number of them occupy deep basins with only a narrow fringe of shallow water so that it is an easy matter to extend the pipes into water that is always clear. To many lakes the tributary streams are of little consequence and there are very few in which a marked turbidity is caused by the inflow from streams. In marl lakes however, there is in some cases constant turbidity because of the action of waves on the marly shores.

Lake currents in reference to contamination. Lake currents become of vital interest in connection with several of the public water supplies of Michigan cities. One of the most striking instances is that of Marquette. The waterworks supply is taken from a harbor north of Light House Point from an intake pipe which extends only 850 feet into the lake and terminates in 26 feet of water. The sewage is all carried into a harbor south of Light House Point. The shortness of this intake pipe suggested the advisability of taking water from farther out, but fortunately the city took the precaution to test the water throughly before making the extension. A small test pipe was carried out to a distance of 3200 feet and samples have been taken from it monthly for the past year and, together with samples from the present intake pipe, were sent to the Hygienic Laboratory of the University for examination. The superintendent of the waterworks informed the writer last October that the analyses of water from the long pipe showed greater contamination than that of water from the short pipe. The long pipe appears, therefore, to be in the path of a current leading out from the sewer laden harbor while the short pipe is out of the path of that current. While therefore, in general, the greater extension of pipe tends to secure a better water, in this case it may secure a poorer water.

On Little Bay de Noc are two neighboring cities, Gladstone and Escanaba, one of which has felt no serious results from the use of the water from the bay while the other has for several years been ravaged by epidemics of typhoid fever. Gladstone, the favored city, stands nearer the head of the bay and opposite a very narrow part. Streams entering the head of the bay cause a preemptible current past this narrow part so that the sewage is seldom or never carried to the intake pipe. Escanaba is not so fortunately situated and the currents appear to mingle the sewage with the water taken for the city consumption at such frequent intervals as to greatly pollute the supply. Plans are now pending for the installation of a filtration plant to purify the water, but it is unfortunate that the city has turned its sewage and allowed the sewage from a hospital to be turned into its source of water supply, when it might at a slight additional expense have turned the sewage into a stream back of the city which would have carried it beyond the part of the bay from which the city supply is taken. However, contamination may occur in lake ports, such as Escanaba, from diseased persons on vessels standing in the harbor as was the case at Sault Ste Marie, so that a filtration plant should be installed in every lake port which draws its supply from a harbor. Inasmuch as the sanitary conditions of the water supplies will be treated by another it is unnecessary to go farther into the matter at this point.

CHARACTERISTICS OF UNDERGROUND WATERS.

Hardness. It is rare to find an underground water supply in which the amount of carbonates of calcium and magnesium fall below 140 parts per million, and in a large part of the State sulphates are also present to increase the hardness. The softest waters appear to be obtained from sand dunes and very shallow wells in sand deposits on the old beds of lakes which extended

somewhat beyond the limits of the present Great Lakes. There are also occasional waters from sandstone formations, and from near the base of the drift (where a supply from underlying sandstone is suspected) in which the waters are soft enough to be fair for boiler use.

Salinity. The salt or brackish waters of Michigan are generally confined to rock formations lying at considerable depth, but there are parts of the Saginaw basin and also places near the borders of Lake St. Clair in which the waters in the glacial deposits are found to carry enough salt to render them objectionable for drinking. In such cases it is supposed that the salt water has risen into the glacial deposits from underlying rock formations, though it is barely possible that the drift deposits themselves carry enough saline matter in these localities to cause excessive salinity of the water. It is worthy of note, that throughout the southern portion if not throughout the entire State a small amount of salt is found in the waters from the drift where no contamination by human agencies has occurred. The amount of chlorine or sodium chloride found by an analyst is not therefore to be taken as a measure of contamination. References may be made to the report of Dr. Lane on Lower Michigan Mineral Waters (Water Supply Paper 31) for numerous analyses which will throw light upon the saltness of water in various localities and at different geological horizons.

Iron. In many of the underground waters iron is present in sufficient amount to color the boiler scale and also to induce the growth of iron-loving organisms such as crenothrix at points within the water pipes or system. The amount of iron necessary to induce the growth of these organisms is small compared with the total solids, less than five parts per million apparently being sufficient. Chemists have found that having the standpipe covered, and light excluded, will greatly retard organic growths in the water. It is a popular notion that the brown, slimy material found along the course of escaping water is mainly iron oxide; but in many cases it is an organic growth, the iron being present only as a stain. Many of the waters from deep wells in the drift, however, contain considerable iron and it is also present in waters from rock formations. Thus at Battle Creek the waters from the Marshall sandstone have been found by analyses made at the University to contain 2.5 to 4 parts per million of iron and the city has wisely delayed a a change to this supply until the effect of the iron has been determined.

Other objectionable constituents. Mention need scarcely be made of bitter water (caused by the presence of magnesium sulphate and magnesium chloride) for it is found in only a few localities and is generally avoided for public water supplies, not only because it is not palatable, but because it scales and corrodes badly by dissociation of the sulphate and production of sulphuric acid.

A much more common agent of corrosion is free carbonic acid gas which is present in large amounts in many of the deep well waters, both from drift and rock, and is met with all over the State. This actively corroding agent probably does much of the damage that so commonly is referred to iron in the water.

Sulphuretted hydrogen especially when associated with calcium sulphate renders water objectionable, but there are only limited districts in which the amount is sufficient to be a source of much inconvenience.

There are limited districts in which oil and inflammable gas have accumulated in the water bearing beds that underlie compact clay, a notable instance of gas accumulation being the district between Milan and Ypsilanti, while oil is especially abundant in wells west of Howell. The oil and gas besides being objectionable in the .water give rise to wild speculation as to their occurrence in paying quantities underneath the water bearing formation. The hopes thus aroused are seldom if ever likely to be realized. The gas of the Milan district appears to be largely from the underlying Devonian shale, while the oil near Howell appears to have been distilled from limestone which there immediately underlies the drift.

Turbidity. The underground waters are seldom turbid, for as a rule the supplies come from beds of sand and gravel too coarse to be held in suspension. There are, however, occasional flowing wells which constantly bring up sediment because of the fineness of material in which the water is obtained. For example, flowing well districts near Pickford and near Rudyard in Chippewa County penetrate large amounts of very fine sand termed "slush" by the drillers, in which some of the wells that terminate in the slush are troubled with turbid water, but the majority reach coarser material. There are also a few places where wells terminate in a marsh mud or in very clayey beds in which water is frequently if not continually turbid.

GEOLOGICAL CONDITIONS FROM SANITARY STANDPOINT.

The leading question in determining a public water supply is that of the healthfulness of the water to the consumer. A study of the sources of supply in use in Michigan cities and villages brings out numerous instances in which the choice of a public supply has been unwise. The individual cases cannot be taken up, but a few general observations will be presented.

It has already been pointed out that the surface waters contain much less mineral matter than the underground waters and on that account they are preferable for drinking and for boiler use, but the chances for contamination are greater than in underground waters. It would seem wise, therefore, wherever surface waters are to be turned into a public supply to have well equipped filtration plants connected with the waterworks system. By this means greater safety will be insured to the 600,000 people who are already using such water and the much larger number which, will use it in the future.

The underground waters are in most cases practically free from danger of contamination. There are, however, certain situations in which the deposits from which water is drawn are liable to become contaminated. The coarse deposits of gravel and sand along water courses that lead through villages are thus exposed and yet are drawn upon in a large number of towns. The water in its underground course naturally works towards the stream carrying with it the contamination which has been received from the bordering districts occupied by the villages. In spite of this fact water-works plants have in some cases been located on the river banks at about the worst place which could have been selected, the determining matter being the convenience of location rather than the safety. In such cases the water-works might generally have been located above the towns with a supply fully as great and with but little additional expense. With the heavy drafts made by pumping the contributing district is enlarged and the danger increased; thus water which at the time of the installation of the wells was found by analysis to be uncontaminated may not long remain safe for use.

It is generally true that flowing wells form a safe source of water supply, since their catchment areas are somewhat remote and the water must flow some distance underground to reach the wells. There are, however, instances in which flowing well districts located in valleys with rapid descent are supplied from the adjacent portions of a valley and its slopes. If such a catchment area is thickly inhabited there is more or less danger of contamination.

Instances have also come to notice of carelessness in the conducting of water from flowing wells to the reservoirs or receiving wells, ordinary drain tile being laid at a slight depth beneath the surface to conduct the water into the receiving well. Where the drain tile is laid through a district bordered closely by cesspools and privies there are opportunities for contamination, for the tile is naturally placed below the surface of the ground water table in order to prevent a loss of the flowing well water on the way to the receiving well, and the rapid current through the tile naturally draws in more or less water from the bordering district.

WATER-WORKS.

In the table of water-works supplies given below the population of the town as well as the source of supply and ownership of water-works has been given, but it should not be inferred that the number of actual users of public water supplies approximates that of the populations of the cities and villages, for this is the case in only a few of the cities outside of the metropolis, Detroit. On the basis of the number of taps reported it is estimated that in the cities with a population between 10,000 and 100,000 only about two-thirds of the people are connected with the public supply, and in towns of less than 10,000 population one-half or less are thus connected. The probable actual users of public supplies are estimated to aggregate about 775,000, or 32 per cent of the entire population of the State in 1900 (2,420,982), while the aggregate population of towns and institutions provided with water-works reaches 1,150,000, or nearly half the population of the State. Of the actual users of water-works supplies nearly 600,000, or about 24 per cent of the population of the State, are supplied from surface water, leaving less than 200,000 supplied from water-works drawing from wells. But of those not connected with the public supplies there are probably not more than 20,000 who depend upon surface water, including springs, while about 1,625,000, or two-thirds of the State's inhabitants, depend upon private wells.

In the matter of ownership and control it will be observed that the great majority of the water-works are municipal and that only a few of the smaller towns are controlled by private companies, Ann Arbor being the largest city whose water-works are under private management. Many cities in which the water-works were constructed by private companies have, within the past ten years, purchased the plants and there is nearly unanimous expression of satisfaction with the result of the change to municipal ownership. Nearly all the State institutions are supplied by independent water-works systems, the important exceptions being the State University at Ann Arbor and the State Normal Colleges at Ypsilanti, Mt. Pleasant and Kalamazoo.

There are a number of villages in which a partial distribution system has been installed for domestic use and others where it has been installed solely for fire protection by private arrangement independent of municipal action, the persons benefitted being either part owners of the supply and plant or purchasers at a stipulated rental. There are also a number of towns not included in the list which have provided cisterns and fire engines, hose, etc., as a means of fire protection, but have not built a distribution system. It was thought best to restrict the table of water-works to the towns in which a distribution system has been installed.

From data presented in the Manual of American Water-works it appears that about 100 Michigan cities and villages have made special provision for a fire pressure above the ordinary pressure of the waterworks systems, and in several cases a special steam fire engine is held ready for use. The fire pressure in the various cities ranges from about seventy-five pounds to 160 pounds per square inch, while the ordinary pressure runs from about twenty pounds to seventy-five pounds. Acknowledgements are made to the Manual of American Water-works for a considerable number of data presented in the table below, but for a majority of the cities and villages the data have been obtained directly from officials or residents.

MUNICIPAL AND INSTITUTIONAL WATER SUPPLIES.

Town.	Population 1900.	Owner.	Source.	Remarks.
Adrian	9,654	P.	S. Raisin R.	Mechanical filter.
Adrian Home for Girls	*400	St. & C.	Drift wells	Adrian WW for fire and sprinkling.
Agricultural College	†800	St.	RW 300 feet	From sandstone.
Albion	4,519	M.	RW 110-176 feet	From sandstone.
Algonac	1,216	M.	St. Clair River	
Allegan	2,667	M.	Drift well	On river bank.
Alma	2,047	C.	Pine River	Hires pumping; chiefly for fire and sprinkling.
Alpena	11,802	M.	Lake Huron	New works planned.
Ann Arbor	14,509	P.	DW 8-30; 75 to 150 feet	Flowing wells; shallow without clay cover.
Armada	863	M.	DW, 94 feet	Flowing.
Atlantic Mine	†3,000	P.	Creek and well	Partial domestic supply from well.
AuSable	1,116	M.	Lake Huron	
Bad Axe	1,241	M.	RW, 200 feet	From sandstone.
Baldwin	388	C.	Drift well	Railroad well furnishes partial supply.
Bangor	1,021	M.	Drift well 60 feet	
Baraga	1,185	P.	Keweenaw Bay	
Battle Creek	18,563	M.	Goguac Lake	Change to sandstone wells contemplated.
Bay City	40,747	M.	Saginaw Bay	Two pump stations, one at shore, the other through conduit, from 3.5 miles off shore.
Bay Mills	†1,000	P?	Whitefish Bay	
Bay Shore	350	P?	Lake Michigan	Only partial supply.
Beacon	†1,500	M?		Hydrants for fire.
Belding	3,288	C.	Flat River	Hires pumping for fire.
Bellaire	1,157	P.	Stream and drift well	Flowing well.
Benton Harbor	6,562	M.	Drift well, 43-80 feet	
Bessemer	3,911	M.	Springs and impounded water	Springs for domestic use.
Big Rapids	4,686	M.	Muskegon River	Flowing wells discontinued.
Birmingham	1,179	M.	Drift well, 45 feet	Flowing.
Blaney	†300	P.	Creek	Operated by Lumber Company.
Boyne City	*2,453	M.	Springs	Gravity system.
Buchanan	1,708	M.	Drift well	Changes pending.
Cadillac	5,997	P.	Little Clam Lake	Also village wells with pumps.
Capac	547	M.	Rock well, 100 feet	From sandstone.
Caro	2,006	P.	Springs	
Carson	906	M.	Creek	Fire protection only.
Carsonville	400	P.	Drift well	Partial supply from mill well.
Casnovia	277	M.	Impounded water	Fire protection.
Cassopolis	1,530	M.	Stone Lake	
Cedar Springs	950	M.	Creek	Chiefly fire protection.
Centerville	645	P.	Drift well, 10 feet	
Central Lake	1,307	P.	Springs	Gravity system.
Charlevoix	2,079	M.	Lake Michigan	Wells not in use.
Charlotte	4,092	M.	Drift well, 80 feet	
Cheboygan	6,489	M.	Rock well 400 feet	Water from limestone.
Chelsea	1,635	M.	Drift well, 25 feet	
Chesaning	1,244	M.	River and wells	Flowing wells.
Clare	1,326	P.	River and wells	
Clinton	1,638	P.	Raisin River	Fire protection to business part, pumped by a woolen mill.
Coldwater	6,216	M.	Drift well, 50 feet	
Coldwater State School	†250	St.	Drift well, 35 feet	
Columbiaville	457	P.	Flint River	
Constantine	1,226	M.	Fawn River	
Coopersville	660	M.	Drift well, 92 feet	Flowing.
Corunna	1,570	M.	Rock wells, 75-100 feet	Sandstone.
Croswell	606	M.	Black River	Fire protection.
Crystal Falls	3,231	M.	Impounded water	
Decatur	1,356	M.	Drift well, 125 feet	
Delray	4,573	Det.	Detroit River	
Detroit	285,104	M.	Detroit River	
Dollar Bay	†1,500	P?		Operated by L. Sup. Min. Co.; partial distribution for employees.
Dowagiac	4,151	M.	Drift wells, 47-100 feet	Flows from deeper wells.
Durand	2,134	M.	Drift wells, 40-75 feet.	

MUNICIPAL AND INSTITUTIONAL WATER SUPPLIES—*continued.*

Town.	Population 1900.	Owner.	Source.	Remarks.
Eagle	142	M?.	Drift well	
East Jordan	1,205	M.	Drift wells, 75-105 feet	Flowing.
East Tawas	1,736	M.	Lake Huron	
Eaton Rapids	2,103	M.	Rock well, 65 feet	Sandstone.
Eau Claire	281	M.	Drift well	Partial distribution.
Edmore	642	M.	Drift wells	Chiefly fire protection.
Elk Rapids	1,733	M.	Elk Lake	
Eloise, Wayne Co. Infirmary	1,200	WC.	Stream for fire; DW for drinking.	
Escanaba	9,549	P.	Little Bay de Noe	
Evart	1,300	M.	Drift well, 15 feet	
Ewen	†500	M.	Drift wells, 208-224 feet	Flowing.
Fairgrove	400	M.	Impounded water	
Farwell	535	M.	Spring brook	
Fenton	2,408	M.	Rock well, about 120 feet	
Flint	13,103	M.	Flint River	Many wells in sandstone.
Flint School for Deaf	500	St. & C.	Well for drinking; city supply for baths, etc.	
Flushing	900	M.	Flint river	Fire protection
Ford	*1,372	C.	Detroit River	Water pumped by Ford Mfg Co.
Fowler	426	M?.	Drift well	
Frankfort	1,465	M.	Drift wells, 90-150 feet	
Fremont	1,331	M.	Drift wells, 225 feet	Flowing.
Fulton	275	M.	Drift well	Partial system.
Garden	465	M.	Rock wells, 104-220 feet	Partial system.
Gaylord	1,561	M.	Drift well, 80 feet	
Gladstone	3,380	M.	Little Bay de Noe	
Gladwin	775	M.	RW, 165-180 feet, and river	River for emergency.
Grand Haven	4,743	M & P.	Drift wells, 20-30 feet	Both systems from shallow wells near Grand River.
Grand Ledge	2,167	M.	Rock wells, 90-130 feet	Flows from sandstone, siphoned to reservoir.
Grand Marais	2,000	M.	Lake Superior	
Grand Rapids	87,565	M.	Grand River	Much spring water sold for drinking.
Grand Rapids Mich. Soldiers Home	1,250	St.	Springs and impounded water	Springs for drinking; impounded waters for boilers and fire.
Grandville	457	M.	Rock wells	Flowing wells with fire plugs.
Grayling	†1,800	P.	Au Sable River	Operated by a lumber company.
Greenville	3,381	M.	Drift well, 40 feet	Flowing.
Grosse Pt Tp (several vill's).	*2,928	P.	Lake St. Clair	Pumping station for villages; also many individual intake pipes.
Haakwood	†100	P.	Drift well	Flowing well; piped to houses of Haak Lumber Company.
Hamtramck	1,559	Det.	Detroit River	Supplied by Detroit.
Hancock	4,050	M.	Filter gallery by Portage Lake	
Harbor Beach	1,149	M.	Lake Huron	
Harbor Springs	1,643	M.	Drift wells, 64-320 feet	Flowing.
Harrison	647	M.	Small lake	
Hart	1,134	M.	Drift wells, 112-152 feet	Flowing.
Hartford	1,077	M.	Drift well, 40 feet	
Hastings	3,172	M.	Drift well, 35 feet	
Hesperia	474	M? & P	White River for fire, flowing wells for drinking	Flowing well water piped at private expense for domestic use.
Hillman	253	M.	Thunder Bay River	
Hillsdale	4,151	M.	Small lake	
Holland	7,790	M.	Drift wells, 25-40 feet	
Holly	1,419	M.	DW, 23-47; 140-180 feet	
Houghton	3,359	M.	Springs	High pressure and low pressure reservoirs.
Howard City	1,398	M.	Creek for fire, DW for drinking.	
Howell	2,512	M.	DW, 70 feet	
Hudson	2,403	M.	DW, 70 feet	
Imlay	1,122	M.	RW, 162-223 feet	Water brackish, from sandstone.
Indian River	†500	P.	DW	Flowing wells piped to many dwellings by natural pressure.
Ionia	5,209	M.	Rock well and springs	Wells in sandstone.

MUNICIPAL AND INSTITUTIONAL WATER SUPPLIES—*continued.*

Town.	Population 1900.	Owner.	Source.	Remarks.
Ionia State Asylum		St.	RW, 359 feet, also springs	
Iowa State Reformatory	700	St.	Springs	Supplies part to Asylum.
Iron Mountain	9,242	P.	Filter gallery by lake	Water flows toward lake.
Iron River	1,482	M?	Iron River	
Ironwood	9,705	P.	Montreal River	
Ishpeming	13,255	M.	Small lake	
Ithaca	2,020	M.	Rock well, 600 feet	Sandstone at 300 feet.
Jackson	25,180	M.	Rock wells, 200-400 feet	Water from sandstone.
Jackson State Penitentiary	†800	St.	Rock well, 200 feet for drinking, river for boiler use.	
Jennings	800	P.	Lake Michigan	Chiefly fire protection.
Jonesville	1,367	M.	Drift well, 56, rock well, 60 feet.	All flow.
Kalamazoo	24,404	M.	Drift wells, 31 and 80-120 feet	Deep wells flow.
Kalamazoo State Asylum	2,000	St.	Infiltration well, 30 feet	From springs, and nearby creek.
Kalkaska	1,504	M.	Boardman River	
Kingston	286	M.	Rock well, 217 feet	Rock at 150 feet.
Lake City	816	P.	Lake Missaukee	
Lake Linden	2,597	M.	Rock well and creek	Flowing wells from sandstone.
Lake Odessa	1,037	M.	Drift well, 50 feet	Flowing.
L'Anse	620	M.	Spring fed creek	Gravity system.
Lansing	16,485	M.	Rock wells, 28-350 feet	Wells in sandstone; some flow.
Lansing Industrial School	800	St.	Rock well, 600 feet	
Lapeer	3,297	M.	Rock wells, 250-290 feet	Wells in sandstone.
Lapeer State Home for Feeble-Minded	†800	St.	Rock well, 337 feet	Sandstone at 146 feet.
Laurium	5,043	C.	Lake Superior	Pumping by mining company.
Lawrence	598	M.	Drift well, 60 feet	
Leslie	1,114	M.	Rock well, 180 feet	Flowing wells from sandstone.
Lewiston	†800	M.	Twin Lake	
Lexington	619	M & P.	Drift wells, 20-25 feet	Flowing wells fill fire cisterns; also piped at private expense to dwellings.
Lowell	1,736	P.	Drift wells	
Ludington	7,166	M.	Lake Michigan	
Lyons	656	M.	Grand River	For fire and sprinkling.
Mackinac Island	665	P.	Lake Huron	
Mancelona	1,226	M.	Drift well, 65 feet	
Manistee	14,200	M.	Drift well, 100 feet	Wells by river bank.
Manistique	4,126	M.	Indian Lake	Village has flowing wells from limestone; waterworks system from lake, installed 1906.
Manton	895	M.	Small creek	Chiefly fire protection.
Marcellus	1,025	M.	Drift well, 50 feet	
Marine City	3,829	M.	St. Clair River	
Marlette	996	M.	Rock well, 60 feet	Wells from sandstone.
Marquette	10,058	M.	Lake Superior	
Marquette State Prison	300	St.	Small stream	
Marshall	4,370	M.	Rock well, about 100 feet	From sandstone.
Mason	1,828	M.	Rock wells, 67-172 feet	Flows from sandstone.
Menominee	12,818	P.	Green Bay	
Midland	2,363	M.	Chippewa River	
Milan	1,141	C.	Saline River	Partial system for fire.
Milford	1,108	M.	Infiltration wells	Wells on river bank.
Millington	638	M.	Rock wells, 182-200 feet	Sandstone at 110 feet.
Mio	150	P.	Spring creek	Chiefly fire protection.
Monroe	5,043	P.	Lake Erie	
Montague	998	M.	Spring-fed brook	Chiefly fire protection.
Mt. Clemens	6,576	M.	Drift well by stream	
Mt. Pleasant	3,662	M.	Drift wells, 20 to 20 feet	Flowing.
Mt. Pleasant Indian School	†368	U. S.	Drift well	
Muir	556	M.	Springs	Partial supply for drinking.
Munising	2,014	M.	Springs and Lake Superior	Lake Superior for emergency.
Muskegon	20,818	M.	Lake Michigan	Infiltration wells.
Nashville	1,164	M.	Rock well, 300 feet	Chiefly fire and sprinkling; flowing wells from sandstone.
Negaunee	6,935	M.	Teal Lake	
Newaygo	1,172	M.	Drift well, 20 feet	

MUNICIPAL AND INSTITUTIONAL WATER SUPPLIES—*continued.*

Town.	Population 1900.	Owner.	Source.	Remarks.
New Baltimore	922	M.	Lake St. Clair	
Newberry	1,421	M.	Drift well, 100 feet	
Newberry State Asylum	600	St.	DW, 186-245 feet, RW, 457 feet.	Water chiefly from drift wells; limestone with water at 320 feet.
Niles	4,287	P & M.	Lake for private waterworks; drift well, 110 feet for city	Private system installed earlier, still in use.
North Muskegon	513	M.	Rain Lake	
Northville	1,755	M.	Springs	Gravity system.
Norway	4,170	M.	Impounded water	Also supplies Vulcan.
Novi	†100	P.	Drift well	Partial system.
Onaway	1,204	M.	Rock wells, 190-235 feet	Wells from limestone.
Ontonagon	1,267	M.	Lake Superior	
Oscoda	1,109	M.	Lake Huron	
Otsego	2,073	M.	Kalamazoo River	Fire protection only.
Ovid	1,293	M.	Drift well, 24 feet	
Owosso	8,696	M.	Drift well, about 70 feet	Some flowing wells.
Oxford	1,172	M.	Drift well, 85 feet	
Palmer	799	P.	Springs and wells	Partial system; for domestic supply.
Paw Paw	1,465	M.	Drift well, 60 feet	
Petoskey	5,285	M.	Drift well, 22 feet	
Pewaymo	446	M.	Drift wells	
Pentwater	1,061	M.	DW, 16-24 ft and Lake Michigan.	Lake for fire and sprinkling.
Pinconning	729	M.	Impounded water	Private flowing wells.
Plainwell	1,318	M.	Kalamazoo River	For fire protection.
Plymouth	1,474	M.	Springs	Gravity system.
Pontiac	9,769	M.	Drift well, 175 feet	
Pontiac State Asylum	†1,450	St.	Drift wells, 100-125 feet	
Port Huron	19,158	M.	St. Clair River	
Portland	1,874	M.	Drift wells, 38-50 feet	
Quincy	1,563	M.	Drift wells, 32-35 feet	
Quinnesec	†600	M.	Mine water	Chiefly fire protection.
Rapid River and Masonville.	†1,200	M.	Rock well, 275 feet	For fire protection; flowing wells from sandstone.
Reading	1,096	M.	Rock well, 56 feet	Flowing wells from sandstone.
Reed City	2,051	M.	Ponds, springs and drift wells	Flowing drift wells.
Reese	416	M.	Drift wells	
Republic	†2,500	M?	Springs and lake	Installed in 1906.
Richmond	1,133	M.	Drift well, 120 feet	Also supplies Lenox.
River Rouge	1,748	Det.	Detroit River	Supplied by Detroit.
Rochester	1,535	M.	Drift wells, 60-80 feet	Flowing wells; gravity system.
Rockford	711	M.	Rouge River	Mainly for fire protection.
Rockland	†1,000	P.	Springs	Water supplied to school and a few dwellings by windmill.
Rogers	544	M.	Drift well, 60 ± feet	For fire protection.
Romeo	1,580	M.	Drift well, 20 feet	
Roscommon	465	M.	Small stream	Chiefly fire protection.
Rose City	300	P.	Drift wells, 60-200 feet	Flowing wells piped by natural pressure to residences.
Saginaw	42,345	M.	Saginaw River	Numerous wells for drinking.
St. Clair	2,543	M.	St. Clair River	
St. Ignace	2,271	M.	Lake Huron	
St. Johns	3,388	M.	Rock wells 222-574 feet	Wells in sandstone.
St. Joseph	5,155	M.	Lake Michigan	
St. Louis	1,989	M.	Pine River	Chiefly for fire; flowing wells (private), for domestic use.
Sault Ste Marie	10,538	M.	Whitefish Bay	
Scottville	554	M.	Drift well, 54 feet	
Shelby	1,081	M.	Drift well, 125 feet	
Sheridan	437	M.	Small lake	Chiefly fire protection.
South Haven	4,009	M.	Lake Michigan	Filter galleries in lake bed.
Sparta	1,126	P.	Drift well and stream	For fire protection.
Stambaugh	695	M.	Iron River	
Standish	829	M.	Wells and streams	For fire protection.
Stanton	1,234	M.	Drift wells, 30 feet	Flowing.
Stevensville	250	M.	Springs	For fire protection.
Sturgis	2,465	M.	Drift well, 140 feet	
Suttons Bay	398	P.	Impounded water	Fire protection only.

MUNICIPAL AND INSTITUTIONAL WATER SUPPLIES—*continued.*

Town.	Population 1900.	Owner.	Source.	Remarks.
Tecumseh	2,400	M	Drift well, 35 feet	
Thompsonville	893	M	Drift wells	Partial system.
Three Oaks	994	M	Drift wells, 76-86 feet	
Three Rivers	3,550	M	Drift wells, 75-108 feet	Flowing.
Traverse City	9,407	M	Grand Traverse Bay	Many private flowing wells from drift deposits.
Traverse City State Asylum	†1,450	St	Drift wells, 100-190 feet	Flowing.
Trenton	1,167	M	Detroit River	
Union City	1,514	M	Drift wells ?	
Vassar	1,832	M	Cass River and wells	Flowing wells from sandstone.
Vicksburg	972	M	Drift well, 60 feet	
Vulcan	†2,000			Supplied from Norway.
Wakefield	1,191	M	Sandy Lake	Chiefly fire protection.
Watervliet	717	M	Drift wells	For fire protection.
West Branch	1,412	M	Drift wells	Gravity system from flowing wells to be installed in 1906.
Weston	†275	P	Drift well	Fire protection for business houses, from elevated tank.
White Cloud	595	M	White River	
Whitehall	1,481	M	Drift well, 67 feet	Flowing.
Williamston	1,113	P ?	Mill pond	Fire hydrants on main street.
Woodland	*320	M	Drift wells	Partial system.
Woodmere	5,034	Det	Detroit River	Supplied from Detroit.
Wyandotte	5,183	M	Detroit River	
Yale	1,125	M	DW, 85-90 and 220 feet	Flowing.
Ypsilanti	7,378	M	Drift well 65 feet	Flowing.
Zeeland	1,326	M	Drift well, 20 feet	

*Population in 1904, from State Census.
†Population in 1906, from officials of the institution.
(a) The abbreviations given under the column for ownership stand for the following: "P" for Private or Company; "M" for Municipal; "C" for Co-operative; "St." for State; "U.S." for United States; "WC" for Wayne County; "Det" for Detroit. Under the column for source "DW" stands for drift well or drift wells, and "RW" for rock well or wells.

ANN ARBOR, MICH., U. S. Geological Survey.

MICHIGAN WATER SUPPLIES.

VICTOR C. VAUGHAN.

MR. CHAIRMAN AND GENTLEMEN: The Hygienic Laboratory of the University of Michigan was opened in October, 1888. The establishment of this laboratory resulted from the activity of the Michigan State Board of Health. This Board memoralized the Board of Regents, asking that the Legislature be requested to make an appropriation for a State Laboratory of Hygiene to be placed under the control of the Board of Regents and to become a part of the University of Michigan. The memorial stated the objects of the laboratory to be as follows:

(1) Original investigations into the causation of disease.

(2) The examination of food and drink for the health officers of the State.

(3) The instruction of students in hygiene and bacteriology.

As director of this laboratory since its foundation I have always held in mind the above stated objects and have endeavored to direct the work of the laboratory along these lines.

The health officers and other village and city authorities have availed themselves of the facilities of the laboratory in the examination of drinking waters used by their communities and up to the present time more than one thousand samples of water have been received from officials and examined. Some of these have come from other states and will not be included in the tabular statements given in this paper.

The method of examination differs from that practiced elsewhere and needs to be briefly stated here. The waters are received in sterilized receptacles and immediately on receipt the examination is begun.

The number of bacteria per cubic centimeter is determined by plate cultures. Two sets of plates are made, both of agar; one is grown at ordinary room temperature and the other at 37° C. in the incubator.

Early in our work we discovered that many of the ordinary water bacteria do not develop at the temperature of the human body (37° C.), while all bacteria pathogenic to man grow best at this temperature. Therefore an abundant growth on the plates kept at room temperature and a slight growth on the plates kept at 37° C. indicates the presence of many saprophytic organisms and the presence of but few, if any, that are pathogenic. At room temperature the saprophytic crowd out the pathogenic organisms, while at the higher temperature the reverse is true. It will be seen that this test is in and of itself of great value in arriving at a correct estimate of the danger that lies in the water.

In the second place beef tea tubes are inoculated with the water and these tubes are kept in an incubator, the temperature of which is kept constantly at from 38° to 40° C. Usually six tubes are so inoculated, the amounts of water in these inoculations running from 0.05 to 1.00 c. c. These tubes are kept in the incubator for twelve hours, at the expiration of which time, 2 c.c. is injected intraabdominally into rats or guinea pigs. If the tubes contain a pathogenic germ the animal is dead in twelve hours. As soon as the animal dies it is opened aseptically and plates made from the heart's blood. Within another twelve hours these plates have developed and cultures are made from the colonies. For these plates litmus agar is used for the purpose of distinguishing between bacteria of the colon group and those of the typhoid group. Moreover the colonies on the plates made from the heart's blood are grown in special media for the purpose of more exact differentiation. However, I will not go further into this point in this paper.

While this bacteriological investigation is being carried on, the ordinary chemical analysis is made.

The cities and villages of Michigan are supplied with (1) well water, (2) waters from small lakes, (3) waters from the great lakes, (4) waters from streams, and (5) waters from springs.

WELL WATERS.

The following table gives the results of the examinations of well waters:

TABLE I.

Well Water and City Waters from Wells.

Place.	No. sample.	Ammonia. Free.	Ammonia. Alb.	Cl.	No. of Germs.	Effect on animals.
Allegan	3	.282	.256	32.	121	.....
Adrian	6	.123	.096	16.7	2,857	4+
Ann Arbor	15	.420	.065	14.8	502	14 + of 36
Attica	1	.100	.170	9.2	1,560	1+
Amasa	5	.126	.238	2.6	702	1+
Alma	5	.226	.122	14.58	1,960	3+
Brown City	1	.220	.096	8.	400	.....
Bay City	5	.130	.101	6.65	3,985	1+
Battle Creek	13	.180	.084	8.7	1,894	6 + of10
Bugleton	1	.080	.05	14.8	300	.....
Burr Oak	1	.030	.050	9.9	100	.....
Coldwater	7	.111	.078	10.1	540	1+
Climax	1	.206	.084	4.5	105	.....
Caro	1	.19	.12	6.	10	.....
Charlevoix	1	0.9	.22	16.5	.....	.....
Cassopolis	1	.01	.01	33.	5	.....
Charlotte	4	.007	.035	17.5	2,225	.....
Corunna	1	.008	.004	4.	1,500	.....
Deerfield	1	.508	.158	695	898	1+
Dowagiac	2	.018	.115	1.8	47	1+
East Lake	2	0.68	.089	23.37	2,920	.....
Escanaba	3	.045	.122	14.8	130,025	1+
East Tawas	1	.005	.062	9.9	22	.....
Eaton Rapids	3	.016	043	30.	1,560	.....
Eloise	1	.130	.120	37.	16,680	1+
Flint	1	.011	040	5.	100	1+
Freemont	2	.....	.....	.....	568	.....
Flushing	6	.012	.080	35.9	870	3+
Grand Rapids	11	007.	.115	12.2	597	1+
Gladwin	1	.374	.044	11.8	63	.....
Gladstone	5	.030	.410	7.5	17,770	2+
Greenville	1	1.46	.40	38	550	1+
Grass Lake	1	.001	.001	9.	300	.....
Gregory	1	.050	.060	11	5,740	1+
Genoa	2	.....	.....	.....	6,150	2+
Hastings	1	.20	.11	18.	850	.....
Hancock	1	.01	.01	53	2,500	.....
Holland	7	.217	.111	21.1	182	1+
Howell	6	.083	.260	19.6	1,707	.....
Holt	1	.030	.050	24.7	2,020	.....

Well Waters, Etc.—Con.

Place.	No. sample.	Ammonia. Free.	Ammonia. Alb.	Cl.	No. of Germs.	Effect on animals.
Irvine	1	.....	.....	.....	3	.....
Inlay City	1	.15	.2	20	24,000	.....
Iron Mountain	12	.558	.802	24.5	2,110	9+
Ironwood	7	.103	.162	22.8	674	3+
Ida	1	.910	.120	155	2,000	.....
Jackson	1	.002	.007	205	81,000	1+
Kalamazoo	25	.041	.068	7.4	3,296	8+
Kalkaska	4	.....	.....	.....	11,385	.....
	1	.020	.200	9.9	365	.....
Laporte	2	.....	.....	.....	394	.....
Lake View						
Leslie	2	.840	.912	13.2	1,522	.....
Lowell	2	.035	.450	.400	6,512	1+
Lawrence	1	.030	.040	10.5	.....	.....
Lansing	10	.07	.037	10.3	712	2+
	2	.195	.129	19	625	.....
Mendon						
Merrill	1	.055	.010	4.3	10	.....
Mackinaw Island	1	.030	.060	10.8	.....	.....
Melvor	1	.040	.240	13	24,000	.....
Manitowoc	1	.200	.090	16.5	.....	.....
Morrice	1	.04	.07	102.	600	.....
Manistee	2	.004	.078	2.2	15	.....
Mancelona	2	.011	.047	8.5	95	1+
Manchester	1	.020	.150	5.5	700	.....
Mt. Clemens	12	.060	.099	15.4	4,060	4+
Morenci	2	.005	.010	24	20	.....
Mt. Pleasant	2	.087	.070	50.6	217	.....
North Branch	1	.010	.010	62.16	72,000	.....
Northville	2	.573	.368	5.1	2,925	1+
Norway	1	.005	.050	.500	6	.....
Nashville	1	.020	0.20	6	4,800	.....
Oak Grove	1	.030	.010	4	400	1+
Okemos	4	.092	.257	43.1	92	1+
Ontonagon	2	.....	.....	.....	73	.....
Pontiac	15	.185	.231	24.8	370	4+
Port Huron	3	.007	.126	8.8	108	2+
Petoskey	12	.048	0.66	8.53	7,421	.....
Parma	1	.058	1.24	100.6	1,234	.....
Petersburg	1	.720	.160	7.00	—160	1+
Romeo	1	.020	.030	9.9	15	.....
Sherwood	3	.092	.41	17.6	1,160	2+
Schoolcraft	1	.....	.010	4.	2,400	.....
Saginaw	8	.113	.197	95.8	437	1+
St. Johns	4	.073	.093	18.7	2,960	1+
Springwells	1	.040	.140	99	.....	1+
Shelby	2	.010	.090	37.1	.....	1+
Sparta	1	.100	.100	49.5	1,250,000	.....
Stockbridge	1	.350	.220	2.2	6,000	.....
Three Rivers	8	.130	.075	5.2	21	.....
Tecumseh	2	0.18	.049	10.	1,220	.....
Torch Lake	2	.....	.....	.....	1,270	1+
Traverse City	6	.008	.008	3.9	933	1+
Tawas City	.....	.080	.285	520	.....	.....
Union City	3	.009	.017	18.2	877	.....
Utica	1	.016	.013	6.6	.....	.....
Wyandotte	4	.133	.171	31.1	625	2+
Wells	3	.270	.046	7	.....	.....
Yale	3	.220	.068	25.2	11,258	2+
Ypsilanti	2	215	.062	22.7	.....	.....
Average	322	.126	.142	25.3	.....	107+
Total	300	.....	.....	.....	4,261	.....

Certain things in this table need explanation. Fifteen samples of Ann Arbor water were examined chemically, but thirty-six samples were examined bacteriologically, and of the thirty-six, fourteen contained bacteria that killed animals. Thirteen samples of Battle Creek water were examined chemically, while only ten were examined bacteriologically, and six out of ten contained bacteria that killed animals.

WATERS FROM SMALL LAKES.

Table II gives the results of the examination of waters from small lakes.

TABLE II.

Waters from Small Lakes.

Place.	No. sample.	Ammonia. Free.	Ammonia. Alb.	Cl.	No. of Germs.	Effect on animals.
Battle Creek	10	.051	.123	6.3	15,183	5+
Cassopolis	1	.070	.100	7.	640	2+
Elk Rapids	7	.204	1.04	5.7	1,185	5+
Ishpeming	14	.150	.048	4.3	.....	5+
Ironwood	1	.018	.300	1	150	.....
Iron Mountain	6	.161	.294	4	23	.....
Island Lake	2	.202	.222	16.5	549	1+
Lake City	1	.154	.280	3	124	.....
Manistique	5	.058	.199	8	.....	1+
Norway	1	.004	.010	9	20	1+
Negaunee	6	.220	.454	20.2	1,108	4+
Pontiac	2	.198	.326	9.8	15	.....
Sturgis	1	.050	.250	4	50	.....
Torch Lake	1	.....	.....	.....	.....	1+
Average	58	.124	.175	7.3	1,731	25+

WATERS FROM THE GREAT LAKES.

I have included among the waters of the Great Lakes those from the connecting rivers, such as the St. Clair and Detroit rivers. It will certainly be understood that most of these cities take their supplies not directly from the Great Lakes, but from some bay or harbor, which is often polluted by the city itself.

TABLE III.

Waters from the Great Lakes.

Place.	No. sample.	Ammonia. Free.	Ammonia. Alb.	Cl.	No. of Germs.	Effect on animals.
Baraga	3	.310	.226	6.5	410	3+
Bay City	3	.235	.513	403.3	400	2+
Detroit	6	.012	.047	14.8	18	2+
Escanaba	32	.049	.084	12.8	19,330	6+
Menominee	15	.035	.092	4.3	.....	4+
Mt. Clemens	1	.040	.030	5	.....	1+
Marine City	2	.110	.070	95	.....	1+
Marquette	80	.020	.050	6	5,692	4+
Port Huron	4	.078	.161	8.6	1,600	2+
Petoskey	8	.033	.056	3.8	944	3+
St. Clair	7	.006	0.20	8	40	4+
Sault Ste. Marie	11	.074	.068	4.5	16,280	2+
Traverse City	5	.050	.066	10	12,152	2+
Wyandotte	3	.011	.228	27.5	3,090	3+
Trenton	1	.020	.012	6.6	840,000	.....
Average	181	.040	.076	15.3	12,067	39+

STREAMS.

Table IV gives the examinations of waters taken from rivers and smaller streams. Some of these constantly contain the colon bacillus and consequently kill animals. This will be seen to be true of the river waters from Alma and Adrian. Every sample of water from the stream supplying Adrian has killed animals, even after filtration. The pathogenic organism invariably found is the colon bacillus, and there have been no epidemics of typhoid at

Adrian. This is quite convincing evidence that the colon bacillus does not cause typhoid.

TABLE IV.

Streams and Rivers.

Place.	No. sample.	Ammonia.		Cl.	No. of Germs.	Effect on animals.
		Free.	Alb.			
Alma	5	.088	.048	6.6	1,001	5+
Adrian	10	.071	.038	10.6	91	10+
Ann Arbor	4	.152	.084	4.4	327	1+
Calumet	2	.050	.300	168	34,000	1+
Flint	2	.075	.290	9.7	2,571	1+
Grand Rapids	11	.034	.127	8.4	16,624	5+
Ishpeming	2	.310	.750	7	.....	.....
Ironwood	8	.047	.172	3.9	699	3+
Kalamazoo	1	.200	.220	6.6	4,000	.....
Mt. Pleasant	1	.094	.208	79	3,000	.....
Petoskey	1	.700	.100	4.5	2,300	1+
Saginaw	2	.1	.180	5.4	2,750	.....
St. Louis	2	.052	.265	23	4,700	.....
Total	51	.....	.....	.....	.....	.....
Average	.....	.091	.153	15.7	5,979	27+

SPRING WATER.

Most of the springs in Michigan are surface springs and are more or less subject to bacterial contamination.

TABLE V.

Spring Water.

Place.	No. sample.	Ammonia.		Cl.	No. of Germs.	Effect on animals.
		Free.	Alb.			
Alpena	1	0.72	.174	4.64	2,880	.....
Albion	1	Trace	.010	30	500	.....
Ann Arbor	10	.0386	.102	5.89	557	.....
Caro	1	.260	.010	3.3	87	.....
Grand Rapids	2	.076	.044	4.2	70	.....
Hart	1	.030	.120	9.9	36,000	*+
Iron Mountain	2	.205	.303	.7	4	.....
Kalamazoo	1	.010	.010	5.1	600	.....
Mt. Clemens	1	.030	.080	26.4	27,500	.....
Negaunee	2	.035	.080	3	80	+
Norway	2	.230	.150	27.15	1,000	.....
Petoskey	1	.020	.080	29.5	1,940	.....
Shelby	1	.....	.....	.....	.....	.....
Thompson	2	.049	.166	130	215	.....
Traverse City	1	.020	.020	2.5	4,200	+
Average	28	.072	.088	8.8	1,309	3+

*This germ count not included in average.

CISTERN WATER.

Six samples of cistern water were examined; chemical analysis of three of these show an average Free NH_3 of 1.001 parts albumenoid, NH_3 of .558 pts. and Cl. as Nacl=6. The bacteriological examination showed an average of 85,040 per c.c. Culture were fatal to animals in five of the six cases.

ARTESIAN WATER.

Nine samples were examined. The average chemical composition of eight was as follows: Free NH_3=0.165 pts. Alb. NH_3 0.092. The average chlorine would be valueless as the highest was 990 pts, and the lowest 1.32. The bacteriological examination showed from 80 to 56,400 per c. c. In but one water were germs absent. Cultures killed in four cases—in two of these B. coli was found.

SUMMARY.

In concluding I will separate the chemical from the bacteriological results. Tabulating the former we have the following:

TABLE VI.

Kind of Water.	No. of Samples.	Ammonia.		Cl.
		Free.	Alb.	
Well water	322	.126	.142	25.3
Waters from small lakes	58	.124	.175	7.3
Water from great lakes	181	.040	.076	15.3
Waters from streams	51	.091	.153	15.7
Spring waters	28	.072	.088	8.8
Cistern waters	3	1.011	.558	6.0
Artesian waters	8	.164	.092	.....

It will be seen from the above that the waters of the Great Lakes make the best showing, so far as both free and albuminoid ammonia go and the cistern waters the worst. Indeed the cistern waters were the most filthy of all examined. It should be said that these waters were from neglected cisterns and it was supposed by the families using these waters that they were to be employed only in daily ablutions, but children and roomers had washed their teeth with these waters and occasionally drank them when the drinking water pitcher was empty. In one family every person under thirty years of age, six in number, acquired typhoid in this way. Contamination from a near-by privy vault was evident. It will be understood that these figures do not indicate the composition of the waters in either the small or great lakes, but do show the composition of such waters as locally contaminated. The artesian waters were from wells recently opened and much of the organic contamination probably came from the surface.

Bacteriologically 300 samples of well water showed an average of 4,261 bacteria per c. c. and 107 (38 per cent) of these contained bacteria that killed animals.

Fifty-eight small lake waters gave an average of 1,731 bacteria per c. c., and 25 (43 per cent) of these contained bacteria that killed animals.

One hundred and eighty-one great lake waters had an average of 12,067 bacteria per c. c. and 39 (21 per cent) of these contained bacteria toxicogenic to animals.

Fifty-one samples of water from streams gave an average of 5,979 bacteria per c. c. and 27 (53 per cent) of these contained toxicogenic bacteria.

Twenty-eight samples of spring water gave an average of 1,309 bacteria per c. c. and 3 (10 per cent) of these contained toxicogenic bacteria.

Five (83 per cent) of the cistern waters contained toxicogenic bacteria and 3 of these gave an average of 85,040 bacteria per c. c. It will, of course, be understood, that these figures do not indicate the composition of the waters of well-kept cisterns any more than the figures for both the small and great lakes indicate the composition of the waters of the open lakes.

The number of bacteria in the artesian waters varied too much (from 80 to 56,400) to make an average of any

value, and out of nine of these waters 4 (44 per cent) killed animals.

It will be seen from the above that spring waters, taking conditions as they exist in Michigan today, furnish the best drinking waters, whether we look at the matter from a chemical or a bacteriological standpoint. Many of the smaller cities in Michigan are furnished with water from superficial springs. So long as the filter beds of these springs are kept from contamination these waters will remain good, but as soon as these filter beds are covered by privy vaults and cesspools these waters will no longer be safe. Many of these small cities are growing rapidly, and what they need to keep their water supplies wholesome is properly constructed sewers and compulsory house connections with these sewers. Nature has given to many localities in this State natural filter beds, which, if they had to be built artificially, would cost for each locality tens of thousands of dollars, and stupidly many localities are polluting these natural filter beds, increasing their death rate and rendering it absolutely necessary to go to a more remote water supply which will not be so safe as their original supply before it was polluted. There are probably but few cities of 20,000 or less inhabitants, in the State, that could not secure an abundant supply of wholesome water near-by if the pollution of the soil was prohibited. There is some excuse for the pollution of our streams because sewage and the waste from factories must be disposed of, but there is absolutely no excuse for the pollution of the soil about our dwellings. Whenever man builds for himself a habitation and pollutes the soil about him there, typhoid fever will sooner or later visit him. There is on this round earth no localty so salubrious that man may not contaminate it and make it unfit for his dwelling.

University of Michigan.

SHALL POLLUTION OF MICHIGAN STREAMS BE PERMITTED?

M. O. LEIGHTON.*

As the subject of this paper is in the form of an interrogation, the discussion will be commenced with a direct answer: Yes, Michigan streams must be polluted. In spite of all the preventive measures possible under ideal legislation, enacted by an ideal legislature, Michigan streams must inevitably be polluted; there is no alternative from this conclusion. Let us review the facts briefly.

The water which flows in a stream is largely derived from the land lying above. The rain falls upon the ground and either runs directly off into water courses or sinks into the ground, to reappear in the form of springs or as seepage, so that ultimately, nearly all the precipitation is drained off into rivers. It is well known that water is an excellent solvent; as it passes over and through the ground, it dissolves larger or smaller quantities of those substances with which it comes in contact. If it passes through a bed of salt, for example, it will, when it emerges, contain some of that salt, or if it encounters filthy conditions, it will contain an abnormal amount of organic matter. Therefore, it may safely be said that the character of any stream water affords an excellent record of the conditions through which it has passed.

Streams draining primeval countries carry what is known as "normal" water, or what is more popularly called "pure" water. Whatever of organic matter such water may contain, consists of the products of decay of vegetable matter. But when man moves upon that drainage area and sets up his establishments, the water draining over and through the land which he occupies must of necessity acquire characteristics which it hitherto did not possess. Such water will contain, in addition to the vegetable organic matter, the products of the decay of animal matter, and just here we have what may be called "initial" pollution.

It is but a short step from the exceedingly minute and immeasurable amount of pollution imparted to run-off waters by one inhabitant, to the large amount which must be the necessary result of drainge of the land occupied by many persons, and so it is, that we may accept the statement as final and axiomatic that no river water can remain unpolluted so long as its drainage area is inhabited. It may, of course, have so small a population per square mile, and the habits of that population may be so regulated that there will be no *measurable* effect upon the run-off; but the effect is there nevertheless.

When, however, we take up the consideration of a stream that drains a populous basin, that has cities and villages upon its banks, like most of those in which we are interested, we may be perfectly sure at the outset that just as long as those cities and villages remain there, the river water cannot be constantly safe for domestic consumption in its raw state. Were every one of these municipalities supplied with sewerage systems, and were the most perfect sewage disposal plants installed, this water would still be unsafe for domestic uses. The natural drainage from closely inhabited land is dangerous enough, but in addition to this there are those occasional and sometimes surreptitious pollutions which are doubly dangerous in themselves, and which inevitably occur whenever people live along the banks of a stream. If we review the history of some of our classic typhoid fever epidemics, we will recall that the ultimate cause of those epidemics was just such isolated and comparatively insignificant pollutions. The Plymouth epidemic, it will be remembered, arose from a single focus of pollution upon a sparsely inhabited drainage area. The conditions in connection with the New Haven epidemic were similar, as were those at Ithaca and Butler. No amount of city sewage purification would have prevented these epidemics. The fact that there was habitation upon the drainage area was sufficient to cause the trouble. Therefore, the pollution of streams draining occupied countries is inevitable and the water of all such streams is dangerous for domestic use in its raw state. The sooner we accept these facts, the more intelligently we can deal with the entire situation.

The admission that our streams must be polluted, does not, however, warrant the conclusion that they may, with propriety be abused. The inevitable pollution of any stream is a reasonable one. It does not affect any of the values of a water course, except that of domestic supply. Such pollution never reduces a river to a stream of liquid filth. It does not render the water a damage to industrial enterprises, nor does it kill fish, nor make the stream a general nuisance. The only damage caused (that of domestic water supply) can readily be overcome by filtration, or similar methods of purification, and the cost of such purification systems, and the expense of their maintenance must be considered as a reasonable price which society must pay in return for the advantages accruing by reason of the industrial and social development upon the drainage area. Surely this is not an unreasonable price.

Therefore, it seems as though the limit beyond which pollution of streams should not proceed is that defined by what may be considered as inevitable and reasonable pollution. Under such a limit no warrant is given to cities to dump immense volumes of raw sewage into a river, nor is a manufacturing establishment justified in pouring out its millions of gallons of damaging wastes into the very streams which must be used for water supply by us and by generations yet unborn. Looking at the matter from this point of view, it is questionable whether or not an industry or a city is not justified in polluting streams up to a point which does not exceed the inevitable degree of pollution. Inasmuch as it is necessary to purify stream waters for domestic consumption, it makes little difference whether or not the pollution be the natural contaminated drainage, or the partly purified effluent of a sewage disposal plant. When, however, the amount of pollution increases so as to make the purification of the water for domestic purposes more expensive or more uncertain, such pollution must be considered as unreasonable and subject to regulation and prohibitive legislation. Filtration systems of water supply are provisions for public safety. When properly constructed and maintained they are absolute safeguards against the infectious pollution in a slightly polluted water. With the increase of pollution in the water, the safety provided becomes more and more precarious. In other words, a filter provides a wide margin of safety in the case of a slightly polluted water, but a narrow, precarious, and expensive margin in the case of a grossly polluted water. No matter how faithful or how expert the attendants in charge of a filtration system may be, there will arise occasions when the effluent of that system will not be purified as completely as the system of purification would warrant. If the water supply is only slightly polluted the danger is not great, but if, on the other hand, it is a dangerously polluted water, then the occasional lapses may and will allow infection to enter the distribution system with serious results.

The above statements indicate with a fair degree of precision the line which may be drawn between permissible or inevitable pollution and unreasonable or gross pollution. In the former case, we are helpless, but in the latter, we should be all powerful.

There are a few observations which may profitably be made concerning the efforts exerted by many authorities, and the legislation prepared and presented by them to prevent stream pollution. Many of the laws which legislatures are requested to enact are altogether unreasonable because they seek to secure that which it is not within the power of man to attain. If those interested in the pollution of streams would take the middle course or the reasonable course, and recognize the limitations by which they must be guided, they would secure immediate recognition by legislative bodies, and the commendation of society at large. A statute that recognizes these limitations, that seeks to secure reforms gradually and expediently, and that tactfully takes account of the fact that long imbued municipal and industrial habits are not to be effaced by the sounding of a trumpet, is the only one that promises success.

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PURIFICATION OF MUNICIPAL WATER SUPPLIES.

G. S. WILLIAMS.

MR. CHAIRMAN AND GENTLEMEN: The subject of water purification here in America is a comparatively modern question. A few years ago, within our easy recollection, there were not many places where water purification was necessary, but with the growth of population the possibilities of obtaining a satisfactory supply of water from the surface of the earth became materially decreased, and we have had to resort to those methods which have been in vogue in the old world for nearly three-fourths of a century. It is only within recent years that the ground water supply of Paris, for instance, has been discovered to be seriously polluted. For many years Paris boasted of a. pure spring supply which was thought beyond all possibility of being contaminated, and yet for a number of years we have noticed that Paris has had a higher death rate from typhoid fever than other European cities. The springs furnishing water come from a fissured rock, and the drainage which contributes to these springs has become polluted, and in time it has been possible for that pollution to seep through the crevices of the rock and infect the springs, and the authorities have now discontinued the use of several of these, and have substituted in their place filtered river water. They have further recently investigated American methods of water purification with a view of their application to the water of the river Seine. The record of water borne diseases is the best criterion of the water supply of a community, so far as the past is concerned, but from many sad experiences we are quite safe in saying that in these days no surface water supply is a safe supply. The distance to which pollution may be transmitted is dependent upon the life of the organisms which may produce infection. That life in the case of the

typhoid germ is ordinarily ten days, and with occasional ones very much longer, perhaps as much as sixty days, perhaps 100, in fact we do not know how long they may live. Therefore the distance to which they may be transmitted is dependent upon their life, and their vitality at the time they may arrive in the conditions where they cause infection. It seems to me that it was pretty clearly shown that the water supply of St. Louis was being polluted by Chicago sewage after the opening of the drainage canal, for the death rate of typhoid fever increased immediately. The Supreme Court has seen fit to differ from me on that point, and perhaps I am not warranted in saying that this was the fact, but as the result of the investigation which was made, I not having, like the Court, to restrict my findings to the laws of evidence, feel quite thoroughly convinced that a very large portion of the increase of typhoid fever in St. Louis has been due to the discharge by Chicago of sewage into the drainage canal.

Now as to the means of purifying water. The best, of course, is distillation. It necessarily kills all living organisms which may be present, as does also boiling. We have the possibility of purifying by certain chemicals, and we have the domestic filtering apparatus, which is nothing more than a fine strainer. We have nature's method, dilution, which is the reduction of the percentage of obnoxious matter that may be present in the stream, by reason of the inflow through its bed, and by its tributaries, of water which is less polluted. The pollution under these circumstances will be further decreased by the fact that a large percentage of the foreign matter which comes into the water is heavy and will settle to the bottom. Then we have purification as the result of aeration. This is an important factor under certain conditions, though not of such direct importance as was once supposed. Vegetable growths which occur in streams also play an important part in the decomposition and reduction of impurities, but all of these processes are more or less impracticable or imperfect on the large scale, so finally we come to the practical methods of purification which it is possible for municipalities to adopt. In these we have two very distinct processes, which unfortunately, are designated by the same name, '"filtration," though they have scarcely any fundamental resemblance. These two processes comprise, first, the so-called natural or slow-sand method, in which the agents are wholly natural, in which we make use of bacteria themselves to get rid of other bacteria; and, second, the mechanical or chemical method in which we make use of chemicals to precipitate the impurities, or to put them in a condition where they may be strained out by passing the water through a strainer. The former method is the older and was introduced in London in 1839. The purpose of introducing it at that time was to remove turbidity. It was not to aid in the bacterial purification of water, for bacteria were then unknown, but rather to make the water more agreeable to the consumer. The effect of this method was so satisfactory that in 1856 its use was made compulsory upon the companies supplying London, except those who took water from subterannean sources. These filters were first designed by James Simpson for the Chelsea Water Company and were of practically the same type as those that are used today in the same process. They consisted of impervious basins, enclosing a system of under drains either of tile or brick, covered with a layer of gravel, which permitted the water to flow to the drains, and the gravel in turn was covered with a considerable depth of sand, the water being brought upon the top and allowed to seep through to the underdrains. In designing these filters, Mr. Simpson established the rate of filtration to be that which was about the same as the ordinary flow of water through the surface layers of the ground or about six feet per twenty-four hours, and when so designed the filters yielded about two million gallons per acre per day. After such a filter has been put in service there accumulates upon the surface a collection of impurities which is known as the mat. This covers the sand grains with slime and the bacteria are entangled and held there, to such an extent that after a while no water will go through the filter, and it is found necessary to remove a portion of this accumulation. The filter is then scraped, a thin layer of sand mixed with bacteria is removed from the surface and washed, and stored until such time as the sand bed is reduced in thickness to a degree that is regarded no longer safe, when the bed is rebuilt. The practice of the English for years was to dig up their filters once a year, but the Americans beginning' along in the 80's have shown that those ideas were wrong, and that the older a bed becomes the better it is; so that now we start these filters with a thickness of four feet of sand and run down to sixteen or twelve inches before renewing; or more frequently we run them down about eight inches at a time and then replace the sand, thus keeping the lower part of the bed undisturbed. After scraping, the water from these filters has to be wasted for a short time to give these surface layers an opportunity to form anew, and the filter should always be refilled with filtered water, which must be permitted to rise very slowly from the bottom. Care must, of course, be taken to prevent disturbing the surface, and the water must be brought upon it at all times without agitation.

The first attention to filtration in this country was when the city of St. Louis, in 1866, sent Mr. James P. Kirkwood, its engineer, abroad to study methods of water purification. At that time he found slow sand filtration in use at Berlin, Altona, Nantes, and Marseilles on the continent, and at Leicester, York, Liverpool, Edinburgh and Dublin, as well as London. He returned and presented a report which was published in 1869, but St. Louis went no farther. Great Britain had meanwhile accepted purification as a matter of course, and they thought no more of it. We over here did not feel the necessity for it generally, but as the result of Mr. Kirkwood's trip abroad there were two or three filters established in the United States. The first at Poughkeepsie in 1872, designed by Mr. Kirkwood, and the second a smaller plant, also from his designs, at Hudson, N. Y., in 1874. About that time St. Johnsbury,

Vt., put in one, the designer of which is unknown. Those remained all the filters of this type in the United States until 1893. During that year the city of Lawrence, as the result of agitation after an epidemic of typhoid, built its famous filter, which was the first to be employed in a large city in this country, Lawrence having at this time 40,000 people. In 1894 Mt. Vernon, New York, put in a filter to supply a community of 11,000 people; in, 1895 Ashland, Wis., as the result of a typhoid epidemic there, added another 10,000 to the users of filtered water, and the city of Milford, Mass., put in a filter, making another 10,000 so supplied. So while at the end of the period from 1872 to 1893, only about 36,000 people were supplied with filtered water in the United States, that number was more than doubled within the next five years. In 1899 the city of Albany put into service a slow sand filter, which added approximately 250,000 to the number of persons using filtered water. Since that time Philadelphia has put into service a portion of its filter plant, it being designed ultimately to supply the entire city, the full capacity of the plant to be 350,000,000 gallons per day. Washington has filters under construction which are nearly ready to put into service. Pittsburgh has filters under construction. New Haven has a plant which is going into service, and Yonkers, N. Y., has one now in service. The general cost of slow sand filters is about five dollars per person, and the cost of operation ranges from $1.25 to $4.00 per million gallons filtered. We find that 98 to 99 per cent of the bacteria are removed by this process. The more impure the water is when it goes through the filter the larger the percentage removed. In Europe, where this process is used, and where they often deal with very impure water, typhoid fever is of such rare occurrence that a case of it is hailed with delight by the students of medicine. The death rates in American cities where filters have been introduced have shown a most remarkable drop. In Albany the death rate from typhoid fever dropped 75 per cent upon the introduction of filtered water. This water was taken from the Hudson polluted with the sewage of Schenectady only a few miles above.

It was my privilege to visit the Lawrence Experiment station in September, 1895, and I saw there sewage from the main sewer of the city of Lawrence, a city of over 40,000 inhabitants, being passed through about five feet of pea gravel at a rate of a quarter of a million gallons per acre per day, an effluent being obtained of sufficient purity to offer no offense if turned into a stream whose waters were used for any but drinking and culinary purposes, saw this effluent then passed through about five feet of sand very similar to our lake sand, at a rate of two and one-half million gallons per acre per day and saw the final effluent of such purity that the assistants in the laboratory had no hesitation in drinking it, its composition being about that of the best spring water.

So we water supply engineers have a good deal of confidence in our ability to purify moderately bad water and render it safe. There are, however, some limitations to the slow sand process. In the case of waters whose turbidity contains no clay, it is found that the slow sand filter works well, but if clay is present it soon fills the pores of the filter and cuts off the flow, and it is very difficult to remove a clay turbidity by simple sedimentation. At times in the spring when the Detroit water is turbid the suspended matter is made up of clay and sand, the sand turbidity will settle out in a few hours, but thirty days will not remove the clay. So where you have a water bearing clay it becomes almost impossible to deal with it by the slow sand process. A feature of the slow sand filter is that while turbidity may go through, it will still do its work in removing bacteria, so a turbid effluent is not an indication of defective purification with this process.

We now come to the other process, that known as the mechanical filter, sometimes spoken of as the mechanical process, sometimes known as the American method, and perhaps more properly called the rapid method. These filters appeared about 1887, and were originally designed for use in paper mills in Maine to take out of water those substances which were detrimental to the manufacture of paper. They consisted of tubs containing coarse sand through which the water was passed. The water coming out was clear and very attractive, and it was thought these filters would be a desirable adjunct to water supply systems. A great many of them were put into hotels and installed in small villages throughout the country. They removed turbidity and a good many supposed they would remove disease infection. The water was passed through this sand at very high rates of speed, 100 times as rapidly as it passed through in the slow sand process, and it was soon demonstrated that little bacterial purification resulted. The next thing that was suggested was the use of chemicals in connection with this rapid filter. Chemicals had been used in Egypt many years for the purification of the water of the river Nile, and the suggestion was taken up by some of the filter companies, and the process developed into the rapid method of filtration as we now know it. The ordinary chemical used is sulphate of aluminum. This substance is first dissolved and the solution introduced into the water to be purified and thoroughly mixed with it. That produces a precipitate which entangles the impurities and carries them to the bottom; a portion of the precipitate in the form of fleecy masses is deposited on and through the sand bed and then entangles other passing impurities as does the mat in the other process. The water is passed rapidly through the sand and the impurities will be washed through it if the bed is run too long, so it must be shut down and washed from time to time. This washing takes place from once in six hours to once in forty-eight hours, dependent upon the character of the water, and is performed by pumping water into the under drains and at the same time stirring up the bed with rakes or compressed air, thus floating the collected impurities to the surface, whence they are carried away to a sewer. Early plants of this type which were put in were not in all cases successful. There were many of those plants that are claimed to have been successful

which really were not so. The filter companies naturally did not wish to build a different machine every time they built one, and consequently they did not make any special study of the water with which they dealt. The treatment of water is not widely different from the treatment of disease. For success you must find out what sort of a treatment a particular water must have. As a result a great many of their plants were failures, and very few, if any, were unqualified successes. Along in the 90's, however, Providence took up water purification, and undertook a series of experiments upon rapid filters. The results showed greater possibilities than had previously been anticipated, and these experiments were followed by others at Louisville, Cincinnati, and Pittsburgh, and since then at St. Louis. There have been constructed within the past two or three years some very successful plants operated on this system. The first was that of the East Jersey Water Company at Little Falls, N. J., having a present capacity of about 34,000,000 gallons per day, designed by Mr. George W. Fuller. The next one of importance was that at Ithaca, and that was followed by one at Watertown, both by Mr. Allen Hazen; the efficiencies being in all three about the same as for slow sand; so that we may say that this method has proved its right to stand with the older one. The difference is that with a slow sand filter the longer you let it alone the better work it will do, but with the mechanical filter the operator has to be on deck all the time. He must see to it that all the water receives the proper dose of medicine. With the rapid filter the water must always be clear to be safe; if it is at all turbid when it comes from the filter, that is absolute proof that the purification is imperfect. So that where you have a water that can be handled with slow sand filtration it is safer. You are less likely to have a slip on account of the failure of an attendant. Where you have to make use of the rapid filter it will give good results if you put it into competent hands.

This has described what we can do with a bad water supply if we have to. I do not advise purifying a bad water, it is better to get a pure water to start with, but if we cannot get such an one naturally, we do not give it up.

University of Michigan.

DISCUSSION.

DR. LANE:

The primary use of a water supply is not domestic use. The primary use of the water supply is fire protection. The first reason for putting in city water is fire protection. The amount of water used is something like 100 gallons per day per person. Of that only about one-quarter is drunk. It might be that it would be cheaper and would pay to make each individual boil his water than to try to make the water safe for drinking use if it were otherwise desirable. There is another thing to be considered; that is the use for laundries and boilers which need soft water. It may be desirable to use artesian wells.

PROF. CAMPBELL:

With many large factories now it is a very important problem as to water softening, and nearly all the large railroads are introducing water softening systems.

MR. LEVERETT:

I think Dr. Vaughan might throw some light on that St. Louis matter.

DR. VAUGHAN:

Prof. Williams was employed by the State of Missouri and I was employed by the State of Illinois. I differ from Prof. Williams on one point. I do not think there was any increase in typhoid fever in St. Louis. St. Louis has kept excellent records of typhoid fever. They have very complete records and there is scarcely a city in the union which has such records. Investigations which followed the Spanish War in 1898 showed that what was thought to be Malaria was typhoid fever. St. Louis, after that reported all deaths as due to typhoid fever, where formerly some were called malaria.

PROF. WILLIAMS:

I would say that it was extremely fortunate that they began this change of recording cases just ten weeks after the opening of the canal; if they had begun six weeks after or twelve weeks after the effect would have been different, but as they began just ten weeks after the canal was opened it saved Illinois' case.

IDEALS CONCERNING MUNICIPAL WATER SUPPLIES.

ISRAEL C. RUSSELL.

The requisite conditions in reference to the water supply of a city may be tersely stated by saying that it should be abundant and wholesome. The first of these postulates must be understood as being sufficiently elastic to meet a wide range of conditions, but the second is rigid, as the same high standard of purity should be maintained in the case of all water used for domestic purposes.

In reference to the amount of water to be supplied to a city, two leading considerations need to be kept in mind; one is the quantity of water desirable for domestic uses, and the other the necessary provision that should be made for fire protection.

Water for Domestic Uses: The quantity of water that should be provided for the domestic use of the inhabitants of a city, has been considered by numerous municipalities, and the conclusion reached although varying between wide limits, is expressed perhaps with sufficient accuracy in a report on the water supply of Philadelphia, published in 1899. In preparing this report a large amount of evidence was carefully considered, and the conclusion reached that the minimum amount should be 150- gallons (681 liters) per individual per day. Although this at first glance may seem an excessive quantity, yet it is to be borne in mind that domestic use

of water in a city cannot be strictly separated from its commercial use, and for fire protection. With these considerations in mind the estimate given above may be assumed as a basis for estimating the volume of water required for a municipal supply. This volume should be continuously available for the use of every inhabitant of a city, and to meet this end a suitable distribution system must of necessity be provided.

Water for Fire Protection: In making plans for the protection of a city against fire, the conditions to be considered vary much more widely than they do when domestic use is alone considered. Cities in which tall buildings exist or are likely to be built, of necessity require greater water pressure, than when the buildings are low. An adjustment in these and analogous respects can be provided by augmenting the hydrant pressure by means of fire engines and of private pumps, but where the pressure in water mains is the chief reliance, a desirable standard as experience seems to dictate, is that a sufficient volume of water should be available to maintain at least four fire streams with a diameter of one inch at the hose nozzle, for five hours, through hose pipes fifty feet long, with a pressure of at least ninety pounds to the square inch. Here again the distribution system needs to be properly adjusted to a variety of conditions; and as an ideal standard each building in the city is within reach of at least four efficient fire streams.

WHOLESOME WATER.

By wholesome water is meant water that when drunk by man is in every way conducive and in no way detrimental to the health of an individual using it. To meet these requirements it should be free from disease producing germs, and of such chemical composition that no deleterious effects to the health of an individual would result from its continuous use for a series of years. In addition to these requirements, water in order to be adjudged wholesome, should be clear, free from unpleasant odors and disagreeable taste and in no way contaminated with sewage or other substances which might lead to prejudice or repugnance against its free use for domestic purposes.

To claim that water for domestic use should be free from germs of all kinds, is beyond the ideal, since as we are assured by bacteriologists, certain bacteria and protozoa, are not only harmless to man, but beneficial, for the reason that they are the natural enemies or competitors of dangerous species. In nature as it appears, the only germ free water that can be obtained for municipal purposes, is such as is supplied by deep wells and by certain classes of springs. Other considerations bearing on the use of such waters will be noted below.

Chemically pure water is of still greater rarity in nature than germ free water, and it is safe to say that every drop of water met with on the earth, contains mineral matter in solution. Chemically pure water, however, is no more to be desired for domestic use than germ-free water, as certain mineral substances in solution when not in too great abundance are not only desirable but requisite. Ordinary surface water, such as forms fresh-water streams and lakes, has a highly complex chemical composition, and in fact nearly all known elements could as it appears be detected in it. The volume of the invisible freight which streams carry, is surprising to persons who have not given it careful consideration. A considerable number of analyses of river water compiled by Sir John Murray, shows that the larger rivers of the earth contain on an average about 762,587 tons of dissolved mineral matter to the cubic mile of water. An average based on analyses of a large number of the river waters of North America, gives for total solids in solution, 150.44 parts per million, and for calcium carbonate, the most abundant substance in solution in ordinary fresh water, 56.416 parts per million by weight. These figures may be taken as representing about the average chemical composition of the waters to which the people of this continent have become accustomed. In other words, an adjustant between human needs and the nature of the water supply has been reached, which furnishes a desirable standard for comparison. An ideal water for municipal purposes as may be justly claimed from the average conditions met with in America, should not contain more of total solids, or of calcium carbonate in solution, than is indicated by the figures just quoted. This standard of purity, however, is more rigid than has been adopted in Europe, where the streams in general are considerably less pure than in North America. At an International Sanitary Congress held in Brussels in 1852, and since reconsidered and readopted at several subsequent conferences of sanitary experts, it was declared that water containing more than thirty-five grains per (imperial) gallon, or 500 parts per million by weight, is not wholesome; and that there "should not be more than one grain of organic matter to the gallon." The consensus of opinion arrived at during the discussions referred to, was .that calcium carbonate in excess of 170 parts per million, is detrimental to health. A standard of purity based on the average chemical composition of the rivers and lakes of this country, would no doubt demand a greater degree of purity than has been decided as sufficient to insure health in Europe, but until such a standard is framed by American experts in hygiene, municipalities will be constrained to assume that water which is good enough for the people of Europe, will suffice for the people of America. It seems but reasonable to assert, however, that water which makes a near approach to the danger line stated above, should be regarded with suspicion, and not used for drinking unless no better supply can be obtained.

Not only is the standard of chemical purity just indicated, desirable in reference to the health of communities, but it has an important bearing on the commercial uses of water. The more nearly chemically pure a water is, the less the expense incident to the formation of "scale" in steam boilers, and the less the cost of soap used in connection with it. The maximum limit of mineral matter in solution, adopted by the United States Geological

Survey, in reference to its use for generation of steam, is 140 parts per million. Each of the items just mentioned as well as several others in reference to the chemistry of water, becomes of great importance when the water supply of a city is considered.

There is an inferior as well as a superior limit, however, to the proportion of mineral matter which water should contain in solution in order to be wholesome, and certain water as that supplied directly by rain for example, may contain too small a percentage of mineral substances to be thoroughly desirable. The lower limit adopted at the Brussels Congress and subsequently confirmed at later conferences of a similar nature, is 130 parts per million for total mineral matter, and for calcium carbonate, sixteen parts per million. The most desirable proportions among the several mineral substances usually occuring in solution, has also been at least approximately determined, but will not be considered at this time.

In reference to the "one grain of organic matter to a gallon," stated by the Brussels Congress to be permissible in wholesome water, it is evident that uncertainties might arise as to the true meaning intended. Disease producing germs are evidently not to be included within this limit. A clearer and as is evident a more reasonable conclusion in this connection, has been placed on record in an essay on the sanitary chemistry of waters, by Professor C. F. Chandler, for a term of years President of the Board of Health of New York, which reads as follows: "Organic matter of a purely vegetable origin, such as occurs to the extent of one, two, or three grains per gallon, in country springs and wells, or in ponds and rivers, even when it contributes a tint of yellow to the water, is entirely harmless and unobjectionable. The nitrates, nitrites and ammonia salts found in wells in densely peopled towns are themselves harmless, but their presence proves the contamination of the water with the products of decomposition of animal refuse, and should always be viewed in the light of a warning of the presence of impending danger." In this same essay, in discussing the dangers arising from animal excreta, the important statement is made that decomposing animal substances are highly dangerous, even when in minute quantities; and that filtered sewage though clear and transparent may carry with it the germs of disease.

In addition to freedom from disease-producing organisms and to the standard just stated in reference to chemical composition, wholesome water should be clear or essentially free from all matter in suspension, and as noted above, not be open to the suspicion that it contains sewage or other material which may lead to prejudice against its use for drinking purposes. This last standard which it seems desirable to establish, may perhaps, by some persons, be considered as ultra-ideal, when practical considerations are taken into account, but it is certainly reasonable to demand that drinking water should not contain sewage or other suspicious ingredients, even though the microscope fails to reveal the presence of disease-producing germs.

In order to establish an ideal towards which persons in charge of the water supplies of cities may strive to approximate, it should also be born in mind that temperature has an important bearing on the wholesomeness of water used for drinking. While the habits of individuals in this connection are not under the control of municipalities, it is obvious that if the water supplied to a city is of such a temperature as to meet reasonable desires, the use of iced water particularly during hot weather would be greatly decreased and a danger to the general health of a community thus lessened. In this connection the desirability of providing reservoirs with covers, to be considered below, is worthy of consideration.

SOURCES OF MUNICIPAL WATER SUPPLY.

The sources of water supply available for the use of cities may be classified as (1) rain water, (2) shallow wells and cold springs,* (3) deep wells and warm or hot springs, and (4) streams and lakes.

Rain Water: In certain instances the only available supply of water for domestic use is rain. So far as I am aware no municipality in the United States endeavors to store rain water for public use, but individuals construct cisterns, etc., for themselves. The amount of water an individual provides for his own use or for the use of a household, etc., is a private matter, but the healthfulness of the supply is of public concern. Intelligent supervision of cisterns when used as a means of domestic water supply, thus becomes as legitimately a matter of municipal supervision as the safeguarding of wells when utilized in a similar way.

Rain, in falling through the air, washes from it dust particles including living organisms, and in thickly settled regions, or whenever disease-producing germs are disseminated through the air, may reach the earth in an unwholesome condition. Its liability to contamination is enhanced as it flows over roofs, etc., and on entering a cistern, the seeds of life thus gathered—for the very reason that they may not be in great abundance or variety, thus allowing such as are present favorable conditions for development—are likely to increase in numbers if the conditions in reference to temperature and light are favorable. To prevent farther contamination and especially to exclude mosquitoes from cisterns, they should be properly covered. Rain water, however, as usually gathered, contains a relatively high percentage of inorganic matter either in suspension or in solution, which is liable to undergo decomposition, and render it foul and unhealthy to man. In order to counteract this tendency as far as practicable, adequate ventilation, suitable overflow pipes, and frequent cleansing of cisterns should be provided for. In reference to the use of rain water for domestic purposes the fact should be borne in mind, as stated above, that it is deficient in the mineral matter in solution to an extent which for continuous use for drinking, renders it unwholesome.

When all precautions have been taken to preserve the purity of rain water, when desired for domestic use, it is safe to assume that it should not be taken internally by man, unless well boiled or thoroughly filtered.

For use as a means of fire protection, rain water is obviously as serviceable as water from any other source, and for use in generating steam it is no doubt superior to any other water that can be obtained, for the reason that its content of mineral matter in solution is far below that of average streams and springs. In regions where water is scarce and even in humid regions where the streams and springs .are abnormally high in mineral matter in solution, the construction of gathering grounds for rain water in excess of that supplied by roofs, might be advisable and practicable, in order to obtain water for fire protection and for generating steam.

*The classification of springs uses here is arbitrary, but suggestive in reference to the domestic uses of such water supplies; by cold spring is meant one not sensibly influenced by the earth's internal heat, and in general conformable in temperature, to the mean annual temperature of the surface at the locality where it is located, and in the case of warm and hot springs the reverse of these conditions obtains

Shallow Wells: In regions where the surface level of soil saturation or the water table, is within approximately fifty feet or less of the surface, the obtaining water by means of ordinary dug wells is practicable, and such wells may be utilized as a source of municipal water supply. The ideal conditions in this connection are; sufficient volume of Water especially during dry seasons, to be obtained economically, and also that the water shall be wholesome.

Shallow wells, however, especially if situated in the vicinity of thickly inhabited regions, are always to be viewed with suspicion; and in general it is safe to say, such sources of supply should not be utilized for municipal purposes except as a last resort. In case it is necessary to use them every possible care needs to be taken to decrease the dangers of contamination, and the water properly filtered before it should be considered suitable for domestic use. The practice sometimes indulged in, of depending on natural filtration during the process of percolating into a shallow well, is not wise, as the condition and nature of the so-called filter is seldom if ever thoroughly known.

The chemical nature of the water supplied by shallow wells and cold or hill-side springs, also demands attention. In many regions where such sources of water supply are utilized, the superficial blanket of rock waste is highly sandy and the underlying rocks contain but a small percentage of easily soluble material, and the water is of a comparatively high degree of chemical purity. If however, the soil and subsoil contain limestone or other easily soluble rock debris, as is the case generally in the moraine covered portions of Michigan for example, the water after percolating through it, is apt to be too highly charged with material in solution to be thoroughly wholesome.

Deep Wells: The deeper a well is sunk in the earth the less the chances of the water supplied by it becoming contaminated with living organisms, but the greater the opportunity for it to disolve mineral matter. These propositions are based of course, on the assumption that water enters the well at or near its bottom.

Deep wells and springs rising from a deep source, furnish practically the only source of water supply for cities which are free from danger of contamination by living organisms. It being understood in this connection that proper care has been exercised in reference to the introduction of organisms into the well during the process of drilling, as on well points for example, and that the water is properly cared for after it reaches the surface. When these precautions are taken, the water of deep wells furnishes the best of all supplies for city use, providing the percent of mineral matter in solution is within certain limits in reference to its nature and quantity.

Having obtained an adequate supply of water from a deep source for municipal purposes, however, it is essential that its freedom from organic contamination should be maintained. In this connection a note of warning needs to be sounded, since in many instances, germ-free water is stored in open reservoirs before reaching the consumer, and thus exposed to the danger of becoming contaminated from the air. This source of danger is especially marked in the case of the class of waters under consideration, since the absence or scarcity of life in them, including forms not deleterious to the health of man, but which as is stated by bacteriologists, are in certain instances the enemies of dangerous species, or at least enter into competition with them, permits of the rapid development of noxious forms in case they do gain admission.

When water from deep wells or pure springs is utilized by municipalities, the conditions under which it existed before coming to the surface, needs to be maintained so far as possible. If the water is stored in reservoirs, such receptacle should be roofed, and during the passage of the water through water pipes, etc., man holes and other similar openings should be tightly closed. Objections arise, however, in reference to the use of covered reservoirs in addition to the expense they involve. In many instances the water delivered by deep wells and by springs, is of such chemical composition as to make it desirable to thoroughly aerate it. In many instances such waters contain gases which it is desirable to allow to escape, or are impregnated with mineral matter such as iron oxide and calcium carbonate, which if exposed to the air will in a measure be precipitated. Then too, water from a deep source is in general deficient in dissolved air, and as people are accustomed to drink thoroughly aerated water, its taste is insipid. For these reasons thorough exposure to the air of water derived from a deep source is in many instances desirable.

How to keep water derived from a deep source from becoming contaminated with objectionable forms of life, and at the same time secure the desired amount of aeration, is a somewhat difficult problem. The details in this connection must of necessity be studied for each

special locality, but in general it is safe to say that such water should be to fall in a spray within a roofed reservoir to which only filtered air is admitted and light excluded. Such a provision carries with it also, a lowering of the percentage of loss on account of evaporation, and prevents a reservoir from becoming a breeding place for mosquitoes, as well as eliminating the danger of its becoming foul on account of the growth and decay of algae.

Streams and Lakes: Lakes are in general expansions of streams, but in some instances and particularly in Michigan, they originate in other ways and are without surface outlets. Examples of enclosed lakes are abundant in many regions where the surface of the land is composed of glacial drift, and occupy depressions which extend below the water table. Water enters them wholly or in part by percolation through the material forming the bordering land and their surface levels are dependent on the horizon of the water table. For this reason they are similar to shallow wells and are exposed to similar danger of contamination.

When streams or small lakes are utilized for municipal water supplies, two general plans for striving to insure freedom from organic contamination present themselves for consideration: one is to endeavor to prevent contamination of the supply and the other to guard against such contamination by filtering or by boiling the water. The most logical method is obviously to take advantage of both of these means. The sources of supply should be safeguarded so far as possible, and the water suitably filtered or boiled before being used for domestic purposes. The boiling of water is as it seems impracticable so far as the municipal care of the supply is concerned, and must be left to the individual.

If the region tributary to a surface water supply can be maintained in its primitive or natural condition, and men and domestic animals excluded, the water derived from it may under normal conditions be adjudged reasonably safe and filtration dispensed with. In a region which is inhabited and to a greater or less extent utilized for agricultural purposes, however, it is seldom possible to insure such a degree of freedom from danger of organic contamination, that the surface water supplied by it can be safely used for municipal purposes without filtration.

In the case of lakes or streams which are utilized for navigation, a special element of danger is introduced which demands serious consideration in case the water from such sources is used for domestic purposes. The passage of vessels over a water body as the Great Lakes for example, leads to the direct introduction into them of refuse of many kinds, including the most noxious of all, namely human excrement. In this connection it should be noted that vessels carry people from city to city, and that cities are centers of distribution for many diseases. This imminent source of danger does not seem to have been duly considered in the case of several of the cities of Michigan which derive their water supply from the Great Lakes.

In addition to the danger of contamination of lakes from vessels, they receive the surface wash from the land tributary to them and in numerous instances are also the receptacles for the sewage of cities, the refuse of factories, etc. In these several ways they are liable to become contaminated, the danger being most imminent in the vicinity of the localities where sewage is discharged into them and where vessels pass in large numbers. To be sure, the great volume of water present serves to dilute the contributions of sewage, and freedom of exposure to the air promotes oxidation, thus diminishing the danger to persons who drink the water, but as is well known, the water of even the Great Lakes has in several instances served to disseminate certain diseases. An important investigation in this connection, which so far as I have been able to learn has not been made, is in reference to the life histories and rate of increase or diminution of diseases producing germs after entering an open water body such as a large lake.

While the waters of lakes at a distance from the mouths of sewers and away from the tracks frequented by vessels, are among the very best of natural water supplies, Lake Superior, for example, being probably the purest, both chemically and bacteriologically, of any considerable water body on the earth, yet it is self evident that a city cannot discharge its sewage into a lake and take its water supply from it at a nearby locality or from the vicinity of the routes frequented by vessels, without serious danger. While the water supply of an individual city, whether taken from a lake or from some other source, presents concrete problems for study and should be specially considered, it is safe to say as a general proposition, that even if the greatest care is taken in locating intakes with reference to the places where sewers discharge and with regard also to the routes followed by vessels, filtration is still desirable. A common sense reason for establishing such a safeguard, is that it is possible to exercise continuous watchfulness when a filtration plant is used, while it is impracticable to predict when contamination will occur in case such a precaution is not taken.

In connection with the use of the water of streams and lakes for municipal purposes, the liability of the supply becoming turbid or even muddy during heavy rains and in the case of lakes, on account of the action of shore currents generated by strong winds, have also to be duly considered. To counteract such undesirable conditions, settling basins for the water used should be provided, or filtration resorted to. In certain instances, as is well known, both of these methods have to be employed.

CONCLUSIONS.

Even a brief review, such as is here attempted, of the ideals which municipalities should strive to attain, renders certain conclusions self evident. These, as it appears, may be stated as axioms from which there is no logical appeal. They are:

First. When water derived from a deep source in the earth is utilized for domestic purposes, every possible precaution should be taken to prevent its becoming contaminated by disease-producing germs, owing to exposure to the air.

Second. Every care should be taken to prevent the contamination of surface waters and shallow wells, but that even when all practicable means to arrive at this end have been employed, such sources of supply are to be viewed with suspicion, and the health of communities still farther guarded in many instances by filtering the water.

In order to reduce the danger of surface water becoming unwholesome, every household, every community, every city, every factory, every slaughter house, etc., should be required to destroy or render harmless and unobjectionable its own refuse, before it is permitted to enter streams or other surface water bodies, and also before it is distributed in such a manner as to be dangerous or annoying through the action of the wind or in other ways. The aim in view in this connection, is to abate the menaces to life and health, and to comfort and happiness, incident to the growth of communities, and reap the benefits of civilization without augmenting the evils that flesh is heir to.

The subjects touched on in this brief essay, have a bearing on and are ultimately to a grave extent dependent on a still larger problem incident to the spread of civilization, namely the conservation of the volume and regularly of flow of streams, by sane forestry and agricultural methods.

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