

UNIVERSITY OF ILLINOIS BULLETIN

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SEPTEMBER 22, 1908.

No. 4

(ENTERED AT URBANA, ILLINOIS AS SECOND-CLASS MATTER)

CHEMICAL AND BIOLOGICAL SURVEY OF THE WATERS OF ILLINOIS

REPORT FROM SEPTEMBER 1, 1906 TO DECEMBER 31, 1907

EDWARD BARTOW
DIRECTOR

WATER SURVEY SERIES No. 6
URBANA, ILLINOIS
PUBLISHED BY THE
UNIVERSITY

PUBLICATIONS OF THE STATE WATER SURVEY

- No. 1. Chemical Survey of the Waters of Illinois. Preliminary Report. 98 pp., 3 pl., 1 map. 1897.
- No. 2. Chemical Survey of the Waters of Illinois. Report for the years 1897-1903. XVI+254 pp., 44 pl. 1904.
- No. 3. Chemical and Biological Survey of the Waters of Illinois. Report for year ending August 31, 1906. 30 pp., 5 cuts, 1906.
- No. 4. Mineral Content of Illinois Waters. In press.
- No. 5. Municipal Water Supplies of Illinois. VIII+123 pp. Map. 1907.
- No. 6. Chemical and Biological Survey of the Waters of Illinois. Report, September 1, 1906 to December 31, 1907. 88 pp., 3 cuts, 9 pl. 1908.

Note—For copies of these reports or information address, Director, State Water Survey, University of Illinois, Urbana, Illinois.

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State Reformatory Print

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ORGANIZATION.

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*To September 1, 1907.

**From July 15, 1907.

†Assistant Hydrographer, United States Geological Survey.

††Field Assistant, United States Geological Survey.

LETTER OF TRANSMITTAL.

STATE WATER SURVEY.

UNIVERSITY OF ILLINOIS,

Urbana, Illinois, June 1, 1908.

EDMUND JANES JAMES, PH. D., LL.D.,

President University of Illinois.

SIR: Herewith I submit a report of the work of the State Water Survey from September 1, 1906 to December 31, 1907, with the request that it be printed as a bulletin of the University of Illinois, State Water Survey Series No. 6.

The report includes a detailed description of the work accomplished during the 16 months ending December 31st, 1907, with a summary, by years, of the analyses made since the foundation of the Survey to that time, and a summary, by months, of the analyses made during the last two years. The new quarters into which the Survey moved during the summer of 1907, are described.

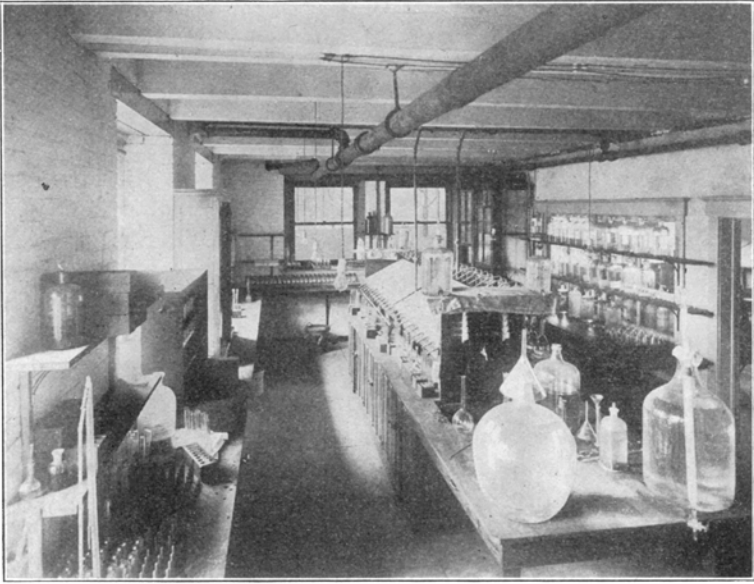
The progress of the co-operative work with the State Board of Health, and with the Engineering Experiment Station of the University of Illinois, the State Geological Survey, and the Water Resources Branch of the United States Geological Survey, is reported.

There are included the descriptions of several experiments or investigations carried on by the Survey. For these investigations special thanks are due to Mr. J. M. Lindgren for his Experiments in Water Treatment, to Mr. A. W. Sellards for the chapter on Sanitary Chemical Examination of Water Bacteria, to both of these gentlemen and to Professor A. N. Talbot, Professor H. S. Grindley, Mr. R. H. Slocum and the Corn Products Refining Company, for assistance and co-operation in the study of Trade Wastes at Waukegan; and to Dr. W. G. Bain for the description of the stand for fermentation tubes.

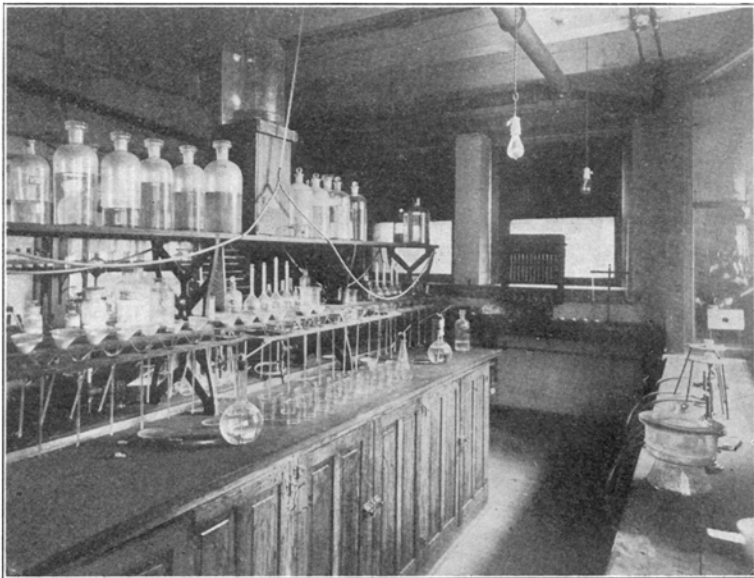
Respectfully submitted,

EDWARD BARTOW,

Director.



LABORATORY FOR SANITARY CHEMICAL ANALYSIS.



LABORATORY FOR MINERAL WATER ANALYSIS.

GENERAL REPORT FOR SIXTEEN MONTHS ENDING DECEMBER 31, 1907.

From the time of its foundation to December 31, 1907, the State Water Survey has received 16,920 samples of water. Of these 7,923 were sent in by private citizens or local health officers, and 2,800 were collected in connection with the investigation of the effect of the Chicago Drainage Canal on the waters of the Illinois River. The remaining samples were collected by members of the staff or under their direction, for the study of special problems in connection with test wells, the investigation of sewage disposal, the pollution of streams or for the determination of the normal character of the water in certain sections of the State.

During the two years ending December 31, 1907, owing undoubtedly to the publicity given to the work of the Survey, because of "the co-operative arrangement with the State Board of Health, which began January 1, 1906," the number of samples submitted by private parties nearly doubled. The amount of work that can be carried with the funds available is limited. Therefore, as the number of samples submitted by private parties increases, there is a noted decrease in the number of samples obtained under the direct supervision of the Water Survey, as shown in Table I. The decrease in special samples is also due to the fact that the Survey has been engaged more than ever before in a study of problems of water treatment, such as described in the chapter on "Laboratory Experiments in Water Treatment".

No significant changes have been made in the methods of analysis during the year. The analytical methods conform quite closely to those recommended by the committee of the American Public Health Association, published in the first supplement of the Journal of Infectious Diseases, May, 1905.

A standard to determine the suitability of a water for drinking purposes and by which all waters could be judged, would be of great advantage. Waters found in the State are so widely varied in character that it is impossible to suggest a general standard, or to suggest a common limit of impurities for waters from the various sources. There is, however, a certain similarity in waters from similar sources, and this has been discussed in the chapter on "Normal Waters", and in the chapter on "Interpretation of Results". The latter chapter contains information sent out with opinions on the results of water analysis. It is revised each year to conform to the latest information obtained by the Water Survey studies.

The sources of supply may be divided into three general classes, rain waters, surface waters, and ground waters. The last two classes are most important and may be again subdivided according as the water comes from streams, lakes and ponds, or from springs, shallow or deep wells, and wells in rock or drift. The number of waters in each of these classes that have been received in each year since the foundation of the Survey, is shown in Table I. Tables II and III show the number of waters of each class examined in each month during 1906 and 1907.

It will be noted that the analyses of water from the shallow drift wells predominate. This is undoubtedly both because such wells are more numerous throughout the state, and because they are very liable to pollution, and thus more open to suspicion, and therefore the water from such wells is more frequently sent to the laboratory. The character of shallow wells compared with deeper wells is shown on page 13 in the discussion of the relative purity of water from wells of different depths.

Analyses of surface waters are next in number. This is because many municipalities obtain their water from streams. Since the water in the streams varies from time to time frequent control is necessary. The Survey has been called upon to make such control and to test the efficiency of filtration.

Deep drift and deep rock wells have been analyzed in nearly equal numbers. These waters are much used as water supplies, both public and private, the former in the central, and the latter in the northern portion of the state. Requests for analysis are usually made because of the turbidity, or the hardness, and the desire to know how to overcome these characteristics. Labora-

TABLE I. SHOWING THE NUMBER OF WATER SAMPLES EXAMINED AT THE DIRECT REQUEST OF PRIVATE CITIZENS
OR LOCAL HEALTH OFFICERS, ARRANGED BY YEARS AND ACCORDING TO THE NATURE OF THE SOURCE.

SOURCES	October 1895, to Dec. 31. 1896	YEARS											Totals for each source
		1897	1898	1899	1900	1901	1902	1903	1904	1905	1906	1907	
Surface waters, rivers, lakes and ponds.	69	72	102	54	59	61	97	75	80	107	304	336	1,416
Springs	16	21	34	23	22	35	28	18	28	41	63	52	381
Cisterns	12	19	17	7	7	3	10	6	7	5	13	29	135
Natural ice	4	12	1	11	9	4	9	3	12	6	4	1	72
Artificial ice	1	1	1	2	1	1	1	1	1	1	1	1	11
Water for artificial ice	3	2	3	3	1	1	1	1	5	2	1	1	16
Water for natural ice	2	2	2	3	3	1	1	1	2	2	6	1	15
Shallow wells in rock	28	16	8	22	12	22	10	17	25	25	19	45	249
Deep wells in rock	58	48	34	26	26	56	59	23	28	66	170	159	763
Flowing wells in rock	45	8	16	12	13	14	3	8	9	11	22	17	178
Shallow wells in drift	500	245	168	243	274	209	243	245	270	292	442	514	3,645
Flowing wells in drift	63	5	4	9	4	4	3	5	5	12	19	25	154
Deer, wells in drift	64	68	43	30	24	36	63	54	51	40	114	154	741
Sewage	37	21	21	25	10	10	1	7	2	6	5	33	147
Total samples from citizens	899	517	448	467	471	444	529	463	525	613	1,182	1,365	7,923
Other samples	888	811	988	1,579	1,866	778	147	419	555	466	445	55	8,997
TOTAL FOR THE YEAR	1,787	1,323	1,436	2,046	2,337	1,222	676	882	1,080	1,079	1,627	1,420	16,920

TABLE II, SHOWING THE NUMBER OF WATER SAMPLES EXAMINED BY REQUEST DURING THE YEAR ENDING DECEMBER 31, 1906, ARRANGED BY MONTHS AND ACCORDING TO THE NATURE OF THE SOURCE.

SOURCES	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Surface waters, rivers, lakes and ponds.	20	21	24	24	22	18	25	58	20	34	21	17	304
Springs.	1	2	1	1	12	2	5	8	10	12	4	5	63
Cisterns.			1	1		1		2	1	4	1	2	13
Natural ice.													4
Artificial ice.											4		4
Water for artificial ice.								1					1
Water for natural ice.					1					4			6
Shallow wells in rock.			1	1		1	4	1	1	5	2	2	19
Deep wells in rock.	6	5	11	13	15	8	7	14	19	25	22	25	170
Flowing wells in rock.					5	2	2	2	6	5			22
Shallow wells in drift.	19	27	13	16	29	22	30	55	57	92	48	34	442
Deep wells in drift.	3	4	14	7	9	6	13	12	9	15	13	9	114
Flowing wells in drift.				1	1		1	3	3	7	1	2	19
Sewage.						2		2	1				5
Total samples by request.	49	60	65	64	94	62	87	158	127	203	117	96	1,182
Other samples.	40	38	32	45	111	38	40	32	58	5	5	1	445
Total for the month.	89	98	97	109	205	100	127	190	185	208	122	97	1,627
Bacteriological analyses.	55	66	64	62	148	70	79	88	94	43	66	57	892
Mineral analyses.	2	11	15	22	22	27	23	39	4	20	7	4	196

TABLE III, SHOWING THE NUMBER OF WATER SAMPLES EXAMINED BY REQUEST DURING THE YEAR ENDING DECEMBER 31, 1907, ARRANGED BY MONTHS AND ACCORDING TO THE NATURE OF THE SOURCE.

SOURCES	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Surface waters, rivers, lakes and ponds.	24	41	25	35	32	30	42	23	25	15	20	24	336
Springs.	3	8	4	4	7	4	10	4	6	2	5	2	52
Cisterns.	1	1	.....	6	7	3	2	1	4	1	2	1	29
Natural ice. . . . .	.....	.....	.....	.....	.....	.....	.....	1	.....	.....	.....	.....	1
Artificial ice. . . . .	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Water for artificial ice. . . . .	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Water for natural ice. . . . .	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Shallow wells in rock. . . . .	.....	1	3	1	2	.....	7	3	4	5	9	10	45
Deep wells in rock.	24	17	11	5	4	9	15	14	9	23	17	11	159
Flowing wells in rock.	1	.....	1	2	.....	.....	1	4	5	2	.....	1	17
Shallow wells in drift.	61	30	40	44	13	34	47	41	42	58	53	51	514
Deep wells in drift.	17	16	12	11	5	10	23	9	8	17	18	8	154
Flowing wells in drift.	2	.....	7	.....	1	.....	1	6	6	.....	2	.....	25
Sewage.	11	2	.....	3	7	3	4	.....	.....	.....	1	2	33
Total samples by request.	144	116	103	111	71	93	152	106	109	123	127	110	1,365
Other samples.	5	9	8	9	3	5	2	2	.....	7	2	3	55
Total for the month.	149	125	111	120	74	98	154	108	109	130	129	113	1,420
Bacteriological analyses.	102	98	99	75	47	80	129	100	104	100	84	88	1,106
Mineral analyses.	7	7	1	8	1	4	5	4	1	16	23	3	80

tory experiments in water treatment (see page 33) have been carried on with a view to solving these difficulties.

Springs are found quite evenly distributed through the state and form the next largest group of analyses.

Shallow wells in rock are comparatively rare, owing to the fact that such a large portion of the state is overlain by glacial drift, and this together with the alluvial drift of the river bottoms, furnishes supplies of water before rock is penetrated.

The widespread demand for water analysis is illustrated by the fact that since the foundation of the Survey samples of water have been sent in from 780 towns; and from every county in the state.

During the year 1907, 1420 samples of water were received for examination, from 290 municipalities, in 90 counties. One thousand two hundred and sixty-nine sanitary-chemical, and 1106 bacterial analyses were made. Sixty-three analyses were made to determine the composition of the mineral content of waters, and 72 special examinations to determine the character of microscopic organisms or to determine the value of waters for use in boilers. Of the samples examined, 101 were sent in by representatives of Boards of Health; 295 by physicians; 347 by authorities in charge of municipal water supplies; and 594 by other citizens.

The majority of the samples sent in are forwarded to the Survey, because of suspected contamination. This is especially true with respect to well waters, and as we would expect, a majority are condemned. With a view to determining the relative number of well waters of various depths condemned, or open to suspicion, a careful tabulation has been made of the well waters examined during 1907.

Following is a summary showing the relative purity of water from 868 wells of different depths.

TABLE IV. PURITY OF WELL WATERS

Depth	25 Feet	25-50 Feet	50-100 Feet	Over100 Feet	Un-known	Total
Number examined	284	224	111	161	88	868
Number condemned	244	173	42	22	34	515
Per cent condemned	85+	77+	37+	13+	38+	60+

A reason for the character of these well waters is found in the fact that 426 of the wells were reported as being within 100 feet of a privy; 276 were within the same distance of stables; 95 were near cesspools; 134 were near dumping grounds for slops; and 122 were located in feed lots.

While 60 per cent of all the waters received during the year were condemned, it is a notable fact that 85 per cent of those from wells under twenty-five feet deep were condemned, 77 per cent of those between twenty-five and fifty feet deep, whereas only 13 per cent of those over one-hundred feet were open to suspicion. The location did not affect deep wells properly cased. Moreover, of the small percentage open to suspicion, many were condemned because of an excess of mineral matter.

During the year 1907, the collection of data for two special bulletins, Water Survey Series No. 4 and No. 5, dealing with the mineral content of Illinois waters and the municipal water supplies of cities respectively, was completed.

Bulletin No. 4, Mineral Content of Illinois Waters, includes tabulated results of 547 analyses of the mineral content of Illinois waters, made prior to December 31, 1905. Each analysis was made with special reference to the value of the water for either medicinal use, or in order to determine the proper method of treatment to make it satisfactory for use in boilers or for manufacturing purposes. The bulletin includes chapters on Interpretation of Results of Water Analyses, Sanitary, Medicinal, and Mineral, a chapter on Boiler Waters by Prof. S. W. Parr, and a chapter on Geological Distribution of Illinois waters by Prof. J. A. Udden, and on Mineral Springs of Illinois, by George Thomas Palmer, M. D. The Survey is called upon to make analyses each year and it is expected that supplementary reports may be issued from time to time which will include the further data thus obtained. This bulletin is also issued as a bulletin of the State Geological Survey, No. 10.

The bulletin on Municipal Water Supplies includes the results of all analyses made of such supplies prior to December 31, 1906. An attempt was made to obtain certain data concerning all the water supplies in cities having more than 1,000 inhabitants. This was necessarily done by correspondence. Letters were sent to the water works superintendents, and to city officials, asking for the data. Replies were received from all but 14 of the municipalities

with 1,000 inhabitants or more at the time of the census of 1900. In some cases the data obtained was very meager. The only satisfactory method of obtaining statistics concerning water supplies would be to send a representative to each plant. It is hoped that it may be possible in the near future for such a representative of the Water Survey or of the State Board of Health to visit each plant, obtain the statistics concerning it, and collect samples of water to be shipped to the laboratory for analysis. It is expected that the publication of this bulletin on Municipal Water Supplies will serve as a basis for a revised bulletin that will be much more complete. The bulletin includes all the sanitary analyses and all the analyses of the mineral content of water from municipal water supplies that had been made to December 31, 1906. It affords an opportunity for the comparison of the various water supplies, and enables those who desire to judge of the character of the waters analyzed. The Water Survey asks the co-operation of all interested in the publication of a revised edition, and will appreciate criticisms and corrections.

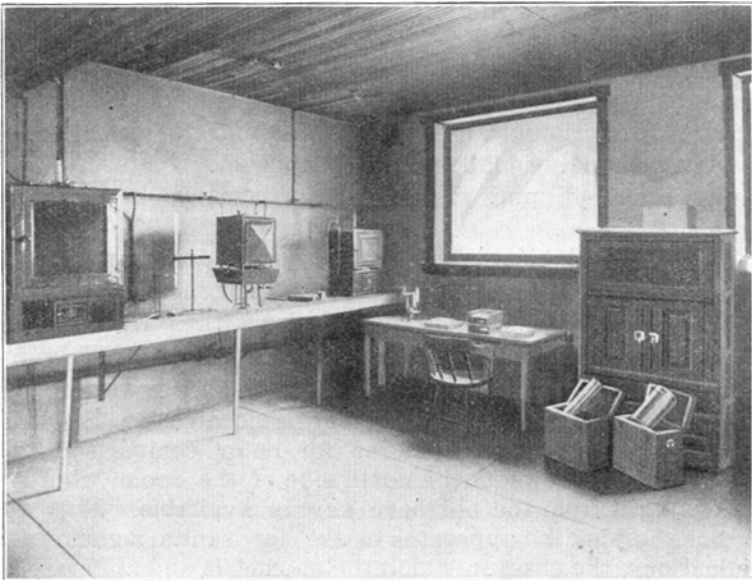
During the summer of 1907, the laboratories of the Water Survey were removed to the space originally assigned to them in the basement of the north wing of the Chemical Laboratory. The offices remained on the first floor of the north wing, in rooms No. 116 to 120. The rooms in the basement have been specially fitted for the analytical work of the Survey. They comprise the following: bacteriological laboratory, sanitary-chemical laboratory, mineral analysis laboratory, balance and computing room, cleaning room, shipping room, and a vault in which the records are kept.

The bacteriological laboratory, cuts of which are shown opposite page 17, is located on the north side of the building, and is fitted with double walls, and triple windows, thus reducing to a minimum the liability to changes in temperature. This room gives ample accommodation for the bacteriological work.

The sanitary-chemical laboratory is located on the northeast corner, allowing the cameras for color comparison to be placed in the windows on the north side of the room, where the reflected light from the northern sky is available. This room contains, besides the apparatus in use for sanitary-chemical determinations, the cases in which the chemicals and apparatus are stored. The cut, opposite page 6 gives a very good idea of the arrangement of this room.



BACTERIOLOGICAL LABORATORY.



BACTERIOLOGICAL LABORATORY.

Adjoining the sanitary-chemical room on the east side of the building is a room containing the balances, and desks and tables where computations are made. This room cuts off the room for sanitary-chemical analysis from the room for the analysis of the mineral content. The latter is shown in a cut opposite page 6. It gives ample accommodation for carrying on analysis of mineral waters. Three or four men can be accommodated here.

The rooms for cleaning glassware and for shipping and receiving samples are separated by a corridor from the regular laboratories, and the shipping room has a special outside door at which express wagons can obtain the shipping cases, and deliver samples.

The provision of a fire-proof vault will prevent loss of records by fire, which happened when the chemical laboratory burned August 16, 1896. The Survey now has nearly 2,500 feet of floor space, giving ample accommodation for the present work with room for considerable expansion in the future.

ILLINOIS CO-OPERATION.

As described in an earlier bulletin*, a co-operative agreement was made in 1906, between the State Water Survey, the State Geological Survey, the Engineering Experiment Station of the University of Illinois, and the Hydrographic Branch of the United States Geological Survey. The object of this agreement was to study the problems relating to water that are of common interest to each party. In accordance with this agreement, several of the investigations outlined have been carried on. A brief summary of the work done follows:

STREAMS INVESTIGATIONS. As described in the above mentioned bulletin, page 25, twenty-eight collecting stations were established on the important streams of the state, as follows:

LOCATION.	STREAM.	LOCATION.	STREAM.
Carlyle	Kaskaskia River.	Marion	Reservoir.
Carmi	Little Wabash River.	Menard	Mississippi River.
Cartter	Reservoir.	Moline	Mississippi River.
Chandlerville	Sangamon River.	Mounds	Cache River.
Charleston	Embarass River.	Murphysboro	Big Muddy River.
Cypress	Reservoir.	Ottawa	Fox River.
Danville	Big Vermilion River.	Peoria	Illinois River.
Decatur	Sangamon River.	Quincy	Mississippi River.
Elgin	Fox River.	Rock Falls	Rock River.
Joppa	Reservoir.	Rockford	Rock River.
Kampsville	Illinois River.	Shelbyville	Kaskaskia River.
Kankakee	Kankakee River.	Springfield	Sangamon River.
LaSalle	Illinois River.	Sterling	Rock River.
Lawrenceville	Embarass River.	Streatof	Vermilion River.

*University of Illinois Bulletin, Water Survey Series, No. 3, October, 1906. Page 19.

From August 1, 1906, to July 31, 1907, samples were collected daily from each of these stations, and sent to the Water Survey Laboratory for examination. These samples were compounded in such a way that three series per month were examined. There were made, therefore, 1008 separate examinations of the mineral content. This work was carried on at first by Mr. W. D. Collins, Assistant Hydrographer of the United States Geological Survey, and afterward by Mr. C. K. Calvert, Field Assistant of the United States Geological Survey, with such laboratory help as was necessary. The complete analyses have been tabulated, averages obtained, and a report of the work, together with a description of streams of Illinois, is being written by Mr. Collins. This is to be published as one of the Water Supply and Irrigation Papers of the United States Geological Survey, and also as a bulletin of the State Water Survey.

WATER RESOURCES OF THE EAST ST. LOUIS DISTRICT.

Also in accordance with the co-operative agreement, an investigation was made during the summer of 1906, of the ground waters of the East St. Louis district. The field work was done by Messers Isaiah Bowman and Chester Albert Reeds, and the report of their work, including a description of the topographic, hydrographic, and geographic features, and a discussion of the economic conditions of the district, has been published as Bulletin No. 5, of the State Geological Survey. The Bulletin includes descriptions of the surface waters, underground waters, and the city and village supplies of the quadrangle. It gives numerous analyses compiled from records of the State Water Survey, and from other sources. The results of the work are summarized by Mr. Bowman, as follows:

CONCLUSIONS REGARDING SURFACE SOURCES OF WATER SUPPLY.

“(1) In those sections of the district where limestone lies above the surface of the ground water and is extensively dissolved out by percolating waters, the available water is karst water. Its recovery is much more difficult than is the recovery of the ground water below it, which it feeds. In this district underground water occurs in the manner in which ground water is

popularly but erroneously supposed to occur—that is to say, in definite underground channels. By reason of the quick descent of rain water to these underground passages karst water is often dangerous for drinking purposes and the population is driven to the use of rain water conserved in cisterns.

(2) The supply of water from streams is not used to the fullest extent today because of the ease with which ground water may be obtained. The Mississippi river is drawn on for city supply in East St. Louis and a few adjacent towns. The water is extremely roily when first drawn, but by the processes of filtering, aerating, sedimentation, baffling and by chemical treatment, it is made clean and pure and wholesome. It scales boilers to some extent, but not so much as the ground water, whose use it supersedes. Use can likewise be made of tributaries of the Mississippi.

(3) A number of ox-bow lakes and artificial reservoirs are utilized, but the extent to which this is done is and always will be quite limited. The lakes are roily in spite of some degree of natural sedimentation, and the rank growth of vegetation and the large amount of city wastes dumped into them would lead to deleterious effects were the water used for drinking purposes. The reservoirs are favorable means for securing a public supply, except to the extent to which the watershed is contaminated by wastes. The growth of vegetation on their bottoms and shores may easily be prevented by deepening and graveling the bottom and paving the sides.

CONCLUSIONS REGARDING UNDERGROUND SOURCES OF WATER SUPPLY.

(4) For drinking and other ordinary domestic purposes the ground water of the flood-plain deposits must always constitute the chief source of supply to the flood-plain population. By virtue of the fact that fine sands overlie the coarser sand and gravel from which the water is derived, the purity of these waters under ordinary conditions, must always be assured. Not that the fine sands prevent the downward movement of the rain water into the gravels and coarse sands, but that they enforce a movement sufficiently slow to insure pretty thorough filtration. The gravel and coarse sand are not more thoroughly saturated with water than the fine sand above them, but their water is more available and wells are not regarded as successful which do

not reach lenses of coarser material. For boiler purposes the flood-plain water is not desirable in its natural state, being too heavily charged with calcium and magnesium carbonates. The use of compounds is required with it. Several companies are considering the erection of purifying plants which will enable the use of this water, but at present city water is used in the boilers.

(5) The greater part of the upland will always be supplied with water from shallow wells in favorable localities in the loess and drift, the bottom of the well lying a few feet below the level of the water table. No special features of water quality or means of acquisition need be summarized here as the problem is wholly one of the simple dug or driven well of the ordinary type.

(6) The deeper waters are all highly mineralized and occur under much greater head than the shallow supplies. They are not valuable except for their medicinal properties, either real or supposed, and can never enter directly into the problem of water supply in a serious way except by possible pollution of sweet surface waters. Occurring with such a great head and with strong mineral substances in solution, they must sooner or later, with the decay of the casings, enter upper horizons to the exclusion of desirable waters. These upper waters are even at present too hard for boiler use, and will be totally unfit for such use if reinforced by the water from deep sources. It would be calamitous, indeed, should such a displacement ever occur, and it cannot be too strongly urged that the State adopt measures which will give the upper horizons adequate protection". This Bulletin, State Geological Survey, Bulletin No. 5, may be obtained by application to the Director of the State Geological Survey, Urbana, Illinois.

EXPERIMENTAL INVESTIGATIONS.

Also in accordance with the co-operative agreement, experimental work upon the treatment of water, has been carried on in the laboratory of the State Water Survey. Two series of experiments have been completed. The first deals with a method for the chemical examination of water bacteria. The results were embodied in a paper by A. W. Sellards, which was read at the 1906 meeting of the American Public Health Association, and which is reprinted in full in this report.

The second experiment deals with the action of lime, sodium

carbonate, and sodium hydroxide on waters of two types which are common in the State. The results of this series of experiments were given in papers read before the American Water Works Association, and the American Chemical Society. These results are reprinted in this Bulletin.

INVESTIGATION OF MANUFACTURING WASTES.

Work on the disposal of manufacturing wastes was carried on to a small extent in an investigation of the character of the waste from the plant of the Corn Products Refining Co. at Waukegan. The experimental work includes several series of tests of the partial wastes from the plant together with the examination of series of samples of Lake water collected with a view to determine the persistence of the waste. These results are given on page 64. As a result of our investigation, the Corn Products Refining Company has made extensive experiments and has erected a plant for the treatment of their waste, before it enters the lake. It is expected that the waste will no longer prove a nuisance to the residents along the shore of the lake.

SYSTEMATIC STUDIES.

The Survey is anxious to make systematic analyses of the water in various sections of the State. A few series of analyses have been made during the year. Through the assistance of Professor F. D. Barber, of the Illinois State Normal University, at Normal, twenty samples of water were sent to the Survey from that city. Series of analyses were also made from water sent from Kenney. As an example of the significance of such series of analyses, we are printing the results of the examinations at Normal. There is indicated the possibility of a satisfactory water supply from drift wells 100 to 200 feet deep in any part of the city, whereas the shallow wells were invariably open to suspicion.

The Survey also began making tests of farm wells in various parts of the State, which will be reported in a later bulletin. Such series of analyses from representative wells in town and country, will be of great value in giving the Survey statistics, with which to compare analyses of suspected samples of water.

SANITARY CHEMICAL EXAMINATION OF WATER BACTERIA.¹

ANDREW WATSON SELLARDS.

In view of the modern theory of disease the problem of sanitary water analysis concentrates itself on the bacteriological rather than on the chemical condition of the water in question, whatever the method may be of arriving at this knowledge. All waters would be perfectly safe for drinking purposes, with certain well-characterized exceptions in the case of mineral constituents, if only the pathogenic bacteria were removed. Our investigations are, therefore, directed toward those bacteria that are pathogenic to man, are capable of being borne by water, and have the possibility of infecting the human subject through the alimentary tract.

The routine sanitary chemical tests, all of which are for substances perfectly harmless in themselves, are merely an indirect method of determining the bacteriological condition of the water. Naturally with such an indirect method there is a very wide range of possibilities in the interpretation of the results. The analytical data of a sanitary chemical analysis indicate merely the presence, recent presence, or possible future presence of pathogenic bacteria. It follows accordingly that by current methods the sanitary chemical analysis of pure distilled water to which a little sterile bouillon has been added would indicate a dangerously polluted water.

Naturally, with the advancement of bacteriology, more direct methods of analysis have been undertaken. These are of course limited to quantitative and qualitative investigations of the bacteria. One does not need to emphasize the difficulty of establishing a standard for the maximum number of bacteria permissible in a potable water, or of the uselessness of searching the Mississippi River or the Great Lakes for a typhoid bacillus.

¹Reprinted from *The Journal of Infectious Diseases*, 1907, Supplement No. 3, pp. 41-49.

The only qualitative work attempted at present is the identification of intestinal forms. The presumptive coli tests are in a very uncertain and unsatisfactory condition. The quantitative estimation of coli is well-nigh impossible in a laboratory where a large number of samples are received for daily routine examination. Though possible presence or absence can be quite satisfactorily made out, even when many samples require attention at the same time, an opinion cannot be based on a qualitative test alone. It is essential to know the quantity of coli bacteria present.

Of the various routine methods of procedure, the direct chemical analysis, being the broadest of all, has one advantage over all, or one disadvantage as the case may be. Such an analysis does not depend on the presence of living active organisms as do all bacterial methods; but the pollution may still be detected where bacteria have died in large quantities after exhausting their food material. Also the chemical analysis will detect the pollution where soil-filtered sewage reaches a water-supply. Probably the most necessary factor in interpreting the sanitary chemical analysis is a thorough knowledge of the source of the water under examination. In this section of Illinois one is utterly helpless in the interpretation of the analysis of a well water, unless he knows whether the well is deep or shallow and in drift or in rock.

The results obtained by analyzing the water from two wells in Urbana will illustrate the difficulty. Amounts are stated in parts per million.

	No. 1	No. 2
Total residue on evaporation	415.	365.
Chlorine in chlorides	3.5	7.5
Oxygen consumed	5.2	2.0
Nitrogen as free ammonia	3.6	0.054
Nitrogen as albuminoid ammonia	0.136	0.056
Nitrogen as nitrites	0.040	0.030
Alkalinity	353.	245.
Bacteria at 20° C	1 c.c.	1 c.c.
<i>B. Coli Communis</i>	Absent	1000. Present

No. 1 is from a well 180 feet deep and has high oxygen consumed and high free and albuminoid ammonia, which are characteristic of deep wells in the drift in central Illinois. Bacterial tests show that the water is in good condition.

No. 2 is a water from a 30-foot dug well, and chemically, according to usual methods of interpretation, it is a better water than No. 1. Bacterially it contains 1,000 bacteria per c.c., and the reaction is positive to the presumptive test for coli.

Generally speaking, the chemist must know the normal constituents of a given locality before he can determine the amount due to pollution.

In addition to the sanitary chemical analysis and the quantitative and qualitative bacteriological examination, a further line of procedure is suggested to the scientist, that is, the chemical analysis of bacterial cultures obtained by the inoculation of water samples into artificial media.

Our experiments upon this principle are based on the supposition that, by the inoculation of water into artificial sterile media, we could, in a way, imitate the changes that would ordinarily be brought about by bacteria in a water containing natural media. One great advantage would lie in the ease with which the artificial media could be analyzed, and the accuracy with which the changes due to the water could be determined. By this means it is possible that local factors which effect the interpretation of the results of analysis may be removed. There arises the possibility of establishing an absolute standard for the maximum limits of impurities.

To establish the value from the sanitary standpoint of the analysis of the cultures of water, our experiments are carried out with a view to securing constancy of results. After a few preliminary tests (see Table V) we chose for a medium an ordinary meat-extract broth of double concentration, to which 2 per cent of gelatin was added. The presence of sugars prevented decomposition of the nitrogenous constituents. When it was desired to study the nitrogenous decomposition products, sugars were not added to the medium, although the extremely small amount of sugar present in ordinary acid meat extract was not removed.

For our first experiments we chose two types of water, one from a small creek, known to be seriously polluted, the other from deep, driven wells of unquestionable purity. We measured accurately 5 c.c. of each medium into test-tubes, inoculated with 1 c.c. of each sample of water, and incubated at 37° C. In these preliminary tests, the cultures, when they showed appreciable differences, were steamed in an Arnold sterilizer 20 minutes, diluted to 1,000 c.c., and subjected to sanitary analysis. *A priori* it was expected that it would be necessary to work with very young cultures, presuming that for old cultures the ultimate analysis of a pure and of a polluted water would be very similar. The waters tested thus far have given decidedly the contrary result. Table V. shows the characteristic effect of variations in media and age of culture. The results are expressed in parts per million of the

diluted culture, 5 c.c. of the inoculated medium diluted to 1,000 c.c. with pure distilled water.

TABLE V. COMPARISONS OF THE ACTION OF PURE AND POLLUTED WATER ON MEDIA OF VARIOUS COMPOSITIONS FOR DIFFERENT PERIODS OF TIME.

Sample	Oxygen Consumed		Acidity		Ammonia				Total Solids	Nitrates		Chlorides	Media
	hrs.	hrs.	hrs.	hrs.	Free	Albuminoid	hrs.	hrs.		hrs.	hrs.		
Hours....	24	89	24	89	24	89	24	89	24	89	24	89	
Tap.....	102	75	12.13	12.13	0.64	1.12	8.00	13.6	...	212	0.48	0.40	37.0
Creek....	97	55	12.13	21.82	4.60	13.20	8.00	4.8	...	124	0.40	0.44	35.5
Control..		75		7.27		0.64		6.80		254		0.48	37.5
Tap.....	165	170	16.97	15.52	0.72	1.00	8.80	14.	...	386	....	0.40	36.0
Creek....	145	145	36.37	54.80	0.76	1.00	7.60	12.0	...	309	....	0.72	36.0
Control..	165	165		14.55		0.64		6.4		433		0.52	35.0
Tap.....	94	92	14.55	19.40	0.52	1.04	18.80	23.2	428	308	....	.56	34.5
Creek....	104	60	24.25	67.90	3.60	23.20	18.80	10.4	397	168	....	0.64	32.5
Control..		85		9.70		0.64		13.2		359		0.52	32.5
Tap.....	185	183	21.82	26.67	0.76	1.12	18.00	23.20	612	489	0.72	0.48	36.5
Creek....	195	163	33.95	60.62	0.84	1.36	19.20	22.4	574	400	0.80	0.60	36.0
Control..		108		16.97		0.64		13.60		557		0.44	37.0

As the most striking changes took place in the nitrogenous constituents, we decided to secure a series of preliminary tests determining only free ammonia. We were sometimes able to nesslerize directly, though more frequently, on direct nesslerization, we secured a greenish color, not comparable with a true nessler color.

In an attempt to establish a maximum limit of free ammonia, allowable, we obtained samples from deep wells of unquestionable purity, from the best available shallow wells, and from chemically pure water artificially polluted. In the following table the cultures were analyzed at different ages as a sufficient variety of waters had not yet been analyzed to determine the most favorable age of culture.

In Table VI the following facts are of special interest. The previous statement that the chemical analysis of pure, deep, and shallow ground waters is entirely different is verified. Noticeable examples are Nos. 18 and 19. In No. 18 and No. 19 the results of the bacteriological analysis are practically the same and also the chemical analysis of the cultures of the two agree very well. This strengthens our hope that a universal standard of purity may be established.

TABLE VI. COMPARISON OF SANITARY ANALYSES OF WATERS, FROM VARIOUS SOURCES, WITH THE AMMONIA THAT IS OBTAINED FROM MEDIA BY INOCULATION

No.	SOURCE	BACTERIAL ANALYSIS		CHEMICAL ANALYSIS, PARTS PER MILLION									ANALYSIS OF CULTURE, P.M. 1-200 DIL.		
		Lab. No.	No. per c. c.	Coli in one c.c.	Nitrogen as				Total Solids	Oxyg'n consumed	Alkalinity	Chlorides	Ammonia		Age Cult. in hrs.
					Ammonia		Ni-trites	Ni-trates					Free	Alb.	
					Free	Albuminoid									
1	Tap, deep, driven wells.		200	-	3.6	0.136	0.004	0.04	415	5.2	353	3.5	0.36		24
2	"Boneyard" polluted creek.		17,000	+	2.8	0.64	0.015	0.585	325	10.75	374.4	45.0	5.80		24
	Control.												1.00		
3	Tap, deep, driven wells.	Same	as No. 1	(above)									0.12		16
4	Driven wells.	Same	as No. 1	(above)									0.56	12.0	69
5	"Boneyard"	Same	as No. 2	(above)									1.52		16
6	"Boneyard".	Same	as No. 2	(above)									18.00	5.2	69
	Control.		14,790										1.20	6.8	
7	Vermilion River, raw.	14725	2,600	+	0.120	0.336	.000	0.40	359	7.15	234.7	3.5	29.00		68
8	Vermilion River, filtered.	14734	120	?+	0.024	0.144	0.01	0.32	322	4.65	215.3	4.0	1.76		68
	Control.		14,791										0.64		
9	Country well, 30 feet deep.	14827	300	+	0.020	0.094	0.004	0.32	608	.....	302.6	16.0	4.8		63½
10	Tap, deep, driven wells.	Same	as No. 1	(above)									0.2		63½
	Control.												1.2		
11	Shallow well, 20 feet.	14978	700	+	0.014	0.048	0.012	0.548	572	2.25	253.4	22.5	1.4		48
12	Shallow well, 30 feet.	14979	1,000	+	.054	.056	.030	0.190	365	2.00	245.7	7.5	2.4		48
13	Deep well, driven.	14980	120	-	1.768	.016	.000	0.040	384	2.75	353.2	2.5	0.16		48
14	Shallow well, 30 feet.	14981	120	-	0.240	0.128	0.125	7.08	384	.00	234.2	7.5	0.16		48
15	Shallow well, 40 feet.	14984	10	-	.082	0.64	.000	0.040	529	1.50	316.8	21.0	0.08		48
16	Driven well.	14986	19	-	.032	.056	.000	.028	475	1.7	291.	14.0	0.00		48
17	Driven well, 30 feet.	14987	33	-	.088	.082	.000	0.40	561	2.75	251.	13.5	0.20		48
18	Driven well, 125 feet.	14988	55	-	3.60	0.184	.000	0.04	439	6.4	350.	3.5	0.00		48
19	Shallow well, 18 feet.	14990	62	-	0.03	0.094	.000	0.32	342	1.65	301.	6.5	0.08		48
20	"Boneyard" polluted creek.	14992	55,000	+	2.8	0.64	.015	.585	325	10.75	374.4	45.0	9.40		48
	Maximum for this locality for shallow well.		500	-	0.02	0.05	0.001	5.0	500	2.0	.....	15.0	.....		48
21	Sewage 1-1,000 dilution.		1,500	+	0.032	0.016	.000	0.010	.....	0.6	.....	.05	1.72		48
22	Sewage 1-10,000 dilution.		150	-	0.018	0.010	.000	.00	.....	0.3	.....	.00	0.20		

Analyses No. 7 and No. 8, raw and filtered river waters, furnish another good example to support our theory. On the whole, direct chemical analyses do not show the true efficiency of a water-filtration plant, as the results approximate each other rather closely. The bacteriological analyses show decided differences, about 97 per cent of the bacteria having been removed by filtration. The chemical condition of the two cultures varies widely. Ordinarily this would be adding comparatively little to the results of colony counts which show the bacterial efficiency of the filter; but in this case, although the efficiency of the filter was 95.4 per cent (there being only 120 bacteria per c.c. in the filtered product) the water responded to presumptive coli tests. After a long series of cultures, no typical coli communis could be isolated, while the culture analysis was obtained on the third day with comparatively little effort. Even this time was unnecessarily long. It seems to us that the relation of this test to the presumptive coli tests will bear further investigation.

The analysis of cultures may also show qualitative as well as quantitative differences in water as indicated in samples No. 9 and No. 10. Here the chemical analyses are comparable and the number of bacteria practically the same. There is a difference in the quality of the bacteria as shown by the presumptive coli test and this difference shows up distinctly upon analyzing the culture. No. 9, which gave the positive coli test, gave 4.8 parts of free ammonia to the culture, while No. 10, which gave the negative test for coli, gave only 0.2 parts of free ammonia to the culture.

Realizing the importance of nitrite determinations in water analysis, we undertook to study their action. As indicated in our first table, the action of nitrites and nitrates could best be studied in media to which nitrites and nitrates had been added. We accordingly added 0.05 per cent sodium nitrite (NaNO_2) to part of our ordinary media. The results of a single experiment were as follows:

	NITRITE MEDIA	CULTURES.
Tap water gave		7.5 parts per million N as nitrite
Boneyard gave		0.0 parts per million N as nitrite
Media control gave		7.5 parts per million N as nitrite

The above test, we believe, differentiated very sharply in this instance, between the nitrites formed by putrefactive bacteria and the nitrites normally very high in a pure water.

According to present methods of interpretation, a good water may be condemned on high nitrites alone; but the absence of ni-

trites does not show that a water is good. Further, the presence of nitrites in shallow wells is assumed to be due not to normal constituents of the soil, but to bacterial action. It is still further assumed that the bacteria concerned are putrefactive forms. Possibly the extent of the assumption is not thoroughly understood. Deep ground waters often contain high nitrites, their presence being explained by the supposition of the reduction of the nitrites present by the ferrous iron. We have, however, isolated very active denitrifying bacteria from these waters, and also from the air. Such bacteria might very naturally gain access to shallow wells containing nitrates and form nitrites. As compared with the relatively few denitrifying bacteria, there is the great mass of nitrifying bacteria universally present in the soil and upon which the preservation of life upon the face of the earth depends. When we consider these two great classes of bacteria it does not seem to us to be proven that the presence of nitrites should condemn a surface water.

The sanitary chemical tests, developed as they were on an entirely empirical basis, before the science of bacteriology was scarcely begun, were naturally difficult of interpretation and mistakes were unavoidable.¹ Our experiments indicate that the present interpretation of nitrites is partly in error, in that high nitrites could not normally be present in a shallow well.

Except in extreme cases it is often impossible to give an opinion of an Illinois water from the ordinary sanitary data, chemical and bacteriological, simply on account of the lack of evidence furnished concerning the source of the sample. Other authors have had the same experience. M. O. Leighton² says:

There has been in the past surprisingly little discrimination used with reference to the selection of determinations for specific purposes. . . . If . . . it is desired to determine the amount of organic pollution in a water and show its value for domestic use, the chemist forthwith begins his round of nitrogen determinations, and closes with a statement of the oxygen consumed and the number of bacteria per c.c. In only a few well-known laboratories has this rule been violated, and such is the conservatism in the chemical profession that it will probably be largely followed in the future. . . . The occasional isolated sanitary analysis of a water is positively without value. There are throughout the country numerous state, municipal, and private laboratories in which sanitary analyses are

¹W. P. Mason, *Examination of Water*, 2nd ed., New York; criticism of Wanklyn.

²T. M. Prudden, *Drinking- Water and Ice Supplies*, 2nd ed., New York, 1901.

Field Assay of Water, Water Supply and Irrigation Paper. No. 151, pp. 10 and 11.

carried on. The water analyzed may be today from a well, tomorrow from a brook, and the next day from a pond. From the results of a single analysis wise and ponderous verdicts are sent broadcast, and the eager, waiting public is duly impressed.

As the basis of our experiments we have taken up the interpretation of chemical data from a theoretical standpoint, and we believe that this standpoint is absolutely essential to the intelligent understanding of sanitary data. For example, oxygen consumed, nitrites, nitrates, total solids, albuminoid ammonia, and chlorides, when *high*, indicate putrefactive bacteria. Putrefactive bacteria under proper conditions *reduce*, often very strikingly, the oxygen consumed, nitrites, nitrates, total solids, and albuminoid ammonia. These statements are in perfect harmony. (Septic tank data would confirm this.) Thus, as the organic matter is converted to inorganic matter, the oxygen consumed (organic) decreases as the free ammonia (inorganic) increases.

The culture tests, since they discriminate sharply between putrefactive changes and normal variations, seem especially adapted for water analysis. The specific tests for sanitary purposes, which seem to be especially applicable, are free ammonia and nitrites.

In its present stage of development we recognize that, as in all other methods, no distinction is made between pollution from animal and human sewage. At times this distinction may be of paramount importance when we consider that typhoid bacteria are neither harbored by lower animals nor multiply in natural water.

We realize that the foregoing experiments can be regarded only as preliminary. Before absolute conclusions can be drawn more experimental work must be done. We would suggest the following topics:

Experiments to illustrate the action of pure cultures of water-borne bacteria on media of various composition.

Experiments to determine the proportion of cultural changes due to the bacteria and to the chemical condition of the inoculated water samples.

Experiments with media of different composition, with especial reference to acidity, and nitrogen, sulphur, and carbohydrate compounds.

Study of both the (1) formation of putrefactive products and (2) their fate when added to the original media; e.g., the formation of nitrites from nitrite-free media rich in nitrates or saline ammonia and their removal when added directly to the original media, or the formation of free ammonia from proteids or its reactions when added to the original media.

Further comparisons of water known to be pure and of water known to be polluted, and artificial pollutions with sewages and pure cultures, guarding against any errors that might arise from overgrowths.

Experiments with cultures of different ages and temperatures.

Experiments on the possibility of mailing small un-iced samples. The forms ordinarily multiplying under these conditions are not the ones which develop at 37°.†

Put pure cultures in water, dilute and incubate with different dilutions.

It is our hope that other investigators in the field of water analysis may take up with us the study along the lines suggested. In closely related work on the bio-chemistry of sewage filters Gage and Clark‡ have already reported considerable success.

In conclusion we wish to express our thanks to Dr. Edward Bartow for his invaluable co-operation in the development of the theoretical and practical considerations involved in the work and to Mr. P. C. Jeans and Mr. J. M. Lindgren who have rendered material assistance in carrying on the analytical work.

†Prescott and Winslow, *Elements of Water Bacteria*, New York, 1904.

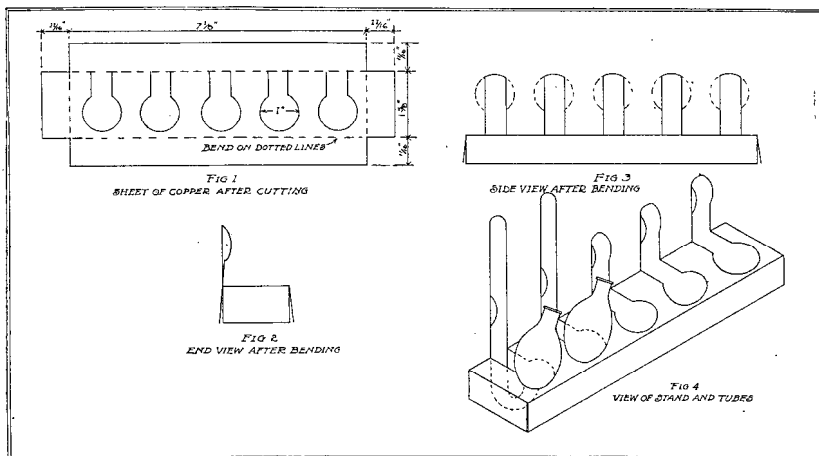
‡*Eng. News*, 1905, 53, p. 27, and *Jour. Am. Chem. Soc.*, 1905, 27, p. 327.

STAND FOR FERMENTATION TUBES.

BY W. G. BAIN.

Routine bacteriological water analysis tests for gas formation require the use of a large number of Smith fermentation tubes. The original tubes mounted on feet, while convenient for individual tests, are unsatisfactory when large numbers are used. Some of the disadvantages may be summarized as follows: first, unstable, there being a strong tendency to tip over when accidentally touched; second, the inconvenience of grouping the separate tubes; third, the tendency of the tubes to crack when heated in the sterilizer or when washed with hot water; and, fourth, the expense of the tubes with feet as compared with the simple tubes.

In order to use the tubes without feet and to group the tubes according to the number of tests made on each sample (in the State Water Survey Laboratory, 5) the stand described below was devised.



STAND FOR FERMENTATION TUBES.

From the corners of a sheet of copper $8\frac{1}{2}$ inches long and 3 inches wide, pieces $\frac{1}{6}$ inches square are cut. (See Fig. 1.). By means of a cold chisel and a one-inch punch, from which one-half inch of the circumference has been removed, outlines are cut as shown in Fig. 1. The sheet is then bent along the dotted lines and the portions cut out bent upward, and the sides of the circular portions curved as shown in Figs. 2 and 3. The completed stand with fermentation tubes in position is illustrated in Fig. 4.

This stand is of advantage in that the tubes without feet are much less expensive than the tubes with feet; a set of tests on one sample can be grouped together; the tubes without feet are less liable to crack when being sterilized and washed, and the stand gives the tubes a firm foundation.

LABORATORY EXPERIMENTS IN WATER TREATMENT.

BY EDWARD BARTOW AND J. M. LINDGREN.*

The water supplies of the University of Illinois and of the cities of Champaign and Urbana, Illinois, are obtained from wells about 160 feet deep. The water of the two supplies has the same characteristics. As these characteristics are similar to those from many wells throughout the state, the University of Illinois water may be considered as a type, and results of experiments with it are applicable to many other waters of the state.

The necessity for a treatment to improve the University of Illinois Water Supply is shown by a variety of unsatisfactory features viz: turbidity forming on exposure to the air; sediment varying in color from black to red according as the amount of oxidation of the iron salts varies; trouble from crenothrix in the mains; soft scale, clogging the feed pipes of boilers; and trouble in dairying and photography. The Champaign and Urbana city water, which is drawn from the same geological formation, has the same drawbacks and also causes incrustation in tea-kettles and the clogging of water backs in ranges and furnaces. Most of the trouble is undoubtedly due to the presence of acid carbonates of iron, calcium and magnesium.

In attempting to improve the water by removing these substances, the amounts removed did not correspond to our calculations. Analyses of the water had been made gravimetrically and also by the briefer methods suggested by the American Public Health Association. The results of the former analysis are as follows.

*Journal of the American Chemical Society XXIX, 1293 (1907)
Proceedings of the American Water Works Association XXVII, 505, (1907)

ANALYSIS OF WATER FROM UNIVERSITY OF ILLINOIS WATER SUPPLY.

Ions	Parts Per Million	Hypothetical Combinations	Parts Per Million	Grains Per U. S. Gallon
Potassium, K	2.6	Potassium nitrate, KNO ₃	1.1	0.06
Sodium, Na	29.0	Potassium chloride, KCl	2.9	0.17
Ammonium, NH ₄	2.3	Sodium chloride, NaCl	3.5	0.20
Magnesium, Mg	34.9	Sodium sulphate, Na ₂ SO ₄	3.6	0.21
Calcium, Ca	70.1	Sodium carbonate, Na ₂ CO ₃	60.5	3.52
Iron, Fe	1.0	Ammonium carbonate, (NH ₄) ₂ CO ₃	6.1	0.36
Aluminium, Al	1.3	Magnesium carbonate, MgCO ₃	121.2	7.07
Nitrate, NO ₃	.7	Calcium carbonate, CaCO ₃	175.2	10.22
Chlorine, Cl	3.5	Iron carbonate, FeCO ₃	2.1	0.12
Sulphate, SO ₄	2.3	Alumina, Al ₂ O ₃	2.5	0.15
Silica, SiO ₂	18.9	Silica, SiO ₂	18.9	1.10
		Total,	397.6	23.18

The water from the university wells, as shown by the analysis contains small amounts of chlorides, nitrates and sulphates, and a considerable quantity of carbonates. The carbonates are combined with sodium, calcium, magnesium and iron.

From the results of these analyses we calculated the amount of lime necessary to react with the acid carbonates of calcium and magnesium, and treated the water accordingly.

The first experiments were performed by Mr. W. F. Wheeler during the summer of 1906.

Considering that a successful treatment would be indicated when the alkalinity to phenolphthalein was one-half the alkalinity to methyl orange, varying amounts of lime were added to portions of the water, the precipitate was filtered off and alkalinity determined in the filtrate. It was found that considerably more lime was needed to obtain the relation of 1 to 2 than could be accounted for by the removal of salts of calcium and magnesium. We thought this due to the fact that the lime was added in powdered form, (prepared by treating lime with one-third its weight of water), and that a considerable residue of calcium hydroxide remained in the precipitate. Later experiments show this theory to be erroneous.

Determinations of the alkalinity to phenolphthalein and methyl orange at varying intervals up to twenty-four hours after the addition of the lime indicated that the reaction was practically complete in six hours. Beyond six hours, there was a slight reaction.

The second experiment, (by the writers), was with lime water instead of the dry lime. The use of varying amounts beyond the

amount calculated, of dry water-slacked lime had made apparently no change in the speed of the reaction nor in the reduction of the alkalinity. On the supposition that the reaction would be more rapid and more complete if lime water was used, varying amounts were tried but without satisfactory results.

The third experiment was planned in order to explain the action of the apparent excess of lime and to determine, if possible, what actually took place during the treatment. A series of tests was arranged which would show the effect of varying amounts of lime on the alkalinity and also the effect of the treatment on the salts of calcium and magnesium.

A liter of water was measured into each of 19 two-liter glass stoppered bottles. Varying portions of a saturated solution of lime water, 10 c.c. of which were equivalent to 23 milligrams of calcium carbonate, were added to each of the 19 samples. The varying amounts of lime water used, with the equivalent in terms of calcium carbonate, are shown in Table VII. Since previous experiments had shown that the reaction was practically complete at the end of six hours, the precipitate formed in each bottle was filtered off at the end of that time. In the filtrate the alkalinity to phenolphthalein and methyl orange and the content of magnesium and calcium were determined. The results of these determinations are shown in Table VII and a diagrammatic representation is given on Plate 1.

The reactions with a water of this class apparently take place in four stages. During the first stage, the reaction is between the calcium hydroxide and the free carbon dioxide, during which the alkalinity to phenolphthalein remains negative, the alkalinity to methyl orange and the calcium content increases, and the magnesium content is unaffected.

During the second stage, the calcium hydroxide reacts with the calcium acid carbonate. The calcium content and the alkalinity to methyl orange decrease at equal rates; the magnesium content and the alkalinity to phenolphthalein are practically constant. This stage requires about 100 c. c. of the lime water.

During the third stage, the calcium hydroxide reacts with the sodium bicarbonate, the alkalinity to methyl orange is unchanged, the alkalinity to phenolphthalein is increased, while the content of calcium and magnesium are constant. This stage requires about 60 c. c. of the lime water.

TABLE VII. TREATMENT OF THE UNIVERSITY OF ILLINOIS WATER SUPPLY WITH LIME.

No.	Lime Water Cubic centimeters	Amount of Lime used Milligrams as CaCO ₃	Alkalinity to Phenolphthalein		Alkalinity to Methyl Orange		Calcium		Magnesium	
			Filtrate Parts per million	Cor. for volume Parts per million	Filtrate Parts per million	Cor. for volume Parts per million	CaO in 250 cc. Milligrams	CaCO ₃ Cor. for volume Parts per million	Mg ₂ P ₂ O ₇ from 200 cc. Milligrams	as MgCO ₃ Cor. for volume Parts per million
1	0	0	0	0	387.5	387.5	26.5	188.7	33.1	124.4
2	10	23	11.5	11.7	378.0	381.8	27.5	198.6	33.2	126.0
3	20	46	10.5	10.7	354.9	361.9	25.8	187.5	33.8	118.0
4	40	92	16.8	17.5	312.9	325.4	18.0	133.9	36.0	131.6
5	60	138	18.9	20.1	270.9	287.1	12.9	97.4	40.5	126.0
6	70	161	12.6	13.5	256.2	274.1	10.8	82.3	39.4	126.0
7	80	184	12.6	13.6	241.5	260.8	9.0	69.0	37.3	121.6
8	100	230	18.9	20.8	222.6	244.9	7.1	54.9	34.2	113.6
9	120	276	31.5	35.3	212.1	237.6	6.6	52.6	34.5	116.0
10	140	322	42.0	47.9	203.7	232.2	5.3	43.2	32.7	112.0
11	160	368	52.5	60.9	200.5	232.6	5.7	46.2	31.9	110.8
12	170	391	65.1	76.2	193.2	226.0	5.7	46.7	30.4	105.2
13	180	414	66.3	78.2	184.8	218.1	5.7	48.4	27.8	99.6
14	200	460	65.1	78.1	163.8	196.6	5.5	46.7	23.4	84.4
15	220	506	58.8	71.7	138.6	169.1	5.1	43.9	5.3	19.2
16	240	552	58.8	72.9	111.3	138.0	4.5	39.7	5.2	19.2
17	260	598	52.5	63.3	98.7	124.4	4.4	38.9	7.7	27.6
18	280	644	50.4	64.5	98.7	126.3	7.0	63.9	5.0	19.2
19	300	690	48.3	62.8	94.5	122.8	6.3	58.4	4.8	19.2

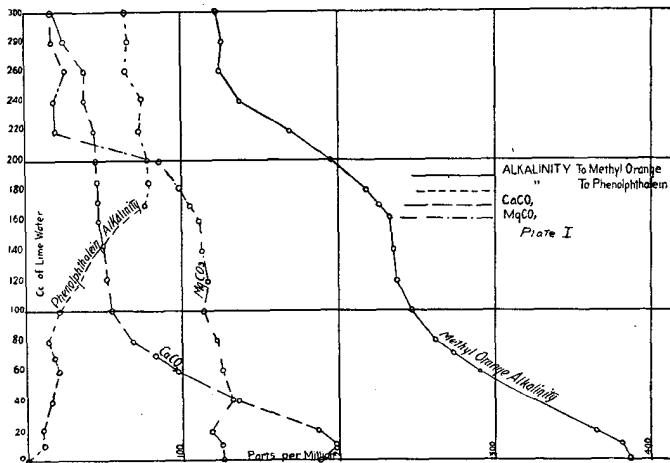


PLATE I. WATER CONTAINING BICARBONATES OF ALKALIES AND ALKALINE EARTHS TREATED WITH LIME

During the fourth stage, the calcium hydroxide reacts with the magnesium bicarbonate with the formation of magnesium hydroxide and calcium carbonate accompanied by a decrease of the alkalinity to both methyl orange and phenolphthalein and decrease in the content of magnesium. This stage requires about 60 c. c. Two hundred and twenty c. c. have been required for the four stages to a point which may be considered as the point of maximum softening.

A fifth stage might be noted when an excess of calcium hydroxide has been added. The calcium, and the alkalinity to both methyl orange and phenolphthalein increase.

The formulas illustrating the reactions during the various stages are as follows:

1. $\text{Ca(OH)}_2 + 2\text{CO}_2 = \text{CaCO}_3 + \text{H}_2\text{CO}_3$.
2. $\text{Ca(OH)}_2 + \text{CaCO}_3 + \text{H}_2\text{CO}_3 = 2\text{CaCO}_3 + 2\text{H}_2\text{O}$.
3. $\text{Ca(OH)}_2 + 2\text{NaHCO}_3 = \text{CaCO}_3 + \text{Na}_2\text{CO}_3$.
4. $2\text{Ca(OH)}_2 + \text{MgCO}_3 + \text{H}_2\text{CO}_3 = 2\text{CaCO}_3 + \text{Mg(OH)}_2 + 2\text{H}_2\text{O}$.

Under the conditions of the experiment we would not wish to imply that these reactions take place in entirety in the order named. There is evidently some overlapping, but the diagrammatic representation shows that the principal part of the reactions takes place in this order.

The series of tests shows the necessity of considering the sodium acid carbonate present, since it must be changed to the neutral carbonate before the magnesium is precipitated. These experiments also suggest the advisability of considering whether it would be profitable to remove both calcium and magnesium or only the calcium.

From Table VII we note that 71% of the carbonate of calcium or about 50% of the combined carbonates of calcium and magnesium are removed by 134 parts per million of calcium oxide, (240 parts per million as calcium carbonate), equivalent to 7.82 grains per gallon or 1.1 pounds per thousand gallons. On a basis of 50 cents per hundred as the price of lime, this treatment will cost 55-100 cents per thousand gallons.

If on the other hand it be desired to obtain the maximum (80%) removal of these compounds, it will be necessary to add 296 parts per million or 17.26 grains per gallon or 2.46 pounds per thousand gallons. This would more than double the cost with an increase of only 30% of carbonates removed.

In order to confirm our results a second water was chosen from the well of the Illinois Hotel Company, at Bloomington, Illinois. An analysis of this water is as follows:

ANALYSIS OF WATER FROM ILLINOIS HOTEL CO., BLOOMINGTON, ILL.

Ions	Parts per Million	Hypothetical Combinations	Parts per Million	Grains per Gallon
Potassium, K	4.9	Potassium nitrate, KNO ₃	0.6	0.03
Sodium, Na	84.4	Potassium chloride, KCl	9.0	0.52
Ammonium, NH ₄	10.8	Sodium chloride, NaCl	15.2	0.89
Magnesium, Mg	30.1	Sodium sulphate, Na ₂ SO ₄	4.4	0.26
Calcium, Ca	55.9	Sodium carbonate, Na ₂ CO ₃	177.2	10.33
Iron, Fe	6.6	Ammonium carbonate, (NH ₄) ₂ CO ₃	28.7	1.67
Alumina, Al ₂ O ₃	1.4	Magnesium carbonate, MgCO ₃	104.2	6.07
Nitrate, NO ₃	0.4	Calcium carbonate, CaCO ₃	139.5	8.13
Chlorine, Cl	13.5	Iron carbonate, FeCO ₃	13.7	0.80
Sulphate, SO ₄	3.0	Alumina, Al ₂ O ₃	1.4	0.08
Silica, SiO ₂	17.7	Silica, SiO ₂	17.7	1.03
Bases	.6	Bases,	0.6	0.03
		Total	512.2	29.84

This is shown to contain a larger proportion of sodium bicarbonate, but smaller amounts of the bicarbonates of calcium and magnesium. The other constituents are about the same as in the University of Illinois water supply.

Portions of this water were treated with lime water as in the previous experiment. The results of the treatment are shown in Table VIII and represented diagrammatically on Plate 2.

TABLE VIII, TREATMENT OF WATER FROM DEEP WELL OF ILLINOIS HOTEL CO., BLOOMINGTON, ILLINOIS, WITH LIME

No.	Lime Water Cubic centimetres.	Amount of Lime Used grams as CaCO ₃	Alkalinity to Phenolphthalein		Alkalinity to Methyl Orange		Calcium		Magnesium	
			Filtrate Parts per million	Cor. for volume Parts per million	Filtrate Parts per million	Cor. for volume Parts per million	CaO in 200 cc. Milligrams	CaCO ₃ Cor. for Volume Parts per million	Mg ₂ P ₂ O ₇ from 200 cc. Milligrams	% MgCO ₃ Cor. for Volume Parts per million
1	0	0	0	0	423	423	13.2	118.1	27.5	104.2
2	20	44	25	26	378	329				
3	40	88	38	56	348	327	5.5	49.9	24.4	93.8
4	60	132	52	72	309	317				
5	80	176	68	90	287	292	3.4	33.9	20.1	85.2
6	120	264	90	105	251	292				
7	140	308	90	110	229	292	3.0	30.9	18.8	82.4
8	160	352	122	140	224	287	3.0	31.9	14.9	67.2
9	180	400	108	150	215	287	2.2	24.2	6.2	29.1
10	200	440	108	145	192	257				
11	240	528	109	143	172	225			2.4	14.5
12	280	616	108	138	162	210				
13	320	704	124	135	148	207				
14	360	792	124	131	138	207				
15	390	880	147	161	118	174	7.8	9.2		
16	340	748	178	242	104	154			1.8	9.0
17	360	792			207	224				
18	100	880			267	373				

It will be noted that the curves are of the same general character as on Plate II.

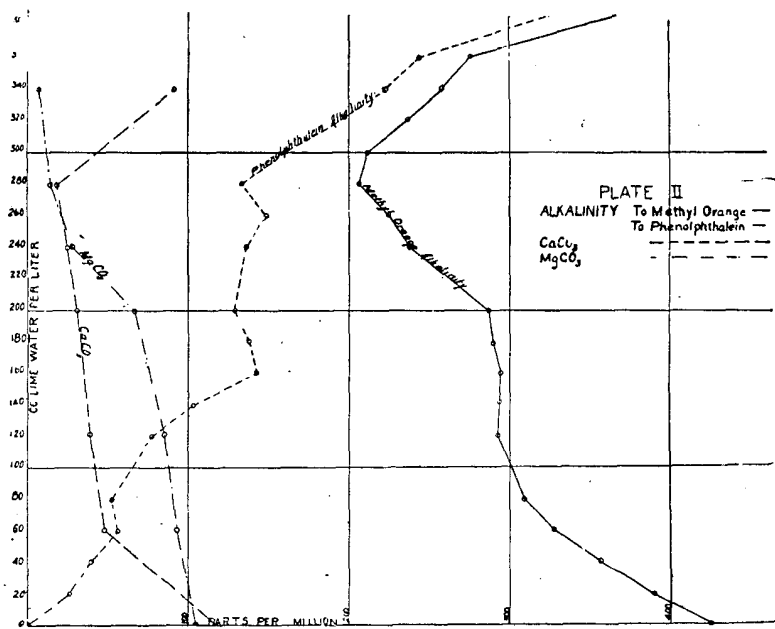


PLATE II. WATER CONTAINING BICARBONATES OF ALKALIES AND ALKALINE EARTHS TREATED WITH LIME.

The methyl orange alkalinity curve corresponding to the reaction between calcium hydroxide and calcium bicarbonate is shorter. The line denoting the reaction between calcium hydroxide and sodium bicarbonate is longer, while the curve where magnesium is reacted upon is shorter, indicating the truth of our hypothesis as to the order of reaction.

In this case an amount of lime equal to 74 parts per million or 4.31 grains per gallon or 6 pounds for 1000 gallons, removed 58% of the calcium carbonate or 35% of the combined carbonates of magnesium and calcium. The cost of this removal would be three tenths of a cent per 1000 gallons.

In order to reach the highest efficiency, a removal of 82% of the combined carbonates, it would be necessary to add 345 parts per million of pure lime equivalent to 20.1 grains per gallon or 2.86 pounds per 1000 gallons.

PRECIPITATION WITH SODIUM HYDROXIDE.

To try to determine the correctness of our hypothesis, that

the sodium bicarbonate interferes with the precipitation of magnesium by means of lime, a series of tests using sodium hydroxide instead of calcium hydroxide was next carried on. The University water supply was treated. The solution of sodium hydroxide was made of ten times the strength of the lime water, and one-tenth the amount was used in each case. Adding such a small amount of the solution, no correction was made for dilution. The analytical results are shown in Table IX and a diagrammatic representation is seen on Plate 3.

TABLE IX. TREATMENT OF THE UNIVERSITY OF ILLINOIS WATER SUPPLY WITH SODIUM HYDROXIDE

No.	Sodium Hydroxide Solution Cubic centimetres	Amount of Sodium Hydroxide Used Milligram	Alkalinity to Phenol phthalein Parts per million	Alkalinity to Methyl Orange Parts per million	Calcium		Magnesium	
					CaO in 250 cc. Milligrams.	CaCO ₃ Cor. for volume Parts per million	Mg ₂ P ₂ O ₇ from 250 cc Milligrams	MgCO ₃ Corrected for volume Parts per million
1	0	0	0	386	26.5	189.1	39.7	120.5
2	1	17	0	405	26.0	185.5	39.8	120.5
3	2	34	22	403	22.1	157.8	38.3	118.8
4	4	68	26	388	12.8	91.3	38.1	118.4
5	6	102	50	388	7.2	50.4	37.4	113.2
6	7	119	72	406				
7	8	136	90	426	5.4	38.4	36.1	109.4
8	10	170	139	468				
9	12	204	147	511				
10	14	238	198	555				
11	16	272	248	589				
12	17	299	270	609	5.4	38.4	28.5	86.2
13	18	316	266	622	4.5	32.0	25.3	76.5
14	20	340	307	650				
15	22	374	334	673	3.0	21.2	15.8	47.8
16	24	408	369	702				
17	26	442	393	728	2.9	20.5	6.8	20.4
18	28	476	417	780				
19	30	510	463	813	2.1	15.0	3.2	9.7
20	32	544	518	845				
21	34	578	549	893	.8	5.5	2.2	6.6

A comparison of plates 1 and 3 shows that the stages of the reactions with sodium hydroxide correspond to those with lime. The first stage, indicated by the increase in alkalinity to methyl orange and the very slight decrease in the amount of calcium, shows reaction between the sodium hydroxide and free carbon dioxide. The second stage, indicated by the decrease in the calcium content and of the alkalinity to methyl orange, shows the reaction taking place between the sodium hydroxide and calcium bicarbonate. It will be noted that the calcium bicarbonate is removed with one-half the equivalent of sodium hydroxide. The third

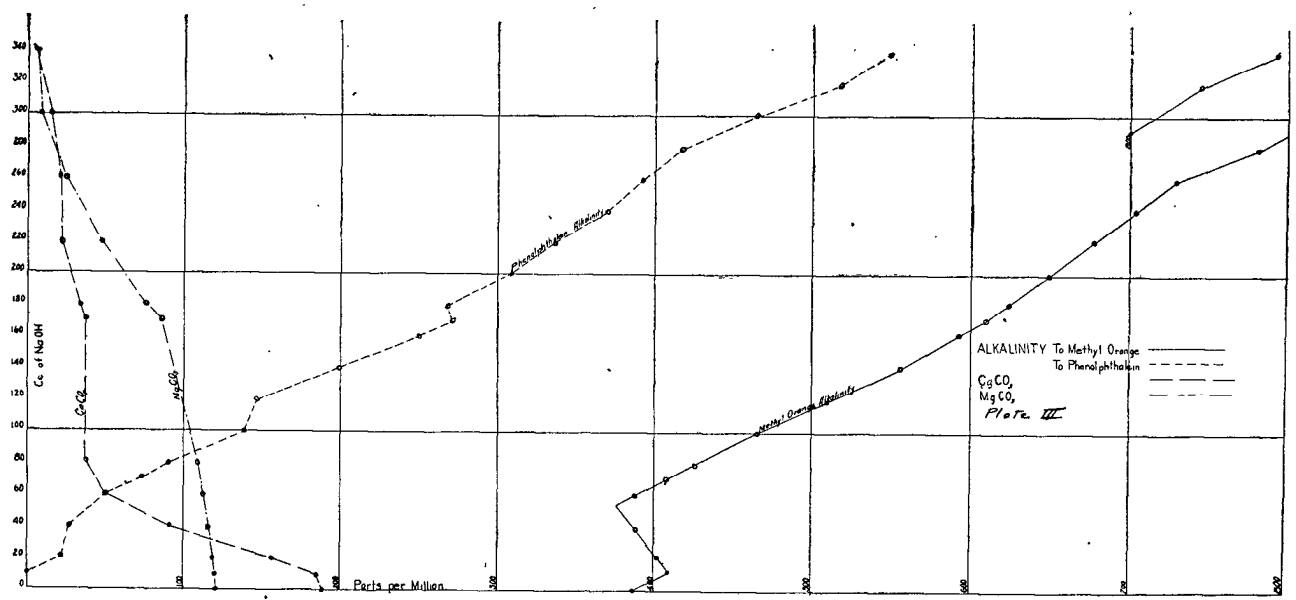


PLATE III. WATER CONTAINING BICARBONATES OF ALKALIES AND ALKALINE EARTHS TREATED WITH CAUSTIC SODA.

stage, indicated by a constant amount of calcium and magnesium implies a reaction between the sodium bicarbonate and sodium hydroxide. The fourth stage, indicated by a reduction of magnesium shows a reaction between the magnesium bicarbonate and sodium hydroxide. Here it is noted that the magnesium decreases much more slowly than when calcium hydroxide is used, and does not reach a minimum until a larger amount of sodium hydroxide has been added.

The results confirm the hypothesis that the sodium acid carbonate delays the precipitation of magnesium. The comparison of Plates I and III would indicate that there would be no advantage in using sodium hydroxide rather than lime to soften a water like the University of Illinois supply. The calcium acid carbonate would be removed with the formation of less sludge, but the increase in soluble residue would more than offset this advantage.

The reactions during the different stages may be written as follows:

1. $2\text{NaOH} + 2\text{CO}_2 = 2\text{NaHCO}_3$.
2. (A) $2\text{NaOH} + \text{CaCO}_3 \cdot \text{H}_2\text{CO}_3 = \text{Na}_2\text{CO}_3 + \text{CaCO}_3$.
2. (B) $\text{Na}_2\text{CO}_3 + \text{CaCO}_3 \cdot \text{H}_2\text{CO}_3 = \text{CaCO}_3 + 2\text{NaHCO}_3 + 2\text{H}_2\text{O}$.
3. $\text{NaOH} + \text{NaHCO}_3 = \text{Na}_2\text{CO}_3 + \text{H}_2\text{O}$.
4. $4\text{NaOH} + \text{MgCO}_3 \cdot \text{H}_2\text{CO}_3 = \text{Mg}(\text{OH})_2 + 2\text{Na}_2\text{CO}_3 + 2\text{H}_2\text{O}$.

The waters of the State of Illinois may be divided into two classes, those containing sodium carbonate and those containing magnesium sulphate. Sodium carbonate is supposed to be present when there is more than enough sodium present to react with all chlorine, nitrate, and sulphate ions. Magnesium sulphate is supposed to be present when there is not enough sodium to unite with all of the nitrate, chlorine, and sulphate ions.

The waters previously used were of the sodium carbonate class.

In order to try the effect of treatment of a water containing no sodium bicarbonate, or a water of the magnesium sulphate class, the water from a shallow well in Champaign, Illinois, was chosen for experiment.

Analysis showed the following mineral content:

ANALYSIS OF SHALLOW WELL OF DEAN-BODE MFG. CO., CHAMPAIGN, ILL.

Ions	Parts Per Million	Hypothetical Combinations		Parts per Million	Grains per, Gallon
Sodium, Na	33.4	Sodium nitrate,	NaNO ₃	1.6	0.09
Magnesium, Mg	50.0	Sodium chloride,	NaCl	39.6	2.31
Calcium, Ca	106.9	Sodium sulphate,	Na ₂ SO ₄	53.7	3.13
Oxides of Iron and Al- umina,	2.2	Magnesium sulphate,	MgSO ₄	145.7	8.49
Nitrate, NO ₃	1.2	Magnesium carbonate,	MgCO ₃	36.4	2.12
Chloride, Cl	24.0	Calcium carbonate,	CaCO ₃	266.8	15.56
Sulphate SO ₄	152.5	Oxides of iron and alumina,	Fe ₂ O ₃ + Al ₂ O ₃	2.2	0.13
Silica, SiO ₂	11.0	Silica,	SiO ₂	11.0	0.64
Bases,	3.0	Bases, with silica	—	3.0	0.17
		Total Mineral Matter	—	560.	32.64

Portions of this water were treated with lime as in the preceding experiments. The results of the analysis of the water after treatment including determination of incrustants according to method of the Am. Pub. Health Ass'n, are shown in Table X and diagrammatic representation is shown on Plate 4.

The reactions in this case are also in stages. The first and second correspond to the first and second stages of the preceding experiments. During the third stage no change is evident. Further data is necessary for explanation. The fourth stage shows a removal of the magnesium bicarbonate, with a corresponding decrease of alkalinity to methyl orange and phenolphthalein. The final stage where calcium hydroxide was added in excess, shows increase of the calcium carbonate and of alkalinity to both methyl orange and phenolphthalein. In this series of tests there was present in the original water 103 parts per million of sulphates of calcium or magnesium. According to the method of making hypothetical combinations which has been used in this laboratory, this would be considered magnesium sulphate. The amount of sulphates (see incrustants Plate 4) of the alkaline earths are unchanged by treatment with lime. There is here a possible confirmation of the statement that the sulphate exists as magnesium sulphate, since during the third stage there is not sufficient calcium present in the water to combine with all the sulphates present, and when the magnesium becomes insufficient to combine with all of the sulphates, the calcium content increases. We may therefore consider that a reaction takes place between magnesium sulphate and calcium hydroxide, forming magnesium hydroxide and calcium sulphate. Our data is as yet insufficient to show

TABLE X. TREATMENT OF WATER FROM SHALLOW WELL, CHAMPAIGN, ILLINOIS, WITH LIME.

No.	Lime Water Used Cubic centimetres	Am't of Lime Used Milligrams	Alkalinity to Phenolphthalein		Alkalinity to Methyl Orange		Calcium		Magnesium		Incrustants
			Filtrate Parts per million	Cor. for volume Parts per million	Filtrate Parts per million	Cor. for volume Parts per million	CaO in 250 cc. Milligrams	CaCO ₃ cor. per volume Parts per million	Mg ₂ P ₂ O ₇ from 200 cc. Milligrams	as MgCO ₃ cor. for volume Parts per million	as CaCO ₃ Parts per million
1	0	0	0	0	332	332	37.4	266.4	57.1	173.1	103.9
2	20	41	0	0	345	351	43.3	307.7	56.5	174.5	
3	40	82	0	0	279	290					
4	60	124	0	0	236	255	24.0	181.6	53.6	174.5	91.7
5	80	165	0	0	209	228					
6	100	206	0	0	191	214					
7	120	247	6.4	7.4	169	191	14.4	114.8	48.8	164.8	93.0
8	140	288	11.9	13.6	118	137	8.5	68.8	45.6	157.9	94.6
9	160	330	25.7	31.0	110	129	8.6	70.8	42.2	148.2	85.4
10	180	371	29.4	35.	108	128	10.4	86.8	41.3	146.8	102.0
11	200	412	25.7	31.	94	118	11.1	93.8	38.1	137.1	104.0
12	220	453	18.3	22.	53	64	9.5	82.8	24.1	90.0	89.8
13	240	494	16.5	20.	51	64					
14	260	536	23.0	29.	39	48	11.3	99.6	15.8	63.6	95.0
15	280	577	31.2	40.	42	54					
16	300	618	41.	54.	66	86					
17	320	659	62.4	85.	83	104					
18	340	700	82.6	110.	101	133	29.62	82.5	1.3	5.5	91.2

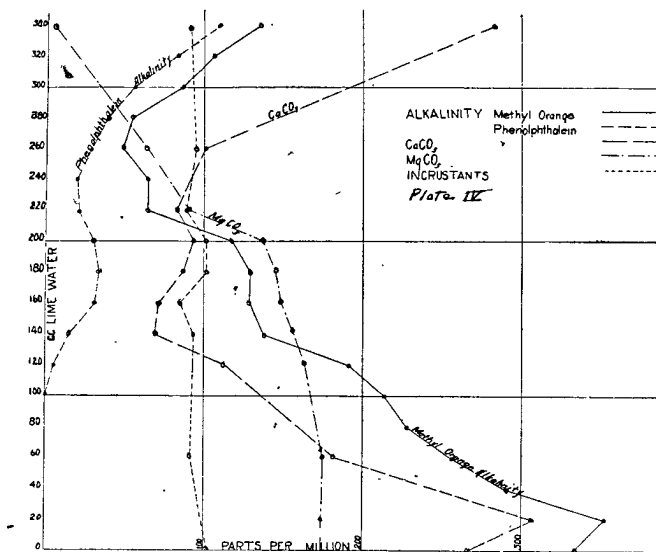


PLATE IV. WATER CONTAINING BICARBONATES AND SULPHATES OF ALKALINE EARTHS TREATED WITH LIME

whether an intermediate reaction takes place between magnesium hydroxide and magnesium acid carbonate, or whether there is interference by other salts. The work of Stillman and Cox¹ would suggest the latter explanation. The series of tests indicates that lime alone is insufficient for the treatment of such water.

An additional determination, that of the incrustants in the water, was made. The incrustants remained constant throughout the series, the amounts of calcium never decreased below 69 parts per million and the calcium increased as the magnesium decreased probably replacing the magnesium in the sulphate. In a water of this class no advantage is obtained by adding more than sufficient lime to remove the carbonates.

A discussion of the comparative cost of removing the calcium carbonate and total alkalinity would therefore be superfluous. The maximum amount of lime, if used alone, would be 161 parts per million, 9.39 grains per gallon or 1.3 pounds per thousand gallons.

¹Jour. A. C. S. 25, 732.

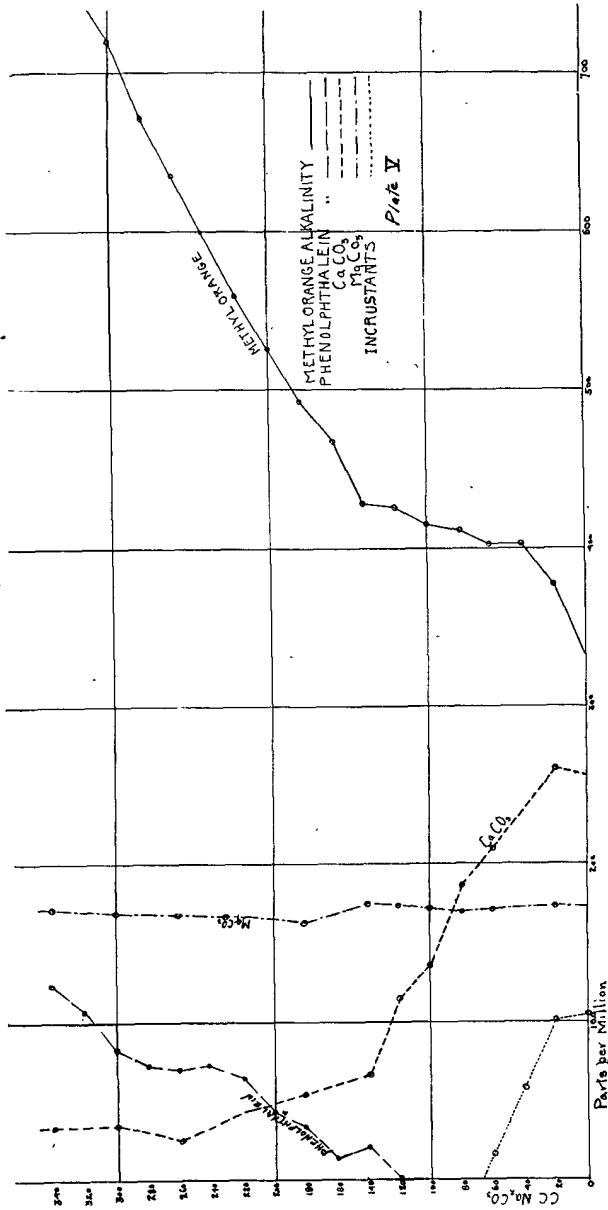


PLATE V. WATER CONTAINING BICARBONATES AND SULPHATES OF ALKALINE EARTHS TREATED WITH SODA ASH.

as the lime water. The results of these tests are shown in Table XI and a diagrammatic representation is given on Plate 5.

This series shows that the reactions take place in three stages. First, the reaction is between sodium carbonate and free carbon dioxide, with an increase in the alkalinity to methyl orange. Second, calcium bicarbonate is precipitated as calcium carbonate and incrustants are removed. Third, there is denoted an excess of reagent. The alkalinity to phenolphthalein and the alkalinity to methyl orange increase rapidly. The magnesium carbonate content remains constant throughout the whole series. This experiment shows that it is profitable to treat this type of water with sodium carbonate alone, but that the amount should not exceed a quantity sufficient to remove incrustants and calcium carbonate. An excess should be avoided as the alkalinity would be increased and at the same time there would be an increase in the soluble residue which would make the treated water liable to foam.

The maximum amount of sodium carbonate is 154 parts per million, 9 grains per gallon, 1.3 pounds per thousand gallons. The reactions of the first two stages are as follows:

1. $\text{Na}_2\text{CO}_3 + \text{CO}_2 + \text{H}_2\text{O} = 2\text{NaHCO}_3$.
2. (a) $\text{Na}_2\text{CO}_3 + \text{CaH}_2(\text{CO}_3)_2 = \text{CaCO}_3 + 2\text{NaHCO}_3$.
 (b) $2\text{NaHCO}_3 + \text{MgSO}_4 = \text{MgH}_2(\text{CO}_3)_2 + \text{Na}_2\text{SO}_4$.

From the results of the two preceding experiments it was decided to combine the treatments using both sodium carbonate and lime. Therefore, a series of tests was carried out using in each test an amount of sodium carbonate which would a little more than neutralize the incrustants and varying the amounts of lime, as in the preceding experiments. The analytical results are shown in Table XII and the diagrammatic representation on Plate 6.

This series shows that the reactions take place in four stages. First, by sodium carbonate the neutralization of the carbon dioxide. Second, the reactions with the alkaline earth sulphates and part of the calcium bicarbonate. Third, the removal of more calcium bicarbonate. Fourth, reaction between magnesium bicarbonate and calcium hydroxide, with removal of magnesium bicarbonate. The reactions during the various stages are as follows;

1. $\text{Na}_2\text{CO}_3 + \text{CO}_2 + \text{H}_2\text{O} = 2\text{NaHCO}_3$.
2. (a) $\text{Na}_2\text{CO}_3 + \text{CaCO}_3\text{H}_2\text{CO}_3 = \text{CaCO}_3 + 2\text{NaHCO}_3$.
 (b) $2\text{NaHCO}_3 + \text{MgSO}_4 = \text{MgCO}_3\text{H}_2\text{CO}_3 + \text{Na}_2\text{SO}_4$.
3. $\text{Ca}(\text{OH})_2 + \text{CaCO}_3\text{H}_2\text{CO}_3 = 2\text{CaCO}_3 + 2\text{H}_2\text{O}$.
4. $2\text{Ca}(\text{OH})_2 + \text{MgCO}_3\text{H}_2\text{CO}_3 = \text{Mg}(\text{OH})_2 + 2\text{CaCO}_3$.

TABLE XII. TREATMENT OF WATER FROM SHALLOW WELL, CHAMPAIGN, ILLINOIS, WITH A CONSTANT AMOUNT OF SODIUM CARBONATE, AND VARYING AMOUNTS OF LIME.

No.	Lime Water Used Cubic centimetres	Am't. of Lime Used Milligrams	Alkalinity to Phenolphthalein		Alkalinity to Methyl Orange		Calcium		Magnesium		Incrustants as CaCO ₃ Parts per million
			Filtrate Parts per million	Cor. for volume Parts per million	Filtrate Parts per million	Cor. for volume Parts per million	CaO in 200 cc. Milligrams	CaCO ₃ cor. for volume Parts per million	Mg ₂ P ₂ O ₇ from 200 cc. Milligrams	as MgCO ₃ cor. for volume Parts per million	
1	0	0	0	0	334	334	29.9	266.4	45.7	173.1	103.9
2	20	36	0	0	340	347	18.0	200.0	43.2	165.0	-5.7
3	40	72	0	0	312	324	14.4	133.5	32.7	167.5	-5.8
4	60	108	0	0	279	296	11.2	106.0	41.3	164.0	0.
5	80	144	0	0	257	278	9.8	95.0	41.1	168.	-19.
6	100	180	0	0	242	266	8.1	79.5	38.0	157.5	-13.2
7	120	216	0	0	224	251					
8	140	252	20	2.3	211	241	7.1	72.5	37.0	159.5	18.2
9	160	288	29	3.4	211	245					
10	180	324	62	7.9	200	236	6.9	72.5	34.3	154.0	9.4
11	200	360	44	5.3	185	222					
12	220	396	33	4.0	158	192	5.2	46.0	29.8	137.0	-6.8
13	240	432	26	3.2	126	156	5.3	47.0	29.8	138.5	-6.9
14	260	468	28	3.5	110	139	6.4	57.0	15.9	75.0	-7.0
15	280	504	9	11.5	66	84	4.9	53.5	5.2	24.0	-18.0
16	300	540	11	14	70	91					
17	320	576	18	24	70	92	5.4	64.5	6.0	29.5	-15.8

NOTE.—To each portion of water 11 cc of sodium carbonate solution containing 116.6 milligrams Na₂CO₃ was added.

In this case the carbonate of calcium is reduced to a minimum with an amount of lime and sodium carbonate equivalent to the lime used when the water was treated with lime alone.

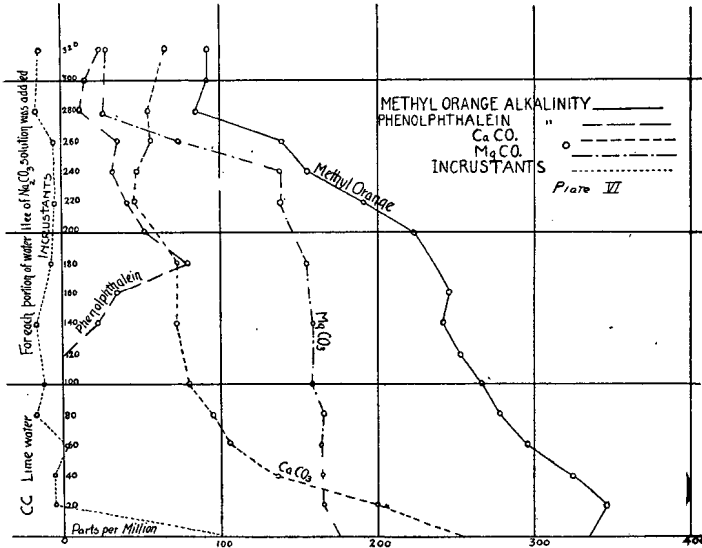


PLATE VI. WATER CONTAINING BICARBONATES AND SULPHATES OF ALKALINE, EARTHS TREATED WITH SODA ASH AND LIME

The calcium content, does not increase during the removal of the magnesium. The magnesium is precipitated at about the same point as when lime alone is used, though it comes out more rapidly than in the former case. The incrustants are shown to be negative, indicating that a slight excess of sodium carbonate was used. For this water 106 parts per million of sodium carbonate or .88 pounds per 1000 gallons with 101 parts per million of lime or .84 pounds per 1000 gallons removed 70% of the calcium acid carbonate and 46% of the combined carbonates of calcium and magnesium. In order to obtain the maximum removal of alkaline earth carbonates (82%), 282 parts per million of pure calcium oxide would be required, equivalent to 16.44 grains per gallon or 2.3 pounds per thousand gallons for lime and 106 grains per gallon or .88 pounds per 1000 gallons of soda ash, making it cost for the removal of the calcium carbonate 1.2 cents per thousand gallons, or for combined carbonates, 2 cents per thousand gallons.

CONCLUSION.

A general comparison of the results would indicate that reactions in water treatment take place in regular order, and the completeness of the reaction depends on the amount of reagent used.

The presence of sodium bicarbonate must be considered in water treatment. It is also probable that other salts besides the acid carbonate of sodium interfere with the reactions.

Owing to the action of sodium bicarbonate on lime, it might pay to consider partial treatment to remove calcium carbonate alone, rather than complete treatment to remove magnesium carbonate also.

Complete treatment of magnesium sulphate waters with lime alone is unsatisfactory since the sulphate of calcium remains in the solution.

Treatment of a magnesium sulphate water with sodium carbonate alone is satisfactory if an attempt is made to remove only carbonate of calcium and to neutralize the incrustants.

Treatment of a magnesium sulphate water with sodium carbonate and calcium hydrate shows similar reactions to the treatment of a sodium carbonate water and a consideration of the relative cost of partial and complete treatment is advisable.

During the first and second stages of treatment with lime there is removed from 70 to 80 per cent. (see tables) of the carbonates of calcium or about 50 per cent. of the alkaline earth carbonates. To remove only a small percentage more requires nearly double the amount of lime; and to obtain the maximum removal (about 80 per cent. in these waters) would require nearly three times as much lime.

A practical application of these results may be found useful in determining the advisability of partial or complete treatment, in the latter case adding a considerable excess of the reagent in order to remove as completely as possible incrusting constituents.

When it is not practicable to treat all of a supply, information as to the exact character of the water and the best method of treatment should be furnished to consumers by the water works officials.

NORMAL WATERS OF ILLINOIS.*

The normal waters of Illinois are as varied in character as are those of other sections of the country. The variation may be accounted for by the size of the state extending as it does 378 miles from north to south and 207 miles from east to west, and also by the varying character of the geological strata from which the waters are drawn.

Leverett** has shown that most of the state is covered by glacial drift, in some places to a depth of 200 feet. Many of the wells and most of the streams are affected by the character of the soluble salts in this drift. Other wells enter the underlying rock strata several of which are water bearing. The water from these deep rock wells varies in different strata, and in the same strata with the dip which is for the most part from north to south.

In discussing normal waters of Illinois, we must, therefore consider the sources. The following divisions have been suggested by Professor A. W. Palmer: ***Surface waters, including, lakes and ponds, springs, shallow wells, deep wells in drift, and deep wells in rock.

To determine the normal in each of these divisions in every section of the state is a task of no mean proportions. In this paper are shown the results of observations which can be regarded as only preliminary.

Portions of the state in which the various classes of water are of most importance are shown by Burdick.† He divides the state into three parts by lines drawn from Quincy to Chicago and from a point on the Mississippi river below St. Louis to Danville. He thus finds that 80% of the water supplies in the terri-

*Read before the Laboratory Section of the American Public Health Association at Atlantic City, Sept. 30, 1907.

**United States Geological Survey Monograph No. XXXVIII, p 542.

***Chemical Survey of the Waters of Illinois, Report for the years 1897—1902, p 15.

†Report of Ill. Soc. Eng. & Surveyors, 1906, p 72. See also Map, page 1, State Water Survey, Series No, 5.

tory north of the line drawn from Quincy to Chicago obtain their water from deep rock wells, 15% from shallow wells and 5% from streams and lakes. (The latter does not include Chicago and the cities on Lake Michigan.)

In the territory between the two lines, 40% of the supplies are obtained from deep wells, 35% from shallow wells in sand and gravel, and 25% from streams and impounding reservoirs. These deep wells are in most cases less than 300 feet deep and do not enter the rock. In the territory south of the line from near St. Louis to Danville with few exceptions the supplies come from rivers or reservoirs.

A comparison of the chemical characteristics of the waters and the geological formation of the strata from which they are drawn accounts for the different sources of supply in the three portions of the state. Many of the deep well waters are in strata that outcrop in southern Wisconsin* and dip to the southward. As we come south we find increasing mineral content until along a line drawn from Quincy to Ottawa corresponding to Burdick's line from Quincy to Chicago, we find the deep rock wells containing upward of 2000 parts per million of mineral matter of which more than 500 parts per million is chlorine. An outcrop of the St. Peter Sandstone at Ottawa marks a break in this line. Referring to Table XIII, analyses of waters from wells over 500 ft. deep in rock, we see that the water from the Streator well to the southwest of Ottawa contains more than 2000 parts per million of mineral matter while the Marseilles well to the northeast contains less than 500 parts.

The water from deep wells in rock across the northern border of the state are similar in character to wells at Marseilles and Elgin as is also shown in the table. They are too hard without treatment, for satisfactory use in boilers, yet are suitable for drinking. Wells along the line from Quincy to Ottawa are similar to the well at Streator. Between this line and the northern border of the state we find the amount of the residue varying from 376 parts per million in the well at Elgin, to 2400 parts per million in the well at Streator.

A well at Belleville is a type for the west central portion of the state. This water is evidently from a different geological formation. It is very soft, the alkalinity being due for the most

*Leverett. United States Geological Survey Monograph, XXXVIII, p. 555.

part to acid sodium carbonate. A deep well at Lawrenceville is a type of the deep wells in the oil fields of the east central portion.

We have very little analytical date concerning the deep rock waters over the central portion of the state, south of the line from Quincy to Ottawa. This is undoubtedly because sufficient water has been found in the drift and the rock has seldom been entered. A few deep wells as at Peoria and Jacksonville produce brines, discouraging further borings.

Such a variation in all the usual sanitary chemical data obtained by analyzing these deep rock well waters is noted that the

TABLE XIII ANALYSES OF WATER FROM WELLS OVER 500 FEET DEEP IN ROCK.

Laboratory No.	Elgin	Marselles	Streator	Belleville	Lawrenceville
Town.....	Elgin	Marselles	Streator	Belleville	Lawrenceville
County.....	Kane	La Salle	La Salle	St. Clair	Lawrence
Depth.....	2000 Ft.	600 Ft.	1115 Ft.	1500 Ft.	170 Ft.
Turbidity.....	20	Clear	Very Slight	Clear	V. Decided
Color.....	1.0	0.7	0	0.2	Brown
Odor.....	0	0	0	0	Brown
Residue on vaporization.....	376	464.	2415.	401.	Kerosene
Chlorine.....	3.5	64.	1000.	16.	22108
Consumed oxygen.....	4.0	2.25	8.45	1.75	17400
Nitrogen as free ammonia.....	1.08	7.080	1.280	0.008	46.3
Nitrogen as albuminoid ammonia.....	0.192	0.032	0.016	0.048	3.44
Nitrates.....	0.000	0.002	0.250	0.008	0.056
Nitrites.....	0.24	0.400	0.070	0.008	0.000
Alkalinity (as CaCO ₃).....	323.	297.	273.2	297.	407.9
Bacterial pol. c. c. 1.....	0	0	95	50.	730.
Colon Bacillus in 1 c. c.....	Absent	Absent	Absent	Absent	

normal can be determined only by a careful study of the water from many wells and by careful consideration of the strata from which the water comes.

Wells in the drift are also variable. Table XIV, "Analyses of Water from Typical Wells in Drift," illustrates this. Tests for consumed oxygen and free or saline ammonia show results that are noticeably high and variable. The free or saline ammonia cannot indicate recent pollution as it is not accompanied by an excessive number of bacteria and the colon bacillus is not found. The waters from the glacial drift usually become turbid on exposure to the air owing to the presence of ferrous iron. They must be aerated or treated before they enter the mains. Their study becomes therefore an investigation of the inorganic content.

TABLE XIV ANALYSES OF WATER FROM TYPICAL WELLS IN DRIFT.

Laboratory No.	13945	15721	14900	15733	16214	14352
Town.....	Onarga	Champaign	Bloomington	Bloomington	Peoria	Mattoon
County.....	Iroquois	Champaign	McLean	McLean	Peoria	Coles
Depth.....	106 Ft.	160 Ft.	167 Ft.	68 Ft.	80 Ft.	70 Ft.
Turbidity.....	Decided	Slight	Distinct	Slight.	None	Decided
Color.....	Little.	0.4	0.2	0.15	None	0.5
Odor.....	Earthy	None	None	None	None	None
Residue on evaporation...	1052.	388.	529.	971.	428.	526.
Chlorine.....	44.	3.0	6.5	16.	28.	13.5
Consumed oxygen.....	3.1	3.4	7.5	2.35	1.8	5.9
Nitrogen as free ammonia.	0.176	3.600	6.40	0.100	0.014	0.760
Albuminoid ammonia.....	0.062	0.136	0.448	0.144	0.060	0.216
Nitrites.....	0.017	0.000	0.000	0.010	0.000	0.003
Nitrates.....	1.983	.240	.40	.230	0.52	0.320
Alkalinity.....	291.8	288.1	495.4	423.7	238.6	392.
Bacteria per c. c.....		60			45.	3.
Colon Bacillus in, 1 c. c.....		Absent			Absent	Absent

More than 500 analyses of the mineral contents* of water from various sources have been made with a view to their classification and the determination of the effect of various methods of treatment. From the data obtained the usable waters of the state (excluding those with more than 1000 parts per million of residue) may be divided into two classes according as there is or is not enough sodium present to combine with all the nitrate, chlorine and sulphate ions. These two classes of water are distributed quite evenly throughout the state; though the sulphate waters predominate in the southern and northwestern parts while the sodium waters are more numerous in the deep drift area.

*State Water Survey series No. 4.

The best waters contain, of course, but little residue and the sodium is nearly equivalent to the combined nitrate, chlorine and sulphate ions. When the acid ions are in excess, treatment with sodium carbonate or hydroxide is required. Where the sodium is in excess and it is desired to soften the water by removing the calcium and magnesium an extra amount of lime is needed for this purpose.* The streams are practically all sulphate waters.

We may take it as a rule that all streams of the state are now normally impure and should at least be filtered before being used for water supplies. The normals to be determined for streams are therefore the suspended matter and the soluble inorganic salts. In cooperation with the Water Resources Branch of the United States Geological Survey, examinations have been made during the past year of the rivers of Illinois at twenty-seven stations. Table XV shows the averages of the results of analyses of water from four of these stations.

TABLE XV. ANALYSES OF WATER FROM STREAMS AUGUST 1, 1906, TO JULY 31, 1907.†

	Carlyle	Decatur	Elgin	Kankakee
Turbidity	183	127	41	42
Suspended Matter	125	88	23	28
Total Soluble Solids	245	291	287	240
Silica (SiO ₂)	18	19	12	12
Iron (Fe)	0.43	0.27	0.2	0.22
Aluminium (Al)	0.6	0.37	.....	1.38
Calcium (Ca)	43	54	51	48
Magnesium (Mg)	20	26	29	16
Sodium and Potassium (Na+K)	14	13	11	10
Bi-Carbonate (HCO ₃)	200	266	262	179
Sulphate (SO ₄) Bi-Carbonate (HCO ₃)	32	33	40	47
Chloride (Cl)	6.7	5.1	5.6	3.8
Nitrate (NO ₃)	4.5	7.3	2.4	3.4

I would call especial attention to the high turbidity and suspended matter in the water at Carlyle. This is characteristic of streams in the southern part of the state. This suspended matter is very finely divided and cannot be entirely removed by the best filter paper. The Kankakee River, rising in swamps in northern

*See Bartow and Lindgren, J. A. C. S. Sept. 1907.

†Samples were collected daily. Ten were combined and an analysis made of the composite sample. The work was done in cooperation with the Division of Hydrography of the United States Geological Survey, the State Geological Survey and the Engineering Experiment Station of the University of Illinois. The analyses were made by W. D. Collins, Assistant Hydrographer and C. K. Calvert, Field Assistant, U.S. G. S.

Indiana is least turbid. It also has the lowest alkalinity but approaches the other rivers in solid residue because it has the highest sulphates. The chlorine varies in all cases with the season, but the general averages do not differ materially.

CONCLUSION

From present data, we may say that waters from deep rock wells though varying in composition at different depths and in different sections show an increase of mineral residue from north to south. This variation is shown at least from the northern border of the state to a line drawn from Quincy to Ottawa and probably to the southeast of the above line as indicated by isolated cases.

The deep drift waters are so very variable that such tests as free ammonia and consumed oxygen have little value as means for judging their purity. Waters containing more sodium than is required to unite with the nitrate, chlorine and sulphate ions predominate.

The streams are all turbid and impure. The turbidity is more persistent to the south. All must be treated before being used for drinking purposes.

INTERPRETATION OF RESULTS.

From the discussion of the Normal Waters of Illinois, it is seen that no hard and fast rules can be drawn for all Illinois waters. Some method, however, is needed for judging the potability of these waters. Each year the Survey issues a circular on Interpretation of Results, which is sent with each analysis. This circular is revised as new or modified methods are adopted and as more is known concerning the normal for the waters of the state. The circular issued December 1, 1908, is as follows:

INTERPRETATION OF RESULTS OF SANITARY WATER ANALYSIS.

The statement of chemical results is made in parts per million by weight, that is in milligrams per liter, since one liter of water weighs, 1,000,000 milligrams. On the scale of 100, one part is equivalent to one ten-thousandth of one per cent. Should the data be desired in terms of the United States gallon of 231 cubic inches, multiply by .058335.

In arriving at the conclusion set forth, the following is the basis for interpretation of the analytical data:

“TURBIDITY” refers to the amount of insoluble matter in suspension. It may be perfectly harmless, though a turbid water is less attractive for drinking purposes than a perfectly clear water. The turbidity standard is silica suspended in water.

“COLOR” refers to colored substances in solution. It is due usually to an extract of vegetable matter. The color standard is the color obtained by a solution of platinum chloride and cobalt chloride in water.

“ODOR” is a descriptive term and is reported as vegetable, fishy, mouldy disagreeable, etc.

“TOTAL RESIDUE ON EVAPORATION” comprises the solid matters left on evaporating the water and drying the residue at 180 degrees Centigrade. It includes both inorganic and organic

substances. Unless the quantity is excessive or the water is to be used for industrial purposes the individual constituents are not separately determined.

“CHLORINE IN CHLORIDES” refers to the quantity of chlorine in combination with metals, for example, sodium chloride (common salt). In unpolluted waters the amount of chlorine, or the “normal chlorine” varies according to location; for example, distance from the sea coast or the presence of salt deposits.

Chlorine is a constant and considerable constituent of sewage—therefore, if it is present in a water in amounts exceeding the normal for that locality, pollution is indicated.

“OXYGEN CONSUMED” refers to the quantity of oxygen required to oxidize the organic matters present in water. However, many organic substances which may be present in water are not readily affected by the oxidizing agent. Sometimes inorganic matter is oxidized, hence the quantity of “oxygen consumed” does not always bear direct ratio to the total quantity of organic matters present.

“ORGANIC MATTERS.” At present we have no practicable means for the accurate determination of the quantity and character of the various individual organic substances contained in water. These substances include living organisms, both vegetable and animal; products of organic life such as fecal matters, and decaying vegetation. Because nitrogen is an essential of all living things, we therefore, base the estimation of organic matters on the determination of nitrogen in four of the forms in which it may exist in water.

“NITROGEN AS ALBUMINOID AMMONIA” represents the nitrogen contained in various organic substances in an undecomposed state but which will decompose under certain conditions. These substances include products of organic life, as albuminous substances, tissues, urea, fecal matters, etc., substances which serve as nutrients for germs. The presence of much nitrogen as albuminoid ammonia usually suggests pollution with sewage or drainage from refuse animal matters.

“NITROGEN AS FREE AMMONIA” so called, represents ammonia contained in the water in either the free or saline condition. It is usually formed by the natural decomposition of nitrogenous organic matters. It is the first stage of oxidation or decomposition. Its quantity ordinarily indicates the amount of organic

matters which are contained in the water in a partially decomposed state. It is a constant and considerable constituent of sewage, though it must be remembered that free ammonia occurs in considerable quantity in the deep drift wells of the state.

The above combinations of nitrogen in undergoing further decomposition are further oxidized, forming nitrous and nitric acids. These acids combine with basic mineral matters forming first nitrites and finally nitrates.

“NITROGEN AS NITRITES.” The presence of any considerable quantity of nitrous acid or nitrites in a water may indicate that decomposition of living organisms is under way. Nitrites indicate pollution, but in the case of pure deep well waters containing soluble iron salts a change of the iron to insoluble compounds causes the formation of nitrites from nitrates which may be present.

“NITROGEN AS NITRATES.” The presence of considerable quantities of nitrogen as nitric acid or nitrates indicates that at least correspondingly large quantities of organic matter have been previously present in the water.

The danger attending the presence of organic matters in water arises chiefly from the fact that disease germs may accompany organic matters of animal origin.

“ALKALINITY” of water helps to determine its value for household and industrial uses. It is measured in terms of calcium carbonate.

“SULPHATES AND IRON” are also helps to determine the household and industrial value.

BACTERIAL EXAMINATION OF WATER.

“THE NUMBER OF BACTERIA” per cubic centimeter reported is the number of bacteria that will develop colonies on gelatine at 20 degrees Centigrade unless otherwise noted.

“COLON BACILLUS.” Bacteria of the colon group are always present in the intestinal tract of men and of animals. They are therefore present in sewage and the determination of their presence or absence while not an absolute test helps in the formation of an opinion.

In the report, the amount of water used is denoted by 10 c. c.; 1.0 c. c. etc.; the number of tests made is denoted by figures

directly under the amount, and the result of the test is denoted by the plus (+) sign when the test gave a positive result and by the minus (—) sign when the result was negative.

STANDARDS OF PURITY.

For the information and convenience of those to whom our reports are sent, the following limits have been provisionally adopted as a reasonable basis for reaching conclusions regarding the wholesomeness of waters in the State of Illinois. No absolute standards of purity whereby to judge the condition of any and all potable waters can be justly established, because of differences due to the nature of the strata from which waters are drawn or with which they have been in contact, the topography of the district, and the general environment of the sources.

TABLE XVI. SUGGESTED LIMITS OF IMPURITIES.
PARTS PER MILLION.

		Lake Mich- igan*	Streams**	Springs and shal- low wells	Deep drift wells	Deep rock wells
Turbidity		None	10.	†None	†None	†None
Color		None	25.	†None	†None	†None
Odor		None	None	None	None	None
Residue on evaporation		130	300.	500.	500.	500.
Chlorine		5.5	6.	15.	15.	5.-100
Oxygen consumed		1.6	5.	2.	2.-5.††	2.-5.††
Nitrogen as	Free ammonia .....	.00	.05	.02	.02-3.	.02-3
	Albuminoid ammonia .....	.08	.15	.05	.20	.15
	Nitrites .....	.000	.000	.000	.005	.000
	Nitrates .....	.00	.5	2.00	.50	.05
	Alkalinity	—	200.	300.	300.	300.
Bacteria per cubic centimeter		500	500	500	100	100
Colon bacillus in one c.c.		Absent	Absent	Absent	Absent	Absent

The formation of a reasonable and just opinion regarding the wholesomeness of a water requires that there be taken into consideration all the data of the analysis, together with the history of

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

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

†None when drawn from wells. They may become turbid and develop color on standing.

††Varies as the water contains ferrous salts.

the water; the nature of the source; the character of the soil and earth or rock strata, and the surroundings. The interpretation of results is a task for the expert. The purpose of this sheet is, therefore, merely to present to the layman such information, touching the evidence and the line of argument, as shall aid him to an understanding and appreciation of the conclusion or opinion.

INVESTIGATION OF MANUFACTURING WASTE AT WAUKEGAN.

In March, 1906, the State Board of Health called the attention of the State Water Survey to trouble presumably arising from the emptying into Lake Michigan of waste from the Warner Sugar Refinery at Waukegan. The Director of the State Water Survey, with Dr. George Thomas Palmer, Assistant Secretary of the State Board of Health, visited Waukegan at that time.

The shore was inspected and the conclusion was that the greatest amount of putrescible waste came from the sugar refinery. The general waste was made up of five partial wastes, steep water, filter press water, water from the starch cones and gluten cones, and condenser water. The last was harmless. The others contained considerable organic matter, both dissolved and suspended. There was not sufficient evaporating capacity to evaporate all the steep water, and an attempt to filter the other wastes was not meeting with great success.

A few months later, a letter was received from Scott, Bancroft, Lord, and Stephens, representing the property owners along the shore to the south of Waukegan, in which they summarized the situation as follows: "For some time past, the residents of Lake Forest and other towns between Chicago and Waukegan have suffered great discomfort from disagreeable and nauseating odors arising from organic matter emptied into Lake Michigan by the sugar refinery at Waukegan. We are taking steps to prevent the special damage caused to certain residents of Lake Forest by this pollution, but as the contamination of Lake Michigan is a matter of vital importance to *all* the citizens of the state, we think that it should be brought to the attention of those who are endeavoring to protect the interests of the public at large.

The great expenditure made by the people of the state to prevent the pollution of the lake by the sewage, will be rendered

futile if manufacturing plants north of Chicago are allowed to pollute the adjacent waters, which by the opening of the Sanitary Canal are carried southward to the water supply of Chicago.”

Steps were at once taken by the State Water Survey to make a more careful investigation of the situation. Early in July, accompanied by Mr. G. E. Chamberlain of the Corn Products Refining Co., which company had recently purchased the plant from the Warner Company, a visit was made to Waukegan and to the lake shore south of that city. On that day an odor was noticeable near the outfall of the sewer from the refinery. This sewer emptied into the lake close to the shore. A strong wind was blowing from the northeast and the flow of sewage could be discerned as a whitish body of water flowing south along the shore until the white color was overcome by the reddish color of the effluent from the works of the American Steel and Wire Company. Then a reddish body of water could be discerned for some distance to the southward. In the trip along the shore, an odor was noticeable at North Chicago, Lake Bluff, and Lake Forest. The odor was also noticed in the moist sand along the shore at North Chicago.

According to the information furnished by the company, concerning the amount and character of the waste from the refinery, it would seem that by far the greatest source of such odors would be their waste. Experiments upon the waste were soon after undertaken by the State Water Survey and by chemists of the company, with a view to its innocuous disposal. The following methods of disposal were considered:

First, Dilution. This would require the mixing of the waste with such an amount of water that the dissolved oxygen in the water would be sufficient to completely oxidize the organic matter of the sewage.

Second, Septic action and filtration. This would imply the construction of tanks of sufficient capacity to allow bacterial action to destroy the greater part of the organic matter before the effluent passes out. Then the effluent from the tanks would be passed through filters of such character that the remaining organic matter would be completely oxidized.

Third, Evaporation. By this method at least the concentrated portions of the waste would be isolated in such a manner that they could be evaporated and the residues made available for commercial use.

Fourth, Chemical treatment. This method, suggested by the chemists for the company, called for the use of precipitating agents that would remove the putrefactive organic matter.

Method 2 was not considered practicable because the concentration of the waste necessitated an expenditure that would be prohibitive. A plant costing \$500,000 would be necessary to treat the waste from the Waukegan plant.

The most feasible solution of the problem seemed to be a combination of Methods 1, 3 and 4; namely, the evaporation of the more concentrated portions and the chemical treatment and dilution of the remainder.

Work along the following lines was suggested and has in a measure been carried out by the State Water Survey:

1. A study of the condition of the shore.
2. Study of the persistence of the waste.
3. Study of the putrescibility of the waste.
4. Determination of the composition of the wastes from the various parts of the plant.
5. Evaporation of the wastes produced and a determination of the nutrition and fertilizer value of the residue.

INSPECTION OF THE SHORE. A trip along the shore from Waukegan to Lake Forest showed several possible sources of pollution, as follows:

1. Waukegan city sewer.
2. Gas factory sewer.
3. Sugar house sewer.
4. Steel and wire mill sewer.
5. Pettibone Creek.
6. Lake Bluff sewer.
7. Lake Forest sewer.

In order to try to learn the effect of the various sources of pollution on the lake water, twenty-four samples of lake water were collected. These samples were taken by Mr. A. W. Sellards at a distance of from 100 to 150 feet from the shore. At the time of the collection there was a light wind, with the current apparently from the south. The action of each sample of water on methylene blue at room temperature was determined at the Waukegan laboratory. The action on methylene blue at 37½° Centigrade, and the amount of oxygen consumed by each sample

on digestion for thirty minutes on the water bath was determined in the laboratory of the State Water Survey at Urbana. The results of these tests, with the point in the lake from which each sample was collected, are shown in the following table:

NOTE.—Results under oxygen consumed are reported in parts per million. The figures in the methylene blue tests indicate the time in hours at which the solution was found to be decolorized.

TABLE XVII. EXAMINATION OF WATER COLLECTED ON SHORE OF LAKE MICHIGAN, SEPTEMBER 7, 1906.

No.	Location	Oxygen Consumed	Methylene Blue Tests	
			Lindgren 37°	Sellards (Room)
1	Lake Forest Sewage.....	57.1	—1 hour	—3 hours
2	Lake Forest Sewage Effluent.....	31.6	—1 hour	—3 hours
3	50 ft. from Sewer Outfall.....	3.3	—15 hours	No change
4	150 ft. from Sewer Outfall.....	3.2	No change	No change
5	½ Mile North Sewer Outfall.....	4.0	—62 hours	No change
6	Opposite Lake Forest Water Works.....	3.5	—72 hours	No change
7	½ Mile South of Lake Bluff Sewer.....	3.7	No change	No change
8	150 ft. South of Lake Bluff Sewer.....	3.25	No change	No change
9	100 ft. South of Lake Bluff Sewer.....	2.95	No change	No change
10	50 ft. South of Lake Bluff Sewer.....	3.05	No change	No change
11	Lake Bluff Sewage.....	51.6	—1 hour	—3 hours
12	100 ft. North of Lake Bluff Sewer.....	2.55	No change	No change
13	¼ Mile North of Lake Bluff Sewer.....	2.55	No change	No change
14	½ Mile North of Lake Bluff Sewer.....	3.75	—36 hours	No change
15	¾ Mile South of Pettibone Creek.....	3.1	No change	No change
16	¼ Mile South of Pettibone Creek.....	3.4	No change	No change
17	Pettibone Creek back of dredge.....	7.8	No change	No change
18	Mouth of Pettibone Creek.....	4.2	No change	No change
19	North Chicago.....	3.5	No change	No change
20	Opposite Steel Mills.....	4.2	No change	—3 hours
21	Opposite Corn Products Sewer 100 feet.....	220.0	—72 hours	—3 hours
22	Opposite Corn Products Sewer 150 feet.....	200.0	—1 hour	—3 hours
23	Opposite Waukegan Sewer 100 feet out.....	3.7	—1 hour	No change
24	Below Pier near boat house.....	3.25	No change	No change

These tests show that the city sewages become quickly oxidized and quickly lose their power of absorbing oxygen, whereas, the waste from the sugar refinery retains its power of absorbing oxygen for a considerable distance into the lake. The persistence of this waste is even better shown in a later series of samples. (Table XVIII.)

The only attempt at treating city sewage was at Lake Forest, but the Lake Forest Sewage Disposal works were in poor condition. The effluent was foul smelling owing to the fact that the tank and the filtration beds do not have sufficient capacity to handle the sewage from the city and that they are not given proper supervision. If, however, as is claimed, the odors are

noticeable in the northern part of the city only when winds are from the north or northeast, the Lake Forest sewage could hardly be responsible for them.

A series of samples of lake water was taken along a line from the sewage outfall straight out into the lake, on a day when there was practically no wind. The waste from the refinery could be traced by its turbidity about three-fourths of a mile into the lake, and tests as shown in Table XVIII trace it one-half mile further.

To sample No. 32 the course of the waste could be distinguished by the turbidity of the water. No unpleasant odor was noticed and it is probable that sufficient dilution was obtained, when the current was directly off shore, to oxidize the organic matter without the formation of such odors.

TABLE XVIII. PERSISTENCE OF WASTE.

No.	LOCATION	SAMPLES COLLECTED		
		Oxygen Consumed	Methylene Blue Tests.	
			Lindgren 37°	Sellards (Room)
25	Sewage at outfall	605.	—15 hours	—24 hours
26	50 ft. " "	35.	—15 hours	—24 hours
27	1000 ft. " "	22.5	—24 hours	—24 hours
28	2000 " " "	11.4	—24 hours	—24 hours
29	3000 " " "	9.0	—24 hours	—24 hours
30	4000 " " "	5.85	—92 hours	—4 days
31	5000 " " "	5.25	—92 hours	—24 hours
32	6000 " " "	5.25	—24 hours	—24 hours
33	7000 " " "	3.6	—24 hours	—24 hours
34	8000 " " "	3.2	—92 hours	No change
35	9000 " " "	3.0	—92 hours	No change
36	10000 " " "	3.65	—92 hours	No change

III. PUTRESCIBILITY OF THE WASTE.

The final waste product from the Corn Products Refining Company's plant is made up of five partial wastes, as follows: Effluent from the Starch Cones, Effluent from the Gluten Cones, Effluent from the Feed Press Cones, Steep Water, and Condenser Water. Samples of each of these partial wastes, together with the combined waste, were collected on September 5, 1906, by representatives of the Water Survey and Mr. Kennedy, the Assistant Superintendent of the Plant. The samples were shipped to the Laboratory at Urbana, and though it is possible that some variation in the composition may have taken place, the comparative results of analyses and experiments made at the Laboratory upon these wastes are valuable.

The next table shows the action on methylene blue of the wastes before and after dilution with different amounts of pure distilled water.

TABLE XIX. ACTION OF WASTES AT THE REFINERY ON METHYENE BLUE AT 37½° C.

Dilution with Distilled Water	None	1 to 1½	1 to 4	1 to 9	1 to 16
Effluent Starch Cones	-68	.....	.....	.....	.....
Effluent Gluten Cones	-68	.....	.....	.....	.....
Effluent Feed Press Cones	.....	.....	.....	.....	.....
Steep Water	-44	-100	-100	.....	-100
Condenser Water	-100	.....	.....	.....	.....
Main sewer, mixture of above samples	-7	-7	-18	-29	-29

The figures in the table indicate the time in hours at the end of which the methylene blue was found to be decolorized. The dashes denote that the color was not removed. In decolorizing the dye, it will be noted that the steep water was the most active; yet, in an incubator at 37½°C. it was 44 hours before the color disappeared. The composite final waste was more active, the color being removed in less than 7 hours when undiluted or when diluted with 1½ times its volume of pure distilled water. When diluted with 16 times its volume of the water the color was removed in less than 29 hours. The greater activity of the final waste is probably due to the fact that the effluent from the sanitary sewers is also included, though the amount from this source is very small compared to the total amount of the waste. Since ordinary sanitary sewage decolorized methylene blue in less than one hour, it will be seen that the partial wastes are approximately sterile. On the supposition that the acid in the waste might have some action on the dye, the wastes were neutralized with sodium hydroxide, but the action was the same.

The greater putrescibility of the final effluent would indicate that mixing the waste with city sewage would have the effect of hastening putrefaction. The location of the sewers along the shore therefore is significant and may explain why complaints come from Lake Forest. Should the untreated waste continue to be discharged into the lake and the Waukegan city sewage be discharged nearer the outlet of the waste from the refinery, it is possible that a greater nuisance may arise at Waukegan. Without contact with any sewage there is a possibility that the fac-

tory wastes might even pass Lake Forest undecomposed, or might be oxidized by the dissolved oxygen of the lake water without causing any troublesome odors.

IV. COMPOSITION OF WASTES FROM VARIOUS PARTS OF THE PLANT.

Several analyses were made of the samples of wastes mentioned above. Determinations were made of the residue at 100° and 140°, of suspended solids; ash; nitrogen as free ammonia, albuminoid ammonia, nitrites, nitrates, and total organic nitrogen; oxygen consumed; chlorine; and alkalinity. Tests made at different times indicate considerable variation in the composition of the wastes. The following tables show the results obtained.

TABLE XX. COMPOSITION OF STEEP WATER

Samples collected	14925	15027	15564
Solids at 100	11975.	41208.	20517.
Solids at 140	9401.	36035.	8849.
Ash	2401.	9093.	1018.
Dissolved Solids at 100	11902.		21260.
Dissolved Solids at 140	9070.		8737.
Ash	2450.		819.
Suspended Solids at 100	73.		
Suspended Solids at 140	331.		112.
Oxygen Consumed	3480.	8390.	5595.
Dissolved			6500.
Suspended			
Nitrogen as Free Ammonia	37.6	15.	76.
Nitrogen as Albuminoid Ammonia			132.0
Dissolved			100.00
Suspended			32.00
Nitrogen as Nitrites .....	.00	.00	.00
Nitrogen as Nitrates	2.4	2.8	79.2
Total Organic Nitrogen	693.0	1320.0	1280.
Dissolved			1000.
Suspended			280.
Turbidity	Decided	Decided	Decided
Color .....	.8	Whitish	.8
Odor	Fermented	Fermented	Fermented

TABLE XXI. COMPOSITION OF THE EFFLUENT FROM THE STARCH CONES.

	14922	15024	15561
Solids at 100	3381.	4450.	3471.
Solids at 140	3007.	4594.	3309.
Ash	503.	760.	576.
Dissolved Solids at 100	2924.		2856.
Dissolved Solids at 140	2639.		2684.
Ash	517.		540.
Suspended Solids at 100	457.		615.
Suspended Solids at 140	368.		625.
Oxygen Consumed	1510.	1575.	1387.
Nitrogen as Free Ammonia	9.2	.8	7.2
Nitrogen as Nitrites	.00	.00	.00
Nitrogen as Nitrates	2.64	1.92	4.00
Total Organic Nitrogen	264.0	224.0	172.0
Turbidity	Decided	Decided	Decided
Color	None	Whitish	.2
Odor	Fermented	Fermented	Fermented
Dissolved Oxygen Consumed			1120.0
Albuminoid Ammonia			47.
Dissolved			45.
Dissolved Organic Nitrogen			148.

TABLE XXII. COMPOSITION OF THE EFFLUENT FROM THE GLUTEN CONES.

	14923	15025	15562
Solids at 100	5227.	2999.	4935.
Solids at 140	4421.	3104.	4656.
Ash	791.	534.	868.
Dissolved Solids at 100	4956.		4797.
Dissolved Solids at 140	4314.		4506.
Ash	812.		873.
Suspended Solids at 100	271.		138.
Suspended Solids at 140	107.		150.
Oxygen Consumed	1685.	1895.	1697.
Dissolved			1620.
Suspended			77.
Nitrogen as Free Ammonia	18.0	11.	12.
Nitrogen as Albuminoid Ammonia			76.
Dissolved			74.
Suspended			2.00
Nitrogen as Nitrites	.0	.00	.00
Nitrogen as Nitrates	2.64	11.2	4.8
Total Organic Nitrogen	416.0	384.0	368.0
Dissolved			192.0
Suspended			176.0
Turbidity	Decided	Decided	Decided
Color	None	Whitish	.4
Odor	Fermented	Fermented	Fermented
Alkalinity		61.4	

TABLE XXIII. COMPOSITION OF THE EFFLUENT FROM THE FEED PRESSES

	14924	15026	15563
Solids at 100	2641.	2625. (?)	3451.
Solids at 140	2378.	2898.	3065.
Ash	414.	498.	650.
Dissolved Solids at 100	2409.		3634.
Dissolved Solids at 140	2134.		3324.
Ash	445.		635.
Suspended Solids at 100	232.		-183.
Suspended Solids at 140	244.		-159.
Oxygen Consumed	1685.	1305.	1385.
Dissolved			1367.
Suspended			18.
Nitrogen as Free Ammonia	10.	10.	7.4
Nitrogen as Albuminoid Ammonia			66.0
Dissolved			64.0
Suspended			2.0
Nitrogen as Nitrites . . . . .	.00	.00	.00
Nitrogen as Nitrates	1.8	1.84	.48
Total Organic Nitrogen	216.	216.	256.
Dissolved			216.0
Suspended			40.
Turbidity	Decided	Decided	Decided
Color	None	Whitish	.6
Odor	Fermented	Fermented	Fermented

TABLE XXIV. COMPOSITION OF THE CONDENSER WATER

	14926	15028	15565*
Solids at 100	292.	182.	1277.
Solids at 140	273.	177.	1018.
Ash	86.	95.	160.
Dissolved Solids at 100			868.
Dissolved Solids at 140			819.
Ash			122.
Suspended Solids at 100			109.
Suspended Solids at 140			199.
Oxygen Consumed	113.	66.0	770.
Dissolved			425.
Suspended			345.
Nitrogen as Free Ammonia . . . . .	.216	1.6	3.2
Nitrogen as Albuminoid Ammonia			9.6
Dissolved			1.8
Suspended			7.8
Nitrogen as Nitrites . . . . .	.000	.000	.000
Nitrogen as Nitrates . . . . .	.12	3.2	.800
Total Organic Nitrogen . . . . .	.360	1.0	52.0
Dissolved			18.
Suspended			34.
Turbidity	Slight	Decided	Decided
Color	None	Yellow	.2
Odor	Fermented	Fermented	Fermented
Alkalinity		117.	

*15565 Poor sample.

TABLE XXV. COMPOSITION OF THE GENERAL WASTE MATTER FROM MAIN SEWER

Samples collected	14927	15029	15566
Solids at 100	1326.	956.0	1837.
Solids at 140	1193.	864.	1801.
Ash	248.	287.	439.
Dissolved Solids at 100	972.		1435.
Dissolved Solids at 140	859.		1306.
Ash	283.		390.
Suspended Solids at 100	354.		402.
Suspended Solids at 140	334.		495.
Oxygen Consumed	741.	780.0	760.
Dissolved			512.
Suspended			248.
Nitrogen as Free Ammonia	6.4	2.8	5.6
Nitrogen as Albuminoid Ammonia			3.6
Dissolved			4.2
Suspended			
Nitrogen as Nitrites . . . . .	.00	.00	.00
Nitrogen as Nitrates . . . . .	.16	7.2	2.0
Total Organic Nitrogen	72.	58.	84.
Dissolved			84.
Suspended			
Turbidity	Decided	Decided	Decided
Color	None	Whitish	.2
Odor	Fermented	Fermented	Fermented
Chlorine		6.	15.
Alkalinity		86.4	65.3

It will be noticed that in each waste the suspended solids make up only a small portion of the total organic matter. It would therefore be impossible to remove much of the organic matter by settling or by simple filtration. Chemical treatment or evaporation are therefore the possible alternatives. It has been proven that the steep water contained sufficient organic matter to allow it to be profitably evaporated. As the evaporating capacity was not sufficient to take care of all the steep water, the company began at once the installation of additional evaporating capacity, so that, by the complete removal of the steep water the final effluent will be reduced in concentration.

The possibility of profitably evaporating the other wastes depends upon the concentration, and the possible nutrition or fertilizer value of the residue.

V. DETERMINATION OF THE NUTRITION AND FERTILIZER VALUE

The composition of the effluent from the starch cones, the gluten cones and from the feed press is shown by the analyses to be similar and to be from one-fourth to one-fifth the concentration of the steep water. This would imply the evaporation of from

four to five times the amount of water to obtain an amount of residue equivalent to that obtained from the steep water, and the possibility of profitably evaporating it will depend upon the cost of the evaporation in comparison to the value of the residue.

The nutrition and fertilizer value was determined in the Food Laboratories of the University of Illinois by Dr. H. S. Grindley, whose report is also given. About three gallons each of the starch cone, gluten cone and feed press wastes were evaporated and submitted to the Food Laboratories for examination.

REPORT OF DR. H. S. GRINDLEY.

“The following data gives the results of our analysis of the three samples of glucose residues:

Description of sample*	Moisture	Fat	Proteid (N x 6.25)	N free extract	Ash	Nitrogen	P ₂ O ₅	K ₂ O
	%	%	%	%	%	%	%	%
Sample No. 1	0.99	.37	42.81	41.31	14.52	6.85	4.10	1.67
Sample No. 2	8.93	Trace	50.25	25.62	15.20	8.04	6.15	1.68
Sample No. 3	8.86	Trace	45.38	28.34	17.42	7.26	5.93	2.97

For the above table the proteid is obtained by multiplying the total nitrogen by 6.25

It is evident from the data given that the residues are all highly nitrogenous. It is probable, however, that much of this nitrogen exists as amid nitrogen and thus does not have a high food value. The high per cent of nitrogen in these samples make them available for fertilizers.

The nitrogen in this form, I take it, would be worth 18 cents per pound. Upon that basis these residues would be worth as a fertilizer considering the nitrogen alone from \$25 to \$30 per ton.

Calculating the N, P₂O₅ and K₂O at the current prices the value of these residues for fertilizers would be as follows: Sample No. 1, \$28.90, sample No. 2, \$34.95, sample No. 3, \$33.25.”

The possibility of profitably evaporating these more dilute wastes is a matter to be settled according to local conditions; namely, the cost of installing plant; cost of fuel; and especially the amount of the waste to be rendered innocuous.

VI. QUANTITY OF THE WASTE.

The quantity of each of these wastes had been only roughly estimated by the company, so that accurate measurements were

*No. 1 from starch cones, No. from gluten cones, No. 3 from feed presses.

taken under the direction of Professor A. N. Talbot by Mr. R. H. Slocum. The data and calculated results are given in Tables XXVI—XXVIII.

TABLE XXVI. MEASUREMENTS OF WASTES FROM THE GLUTEN CONES.

Time	Readings, inches		Rise in box. Feet.	Time of test, Sec.	Contents of box. Cu. ft.	Discharge	
	Initial	Final				Cubic feet per sec.	Gallons per 24 hours
2:30	23½	3 1/8	1.695	160	24.95	0.1556	100,700
3:00	23¼	4 5/8	1.550	150	23.05	0.154	99,700
3:30	23¾	6¾	1.22	90	21.00	0.233	151,000
4:00	23¾	6 5/8	1.43	100	21.09	0.2109	136,500
4:30	23¾	6½	1.44	100	21.15	0.2115	136,900
5:00	23¾	7	1.40	100	20.90	0.209	135,300

Measured in a box of 15.11 sq. ft. area.
Deduct .34 sq. ft as an average value for cross plank.

TABLE XXVII. MEASUREMENT OF WASTE FROM THE STARCH CONES.

Time	Head on Weir			Discharge	
	Ins.	Ft.	Corrected for vel. of approach Ft.	Cu. ft. per. sec.	1000 gal. per 24 hours
2:30	5 5-16	.442	.498	1.97	1.277
3:00	4 ½	.375	.431	1.60	1.038
3:30	4 ¾	.396	.452	1.71	1.109
4:00	5 ½	.458	.514	2.07	1.341
4:30	4 ¾	.396	.452	1.71	1.109
5:00	4 9-16	.380	.436	1.62	1.050

Measured by means of a 20-7/8 in. weir (with end contractions)

TABLE XXVIII. MEASUREMENT OF EFFLUENT FROM THE MAIN SEWER. DATA

Time	A		C		D		F	
	Gage Ins.	Velocity Ft. sec.	Gage Ins.	Velocity Ft. sec.	Gage Ins.	Velocity Ft. sec.	Gage Ins.	Velocity Ft. sec.
2:30	18¼	9.9	18	9.83	16½	9.43	16¾	9.50
3:00	17½	9.7	16½	9.43	28	13.00	21½	10.72
3:30	29	12.47	22	10.85	6	*1.8	24	11.28
3:30	21½	10.73	17½	9.78	17	9.57	18	9.85
4:00	20	10.38	17	9.57	28½	12.38	18½	9.96
4:00	20	10.38	20½	10.50	28½	12.38	22	10.85
4:30	20	10.38	17	9.57	21	10.61	17	9.55
5:00	25	11.57	22	10.85	25	11.57	22½	10.96

* Flow did not fill nozzle as set.
Measured by means of a specially constructed nozzle and Pitot tube.

CALCULATED RESULTS

Time	2:30	3:00	3:30	3:30	4:00	4:00	4:30	5:00
Average Vel. ft. per sec.....	9.665	10.72	9.085	9.98	10.57	11.03	10.03	11.24
Discharge cu. ft. sec.....	9.81	10.90	9.23	10.13	10.72	11.21	10.20	11.42
Discharge 1,000 gal. 24 hours	6,355	7,070	5,985	6,580	6,960	7,275	6,620	7,415

These measurements show an average flow from the gluten cones of 126,700 gallons per 24 hours; from the starch cones of 1,154,000 gallons per 24 hours, and from the main sewer, which contains all the wastes, 7,043,000 gallons per 24 hours. The difference between the flow from the main sewer, and the sum of the effluent from the starch and gluten cones is practically all condenser water, since the effluent from the feed presses is almost negligible in amount. The greater part of the waste is seen to be the condenser water, which need not be treated.

It is, however, shown to be necessary to treat more than a million and a quarter gallons of the effluent per day and an installation to evaporate this amount of water would be enormous, and the returns from the residue obtained possibly insufficient to warrant such an installation. This method of solving the problem would be the ideal as there would be absolute removal of all putrescible matter and there would be no unusable sludge to dispose of.

Experiments made by the chemists for the Company with the chemical treatment of the waste give promising results. The wastes were treated with iron sulphate and lime and the mixture passed into large settling tanks. A comparison of the action of the untreated waste and of the waste treated in this way indicates the possibility of improving conditions by such treatment, especially if the outlet of the sewer is extended some distance into the lake where sufficient water for dilution can be found.

The effect of diluting the treated and untreated waste water with varying amounts of lake water is shown by tests of the dissolved oxygen and oxygen consuming capacity of diluted waters at intervals after treatment. The accompanying curves show results obtained by Mr. O. Sjostrom.

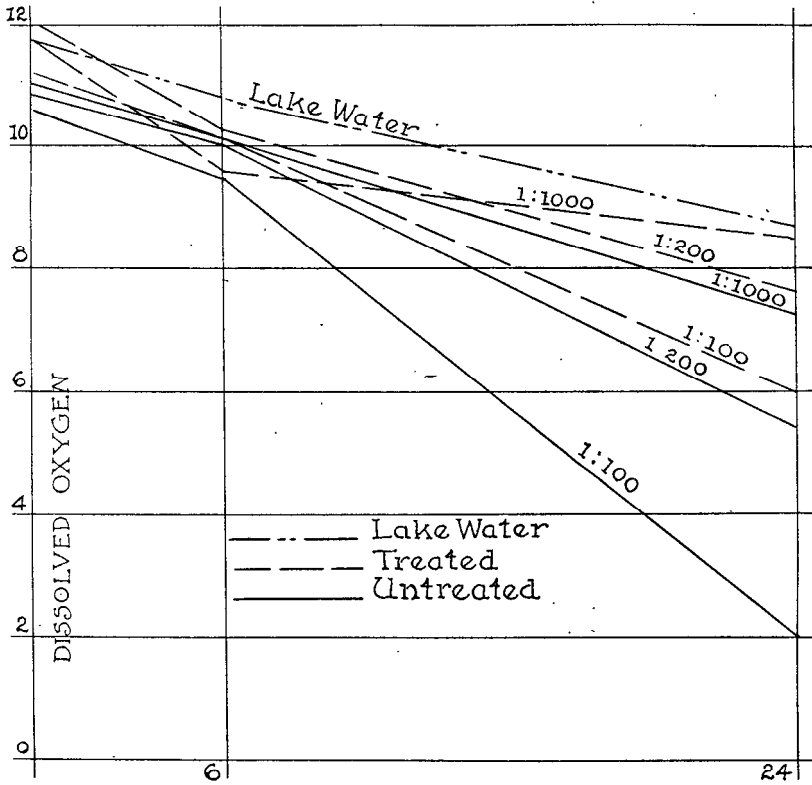


PLATE VII. DISSOLVED OXYGEN (PARTS PER MILLION) IN MIXTURES OF TREATED AND UNTREATED WASTE WITH LAKE MICHIGAN WATER.

These indicate the effect of the treatment. It will be noted that the oxygen consuming capacity was less in the treated wastes than in the untreated at the end of 6 hours, and that the dissolved oxygen in the water containing the treated waste was greater than in that containing the untreated. This would indicate a less putrescible solution. As a result of comparative tests made by the chemist of the company, a plant has been constructed to treat the entire effluent from the starch and gluten cones, and arrangements were made whereby the wash water would be carried 1,800 feet into the lake.

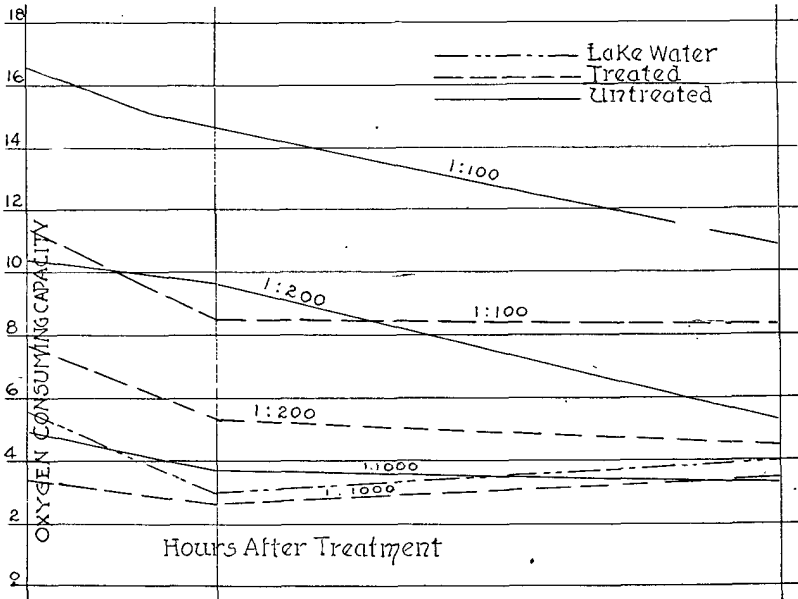


PLATE VIII. OXYGEN CONSUMING CAPACITY (PARTS PER MILLION) OF MIXTURES OF TREATED AND UNTREATED WASTE WITH LAKE MICHIGAN WATER.

CHARACTER OF THE UNDERGROUND WATERS OF NORMAL.*

An attempt has been made to carry on a study of the ground waters of the different municipalities of the state. Because of other work, and lack of funds the State Water Survey has not been able to do as much on this line as was anticipated. Only as municipalities or public spirited citizens assist has anything of this kind been done.

Frequently the people of a city or village prefer to use water from shallow wells located near their homes, in preference to using water from the general city supply. It may be that the city water is harder, or has an odor, or is slightly turbid; whereas, the water from the home well is softer, odorless, clear and sparkling. They do not realize that the ordinary dug well located in a back yard, often with privies, cesspools, or barns nearby, obtains part at least of its water supply from the surface of the ground, and is likely to contain impurities including disease germs which wash in with the surface water.

It is the general belief among water analysts that shallow dug wells in a village should be avoided. Lest, however, an error be made it is desirable that as much data as possible concerning each community be collected. It was very gratifying, therefore, when, with the assistance of Professor F. D. Barber, of the Illinois Normal University at Normal, Illinois, the State Water Survey was enabled to make a study of the ground waters of that city. Water was collected directly from the city well, and from various parts of the city system, together with water from wells of various depths in all parts of the city. The accompanying table shows the results of analyses of twenty samples of water, together with the opinions concerning them. It will be noticed that the deep wells are placed first in the table and that the water from

*Bulletin State Board of Health, Illinois, June 1908.

TABLE XXIX. SAMPLES FROM NORMAL, ILLINOIS, COLLECTED OCTOBER 28TH, AND NOVEMBER 21, 1907.

Number.	Laboratory number.	APPEAR- ANCE.			Total solids.	Chlorine.	Oxygen consumed.	NITROGEN AS				Alkalinity.	Bacteria per c. c.	COLON BACILLUS.			Depth, feet.	Location.	Character.
		Turbidity.	Color.	Odor.				AMMO- NIA.	Free.	Albuminoid.	Nitrites.			Nitrates.	10 c. c.	1 c. c.				0.1 c. c.
1	16782	5	4	0	356.	4.	4.5	1.40	.096	.000	.160	383.	30	1—	2—	2—	103	No. 3 Linden street.	Good
2	16673	10	6	0	456.	15.	10.5	3.60	.240	.000	.080	406.6	150	1?	2—	2—	180	6 feet East of pumping house.	Good
3	16785	5	0	0	334.	4.	3.2	1.40	.064	.004	.076	378.7	0	1—	2—	2—	105	Soldiers Orphans Home.	Good
4	16784	20	4	0	432.	13.	7.2	1.80	.240	.000	.320	398.	50	1?	2—	2—	220	At Power house.	Good
5	16789	20	4	0	467.	15.	8.6	2.00	.360	.000	.240	417.3	90	1?	1? 1+	2—		City supply. Cor. Fell and Highland ave.	Good
6	16666	25	8	0	486.	15.	11.3	2.80	.400	.000	.080	406.6	500	1?	2+	1? 1—		Yard Hydrant. 603 Hustler ave.	Poor
7	16786	20	0	0	597.	15.	10.2	1.112	.550	.000	.080	417.3	120	1+	2—	1—		City Hydrant. Cor. Hester ave. & Third st.	Poor
8	16669	30	6	0	582.	15.	10.5	2.00	.344	.000	.080	406.6	30	1?	2—	1—1?		Tap. City supply. Chemical Laboratory.	Good
9	16788	0	0	0	419.	38.	5.2	.036	.110	.300	6.9	230	1+	1+1+	2—	25	Cor. Fell and Highland ave.	Poor	
10	16787	0	0	0	419.	17.	2.0	.024	.044	.002	10.0	900	1+	2+	2+	20	Cor. Florence and Fell ave.	Poor	
11	16668	0	0	0	751.	36.	3.5	.016	.080	.000	2.20	222.8	Lost	1+	1? 1+	2+	60	505 Fell ave.	Poor
12	16675	0	0	0	1213.	67.	4.4	.038	.126	.040	4.76	284.6	Lost	1+	1+1?	1—1?	30	Brackshier.	Poor
13	16670	0	0	0	1233.	58.	3.9	.008	.052	.004	3.996	291.	Lost	1?	2?	2+	30	307 Mason street.	Poor
14	16671	0	0	0	561.	55.	3.9	.022	.072	.004	.996	243.9	Lost	1+	2+	2+	20	Cor. Mason and School streets.	Poor
15	16674	0	0	0	889.	44.	2.8	.026	.092	.002	3.20	278.2	1400	1+	1+1?	1+1—	25	Sewell's 310 Mason street.	Poor
16	16667	0	0	0	1353.	30.	3.7	.014	.056	.030	1.57	321.	1280	1?	2?	2?	30	S. E of Main Building.	Poor
17	16672	0	0	0	1094.	48.	4.9	.100	.076	.030	19.992	402.3	Lost	1?	2?	2—		Old city well 100 ft. S. W. of pumping station.	Poor
18	16783	0	0	0	1145.	70.	1.4	.032	.082	.008	1.57	267.5	1170	1—	2—	2—	25	111 Locust street.	Poor
19	16781	0	0	0	303.	13.	1.3	.016	.048	.007	1.593	179.7	220	1+	1+1?	1—1?	65	309 Normal ave.	Poor
20	16780	0	0	0	563.	10.	2.0	.024	.048	.017	.143	376.6	1500	1+	2+	2+	20	608 N. School street.	Poor

all the deep wells was good. Water from two hydrants of the city supply near a dead end of a newly laid main, and water from the shallow wells, without exception, was bad.

It will be noticed that in only one case did the water from a deep well, or a city supply, have more than 150 bacteria per cubic centimeter, and in no shallow well was there less than 220 bacteria per cubic centimeter. Where the bacteria tests were lost it was due to the fact that there were so many bacteria that it was impossible to count them.

From a physical standpoint it will be noticed that the deep well waters are invariably turbid and have color; that the shallow well waters have no color and never have a turbidity exceeding 5. Naturally, therefore the shallow well waters are from the external appearances more attractive.

Comparing results obtained from each analysis, considering each chemical constituent, we find that the deep waters contain less than 500 parts per million of residue on evaporation, whereas, in only two cases do the shallow wells have less than that number.

The chlorine, usually considered an evidence of pollution, is 15 parts per million or less in the deep wells, whereas only three shallow wells have less than 30 parts per million.

The oxygen consuming capacity of the deep wells is high. This is however, a normal characteristic of deep wells in the drift of Central Illinois. But the oxygen consuming capacity of the shallow wells is higher than is usually found in shallow wells of this state.

The free ammonia is very much higher in the deep wells than in the shallow wells, but high free ammonia is also a normal characteristic of deep wells in the drift, sometimes being very much higher than in these wells at Normal. The free ammonia in most of the shallow wells is low.

Albuminoid ammonia is also characteristically high in the deep wells, but higher than normal in the shallow wells.

Nitrogen as nitrites are absent in all but one test of deep well waters, whereas in only one shallow well was it absent.

Nitrogen as nitrates is very low in the deep well waters, whereas it was more than 1.5 parts per million in all but two shallow well samples.

The alkalinity of the deep wells was slightly higher than the alkalinity of the shallow wells, indicating that practically all of

the mineral content of the deep well water consists of carbonates, whereas the residue of the shallow wells must be made up of chlorides, nitrates and especially sulphates, in addition to the carbonates.

In nearly all of the tests of deep well waters the colon bacillus was shown to be absent, whereas in the shallow well water it was found in the majority of cases.

The accompanying map, Plate VII, shows the distribution throughout the city of the waters examined. The shallow and deep wells are distinguished, and the amount of chlorine found in each water is noted by the figures.

From this survey one can not but conclude that shallow well waters in Normal should be avoided as far as possible; that the city water supply, though turbid and slightly colored, is much more healthful than the private shallow wells.

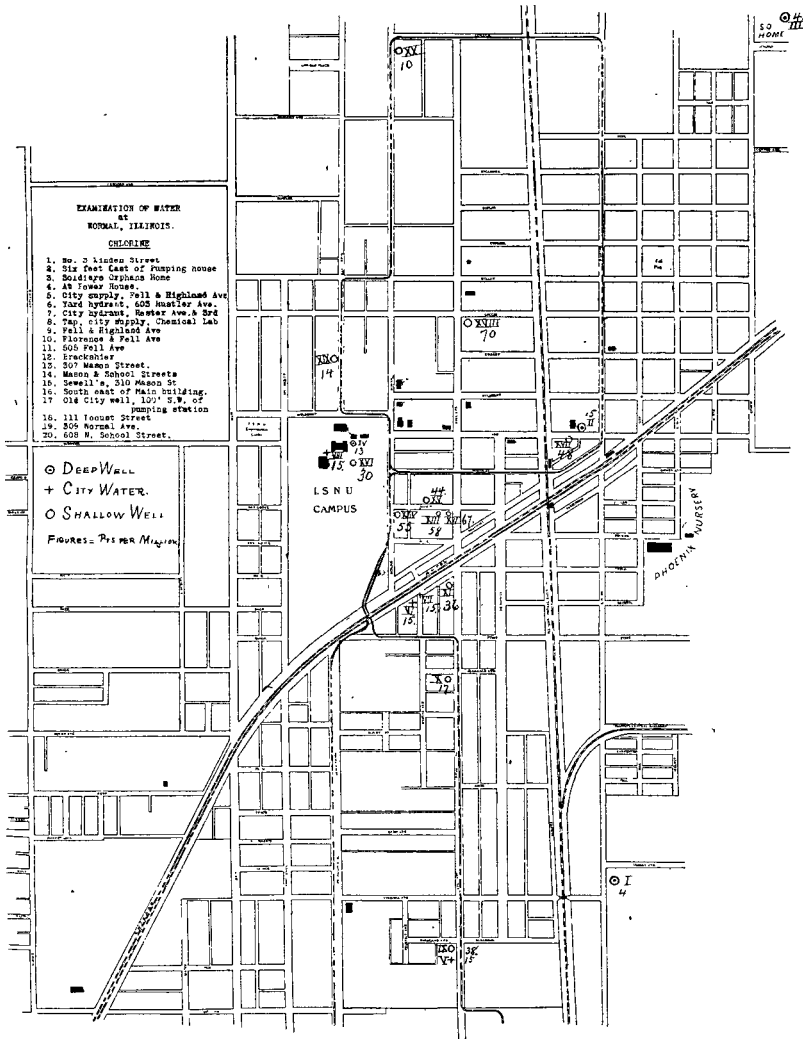


PLATE IX. MAP OF NORMAL, ILLINOIS, SHOWING CHLORINE.

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