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STATE WATER SURVEY

No. 16

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DEPARTMENT OF REGISTRATION AND EDUCATION

DIVISION OF THE

STATE WATER SURVEY

EDWARD BARTOW, Chief

BULLETIN NO. 16

CHEMICAL AND BIOLOGICAL SURVEY OF THE WATERS OF ILLINOIS

REPORT FOR YEARS 1918 AND 1919

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[1]On leave with U. S. A. and Am. E. F., September, 1917, to July, 1919. [2]To June, 1919. [3]To July, 1919. [4]With Am. E. F., from March, 1918, to August, 1919. [5]From July, 1918. [6]To October, 1918. [7]With U. S. A. and Am. E. F., April, 1917, to April, 1919. Resigned June, 1919. [8] To June, 1918. [9]To May, 1918. [10]To September, 1918. [11]To February, 1918. [12]From July, 1918, to September, 1919. [13]From October, 1918. [14]From July, 1919. [15]From September, 1919. [16]Part time. [17]Summer 1918. [18]From July, 1919. [19]From April, 1918, to July, 1919. [20]To April, 1918. [21]From September, 1918, to June, 1919. [22]From October, 1919. [23]To August, 1919. [24]From August, 1919. [25]From October, 1919.

LETTER OF TRANSMITTAL.

STATE OF ILLINOIS,
DEPARTMENT OF REGISTRATION AND EDUCATION,
STATE WATER SURVEY DIVISION.

URBANA, ILLINOIS, *May 1, 1920.*

Francis W. Shepardson, Chairman, and Members of the Board of Natural Resources and Conservation Advisors.

GENTLEMEN: Herewith I submit a report of the work of the State Water Survey Division for the two years ending December 31, 1919, and request that it be printed as Bulletin No. 16.

The report includes a brief description of the work done during the two years with summaries by months of analyses made. Abstracts of investigation of municipal water supplies and sewage disposal plants are given. Reports of special scientific investigations including several theses submitted to the faculties of the University of Illinois completed during the two years are given.

Thanks are due to the regular staff and to graduate students in water chemistry and water bacteriology of the University of Illinois for the interest they have shown in the work. Credit has been given in appropriate places in the Bulletin. Thanks are also due to Mr. B. E. Powell who has edited the report.

Respectfully submitted,

EDWARD BARTOW, *Chief.*

CHEMICAL AND BIOLOGICAL SURVEY OF THE WATERS OF ILLINOIS.

REPORT FOR THE YEARS 1918 AND 1919.

GENERAL REPORT.

ADMINISTRATION.

At a meeting of the Board of Trustees of the University of Illinois held in 1895 it was resolved that the Professor of Chemistry proceed to make a systematic survey of the waters of the State and accordingly work on such survey was begun in September of that year. By authority of the Fortieth General Assembly of Illinois, the Board of Trustees of the University of Illinois in 1897 created the Illinois State Water Survey and made it a division of the Department of Chemistry. The Forty-seventh General Assembly in 1911 authorized and instructed the State Water Survey "* * * to visit municipal water supplies and to inspect watersheds, to make such field studies and to collect such samples as are necessary, to analyze and test samples and to make any investigations to the end that a pure and adequate public water supply for domestic and manufacturing purposes may be maintained in each municipality * * *"

In 1917 the Fiftieth General Assembly enacted The Civil Administrative Code of Illinois. It repeals "An Act to establish a chemical survey of the waters of the State of Illinois" and "An Act imposing new and additional duties upon the State Water Survey. * * *." Nine departments of the State government and advisory and non-executive boards were created including the Department of Registration and Education and a Board of Natural Resources and Conservation Advisors in this department. The State Water Survey Division of the Department of Registration and Education was created in accordance with provisions of the act. Cooperating with other divisions of the department, the State Water Survey Division is to investigate and study the natural resources of the State and to prepare plans for the conservation and development of the natural resources; to cooperate with and advise departments having administrative powers and duties relating to the natural resources of the State and to cooperate with similar departments in other states and with the United States Government; to study the geological formation of the State with reference to its resources in mineral and artesian water; to collect facts and data concerning the water resources of the State; to determine standards of purity of drinking water for the various sections of the State; to publish, from time to time, the results of its investigations of the waters of the State to the end that the available water resources of the State may be better known and that the welfare of the people in the various communities may be conserved; to make analyses of samples of water from municipal or private sources; to distribute, in its discretion, to the various educational institutions of the State specimens, samples and materials collected by it after the same have served the purposes of the department; to consider and decide all matters pertaining to water and water resources and allied research, investigational and scientific research; to cooperate with the University of Illinois in the use of scientific staff and equipment and to cooperate with the various departments in research, investigational and scientific work useful in the prosecution of the work of any department.

During 1918 and 1919 the laboratory and field work of the State Water Survey Division was continued in accordance with duties as outlined by the Board of Natural Resources and Conservation Advisors.

There were many changes in the staff during the two years. Edward Bartow, Chief, who on leave of absence had served in the Sanitary Corps and had been in charge of the Water Analysis Laboratories of the American Expeditionary Forces in France, returned in July, 1919. The services of Wilson Forsyth Monfort, chemist, who had been in charge of chemical work from October, 1917, terminated on the return of Edward Bartow. Robert Edman Greenfield, bacteriologist; Harry Foster Ferguson, engineer; and Carl Clarence Larsen, chemist, resumed their duties with the survey after serving with the American Expeditionary Forces in France. William Durrell Hatfield, chemist, resigned in October, 1918, to serve as Lieutenant in the U. S. Army. John Francis Schnellbach, after serving faithfully five years as, assistant engineer was forced to resign in June, 1918, on account of ill health and died on October 31, 1919. Other changes are noted in the list of the staff.

Instruction in the analysis and purification of water and sewage has been given by members of the Water Survey Staff, who are also members of the University of Illinois faculty on a part time basis.

There is one course for undergraduates, Chemistry 10, Chemistry of Water and Sewage, which deals with the analysis of potable waters, waters for industrial purposes, sewage and sewage effluents. It includes lectures on the history, sources, contamination, and standards of purity for water supplies. There is one course for graduates, Chemistry 110, Water Supplies, which is an advanced course in the chemistry and bacteriology of water and sewage.

Undergraduate and graduate students registered in Chemistry 11 or Chemistry 111 or Bacteriology 107 may prepare theses on subjects connected with the chemistry or bacteriology of water and sewage. Many of the theses thus prepared have been published in the scientific and technical press and in bulletins of the State Water Survey Division. Several will be published in this bulletin.

. LABORATORY WORK.

During 1918, 1,565 samples of water were examined at the direct request of private citizens or local officials and 198 samples were collected by or under the direction of the members of the staff. During 1919, 1,715 samples of water were examined at the direct request of private citizens or local officials and 88 samples were collected by or tinder the direction of members of the staff. From the time of its foundation in September, 1895, to December 31, 1919, 42,291 samples of water have been received. The number collected from various sources for each month of the two years and the total number collected since the foundation of the Survey is given in Table 1.

TABLE 1-"A".—NUMBER OF WATER SAMPLES EXAMINED DURING EACH MONTH OF THE TEAR 1918, AND TOTAL TO DATE, CLASSIFIED BY SOURCE.

Samples by request.	January.	February.	March.	April.	May.	June.	July.	*August.*	September.	October.	November.	December.	Total *for year* 1918.	Total Sept. 1895 to Dec. 31, 1918.
Surface waters	39	41	52	49	56	44	67	53	37	42	41	35	556	6,893
Springs	----	1	2	1	1	1	2	4	4	1	2	1	19	855
Cisterns	3	----	----	----	----	1	----	2	10	6	----	1	23	520
Natural ice	2	----	----	----	1	----	----	----	----	----	----	----	3	177
Artificial ice	----	----	----	----	----	----	----	----	----	----	----	----	0	35
Water for artificial ice	----	----	----	----	----	----	----	----	----	----	----	----	0	21
Water for natural ice	----	----	----	----	----	----	----	----	----	----	----	----	0	21
Mine water	----	----	----	----	----	2	----	1	----	----	2	----	5	40
Shallow wells in rock	----	----	----	----	----	----	----	----	----	----	----	2	2	480
Deep wells in rock	10	13	28	10	20	17	16	28	14	40	13	8	217	3,417
Flowing wells in rock	----	----	----	----	----	----	----	----	----	----	----	----	0	243
Shallow wells in drift	10	21	12	30	32	36	32	55	45	34	22	7	336	9,710
Deep wells in drift	6	14	20	85	22	10	14	36	17	22	6	4	256	2,504
Flowing wells in drift	----	----	----	----	----	----	----	----	----	----	----	----	0	164
Sewage	----	----	----	----	----	----	----	----	----	----	----	----	0	232
Distilled water	----	----	----	----	----	----	----	----	----	----	----	----	0	22
Miscellaneous	10	3	4	14	8	2	----	2	3	9	3	----	58	172
Swimming pools	2	2	2	2	2	2	2	3	2	1	----	1	21	303
Unknown	4	4	4	----	3	9	8	8	10	4	6	9	69	302
Total	86	99	124	191	145	124	141	192	142	159	94	68	1,565	26,111

MADE ON INITIATIVE OF WATER SURVEY.

Surface waters						1	3	11					15	
Springs		1					1	1					3	
Mine water													0	
Shallow wells in rock													0	
Deep wells in rock	1	4	5	3	5	2	9	6	1				36	
Shallow wells in drift	2	8			6	3	8	2					29	
Deep wells in drift	6	22	1	35	5	9	6	3					87	
Sewage		6						4					10	
Distilled water													0	
Miscellaneous	2			2				2		1			7	
Swimming pool												2	2	
Unknown						1		2	6				9	
Total	11	41	6	40	16	16	27	31	7	1	0	2	198	14,377
Grand total	97	140	130	231	161	140	168	223	149	160	94	70	1,763	40,488

TABLE 1–"B".—NUMBER OF WATER SAMPLES EXAMINED DURING EACH MONTH OF THE YEAR 1919, AND TOTAL TO DATE, CLASSIFIED BY SOURCE.

Samples by request.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total for year 1918.	Total Sept. 1895 to Dec. 31, 1919.
Surface waters	37	39	44	41	42	37	57	56	45	48	39	46	530	7,424
Springs		3	2	4	4	4	5	3	4	5	4	4	41	894
Cisterns	3	2	1	5	1		1	2	6	5	1	2	29	549
Natural ice													0	177
Artificial ice													0	35
Water for artificial ice													0	21
Water for natural ice													0	21
Mine water		6	3	1						1		1	12	52
Shallow wells in rock		3		4	1	1	1	2		1		1	14	494
Deep wells in rock	17	7	24	19	20	20	24	12	18	16	34	10	222	3,640
Flowing wells in rock													0	243
Shallow wells in drift	7	14	9	15	11	15	32	28	36	35	26	31	257	9,969
Deep wells in drift	15	7	6	20	8	8	11	23	16	13	12	15	154	2,660
Flowing wells in drift													0	164
Sewage												6	6	238
Distilled water													0	22
Miscellaneous		1	10	22	1	2	1					3	40	211
Swimming pools	2	1	4	5	15	27	33	16	4	42	37	22	208	512
Unknown	7	9	3	10	24	26	33	26	17	27	9	8	203	501
Total	88	92	106	146	127	140	198	168	146	193	162	149	1,716	27,826

MADE ON INITIATIVE OF WATER SURVEY.

Surface waters									14			5	19	
Springs					1			8	1				10	
Mine water									2	3			5	
Shallow wells in rock														
Deep wells in rock				1	6	1			1		2	4	15	
Shallow wells in drift				1					1		1		3	
Deep wells in drift				2	1					1	3	1	8	
Sewage			4			1	12		6	2			25	
Distilled water														
Miscellaneous												1	1	
Swimming pool											1		1	
Unknown												1	1	
Total			4	4	8	2	12	8	25	6	7	12	88	14,465
Grand total	88	92	110	150	135	142	210	176	171	199	169	161	1,803	42,291

As the greater part of the State is covered by from 50 to 300 feet of glacial drift, the greatest number of samples has been taken from wells in drift. Satisfactory water can be obtained from the deep wells in rock in the northern part of the state and from deep wells in drift in the east central part of the State.

Because of the increase in the number of filtration plants and the desire for the water works officials to have frequent chemical analyses for the operation of these plants, the number of samples of surface waters received by the State Water Survey Division is next to the number of supplies from shallow wells. Many filter plants are sending samples each month for chemical control by the State Water Survey Division. The Division advocates daily control in a laboratory connected with each plant. This daily control, together with the bacteriological and chemical tests made by the Division should insure satisfactory operation of the treatment plants.

There is a notable increase in the number of samples obtained from swimming pools. This is due to the increase in the number of swimming pools established by municipalities, park boards or Y. M. C. A's. The number of analyses shown in the table does not include a large number of samples taken from the swimming pools at the Men's Gymnasium and the Women's Gymnasium at the University of Illinois. These will be reported in a special paper in this bulletin.

Well waters sent to the Survey for examination from 1907 to 1919, have been classified according to the depth of the wells. The percentage from each depth which has been condemned is given in Table 2.

The number condemned in each year 1907 to 1917 is shown in Bull: 15, 10.

The number condemned decreases as the depth of the wells increases. During the years mentioned 71 per cent of the samples from wells less than 25 feet deep were condemned, whereas, only 14 per cent of those from wells more than 100 feet deep were condemned. Of the samples analyzed a larger proportion is condemned during the summer than during the winter. Many samples of water from the deepest wells were condemned not because of contamination but rather because of excessive mineral content. As ordinarily constructed the chances for contamination from the top and upper part of a well are much less with drilled than with dug wells. Of all well waters 43 per cent were condemned. About two-thirds of the waters from dug wells and one-fifth of the waters from drilled wells were condemned. The character of the well waters examined is not representative of all well waters from the State, as by far the greater number of samples are sent in because of suspected contamination.

TABLE 2.—PERCENTAGE OF WELL WATERS CONDEMNED BY THE WATER SURVEY, CLASSIFIED BY DEPTH.

	1918	1919	1907-1919
DEPTH LESS THAN 25 FEET.			
Number examined	131	131	2,858
Number condemned	79	69	2,024
Percentage condemned	60	53	71
DEPTH 25 TO 50 FEET.			
Number examined	193	191	3,961
Number condemned	118	102	2,436
Percentage condemned	55	53	62
DEPTH 50 TO 100 FEET.			
Number examined	126	123	2,060
Number condemned	31	31	700
Percentage condemned	24	25	34
DEPTH MORE THAN 100 FEET.			
Number examined	564	357	4,776
Number condemned	111	40	690
Percentage condemned	20	11	14
DEPTH UNKNOWN.			
Number examined	44	64	817
Number condemned	13	18	356
Percentage condemned	30	28	44
TOTAL.			
Number examined	1,058	886	14,515
Number condemned	352	260	6,211
Percentage condemned	33	30	43

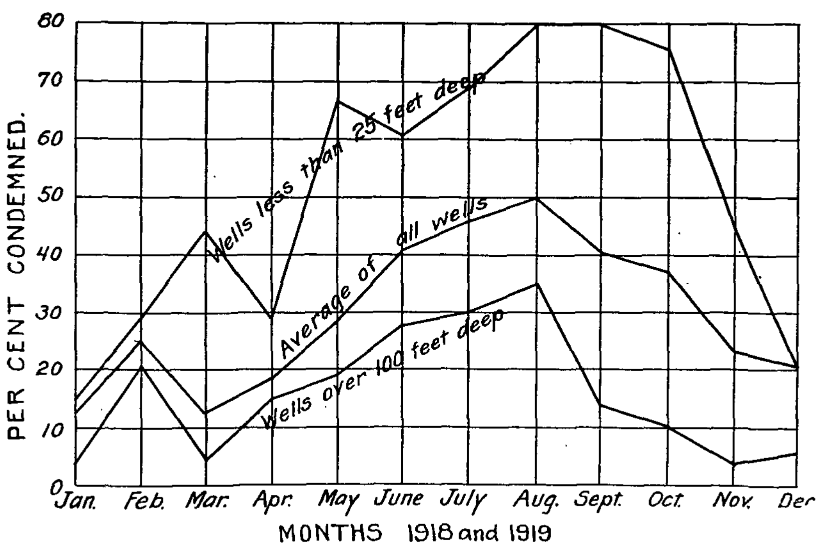

Figure 1.—Per cent well waters condemned during years 1918 and 1919.

Examination of samples of water from wells whose purity was not suspected has shown much better condition than is indicated in Table 2. The number condemned is given in Bull. **10**, 79 (1912). Samples of farm waters have been collected by the State Water Survey Division and information in regard to these supplies may be found in Bull. **7**, 78-97; **8**, 128-135.

FIELD INVESTIGATIONS.

During the past two years investigations were made of water supplies and proposed water supplies of 141 municipalities listed in Table 3.

TABLE 3.—PLACES VISITED FOR INVESTIGATION OF WATER SUPPLIES OR PROPOSED WATER SUPPLIES.

Aledo.	Fulton.	Martinsville.	Shelbyville.
Arcola.	Galena.	Mascoutah.	Sheldon.
Arlington Heights.	Galesburg;	Mason City.	Silvis.
Ashland.	Galva.	Mattoon.	Sparta.
Atlanta.	Geneseo.	Melrose Park.	Springfield.
Aurora.	Geneva.	Milan.	Steger.
Avon.	Gibson City.	Minooka.	Stockton.
Barrington.	Gilman.	Momence.	Stronghurst.
Batavia.	Glasford.	Monticello.	Taylorville.
Bement.	Glenview.	Morris.	Thomson.
Berwyn.	Granville.	Morrison.	Tinley Park.
Blue Mound.	Grayslake.	Morrisonville.	Tolono.
Bourbonnais.	Greenview.	Mount Sterling.	Tremont.
Cambridge.	Hamilton.	Neoga.	Tuscola.
Carbondale.	Hebron.	Oakland.	Union.
Carbon Hill.	Herrin.	O'Fallon.	Valier.
Carlyle.	Hoopeston.	Onarga.	Vandalia.
Carrollton.	Jacksonville.	Ottawa.	Vermont.
Carthage.	Johnston City.	Pearl.	Villa Park.
Casey.	Joliet.	Pekin.	Viola.
Cerro Gordo.	Kankakee.	Peoria.	Warren.
Charleston.	Kansas.	Peotone.	Watseka.
Chicago Heights.	Ladd.	Piper City.	Waukegan. '
Chrisman.	LaGrange.	Pittsfield.	Waverley.
Coal City.	LaSalle.	Poplar Grove.	Waynesville.
Coltax.	Lee.	Rankin.	West Brooklyn.
Collinsville.	Little York.	Rantoul.	Westfleld.
Creston.	Lombard.	Red Bud.	West Frankfort.
Danville.	Lostant.	Rochelle.	Westville.
Decatur.	Lyons.	Rockford.	Wheaton.
Delavan.	McHenry.	Roseville.	Wilmington.
Dwight.	Mackinaw.	St. Charles.	Winchester.
East Dubuque.	Manteno.	San Jose.	Winslow.
Elmhurst.	Maroa.	Savanna.	Witt.
Fairbury.	Marshall.	Sesser.	Wood River.
Freeport.			

Investigations of pollution of waters were made at Carbondale where tie plant wastes are discharged into Big Muddy River; at Murphysboro where gas plant wastes are discharged into Big Muddy River; at Cambridge, Edwardsville, Normal, and Rantoul where streams are polluted by domestic sewage; at Hoopeston, Rochelle and Washington where streams are polluted by cannery and other wastes; at Gillespie where wastes from a coal washer are discharged into a stream; at DePue where acid wastes from a zinc plant are discharged into Lake DePue; at Springfield where acid wastes from a powder plant are discharged into Sangamon River; and at Waukegan where wastes from a. tannery are discharged into Lake Michigan.

The cause of tastes and odors in the public water supply of Danville was investigated and treatment was prescribed.

A laboratory was installed at the water works at Murphysboro by the Murphysboro Water Works and Electric and Gas Light Company with the cooperation of the State Water Survey.

Chemical and biological surveys were made of Big Muddy, Embarrass, Illinois, Kaskaskia, Sangamon and Vermilion Rivers.

The investigations at DePue, at Springfield, and the surveys of the Sangamon and the Big Muddy are described in this report. Data concerning the others are on record in the office of the State Water Survey Division and information concerning them may be obtained on request.

There are 434 municipalities in the State with public water supplies. The source of supply of each municipality and data in regard to treatment of the supplies are given in Table 5, Bulletin 15. Since that bulletin was published the installation of a public water supply has been completed at Rankin where water is obtained from a well 270 feet deep in drift.

Abstracts of reports of water supplies visited during 1918 and 1919 are given in this report.

SCIENTIFIC AND SPECIAL STUDIES.

Routine analyses made in the laboratory of the Water Survey, inspection of private and municipal water supplies and sewage disposal plants, and questions suggested by the citizens of the State, bring to the attention of the Water Survey Division many special problems relating to water, water supplies, sewage and sewerage.

Members of the staff are, therefore, called upon to study special problems and each member has usually one or more such problems under consideration. The following summary indicates the special work, which has been completed during 1918 and 1919 and which is published elsewhere in this report. The regular staff has at times been assisted by instructors and graduate students in the University.

The fertilizer value of activated sludge.—Experiments with pot cultures and in the field have shown that activated sludge has fertilizer value equal to or better than other nitrogenous organic fertilizers containing equivalent amounts of nitrogen. An excess of the sludge was not toxic to wheat. Dried blood in excess was toxic but in small amounts gave satisfactory results. Either the wet or dried activated sludge gave good results as a fertilizer; wet sludge results being slightly better.

Nitrogen is present as nucleo-protein and its hydrolytic products which are beneficial to plant growth.

Drying on sand beds was impracticable in this climate. Filter pressing was not successful under the conditions available. Centrifugal machine containing an imperforate bowl produced a cake with 88 per cent of moisture; acidifying with sulfuric acid rendered the material easier to filter and in one experiment a cake of 80 per cent moisture was obtained.

Drying of this sludge was reported as practical by a manufacturer of driers.

Silicic acid, its influence and removal in water purification.—Silicic acid and silicates are found to a considerable extent in the waters of the State. A study of its relation toward electrolytes and various precipitants was made. The optimum hydrogen ion concentration for the removal of silicic acid with aluminium hydroxide was found to be $1x10^{-8}$ calcium hydroxide was shown to be the best agent for promoting the precipitation of aluminium hydroxide.

Silicic acid retards the clarification of water by aluminium hydroxide and the addition of certain electrolytes is helpful in water purification.

Some factors in the purification of sewage by the activated sludge process.—A study was made to determine the factors in the purification of sewage by the activated sludge process. Experiments were carried out in an attempt to find different sterilizing agents which would not alter the colloidal properties of the sewage or the activated sludge, in order to prove what part bacteria might play in the purification process. Experiments were carried out to determine the colloidal properties of sewage and activated sludge. Mechanical agitation and agitation with different gases were tried. The results of the work show that the purification is largely due to oxidation which is carried out by aerobic bacteria. Both the sewage and the activated sludge contain the bacterial flora necessary for the purification. This biological oxidation is attended by the absorption of the sewage colloids by the activated sludge. The colloids are, for the greater part, positively charged and may be largely removed by the introduction of negatively charged colloids. The activated sludge process is not comparable to the Miles Acid Treatment since purification does not depend upon the acidity produced..

A new sampler for collecting dissolved oxygen samples.—An apparatus was devised for the collection of samples of water to be used for the determination of dissolved oxygen. This apparatus was constructed from an ordinary wide-mouthed, common-stoppered bottle and other pieces equally common in the ordinary laboratory. The apparatus was compact, easy to operate and not at all fragile. These qualities in connection with the fact that it was constructed from ordinary laboratory appartus made it superior to other types. An all metal apparatus was designed along the same lines as the one constructed with the glass bottle. It had all the advantages of the former with the exception that it could not be constructed in the laboratory. It had the additional advantage of being non-breakable.

Preparation of ammonia free water.—Ammonia free water may be prepared by passing distilled water through permutit. This method has advantages over other methods in ease of operation and production of large quantities at minimum expense. Its disadvantages are that it gives a water of higher mineral content and that it does not remove nitrate, nitrite or albuminoid nitrogen. Indications are that American permutits, except the especially prepared Folin permutit will not quantitatively remove ammonia, but the English and German permutits seem satisfactory.

Experiments on the preservation of mud samples.—The experiments were made to determine a suitable method for preserving mud samples for the determination of ammonia and total nitrogen. After the first experiment, only ammonia determinations were run. Satisfactory preservation of the mud was obtained by a sufficient amount of benzoic acid either with or without the addition of sulfuric acid.

Some atypical colon-aero genes forms.—Three hundred and ninety-four cultures isolated from the routine samples were studied. After transferring from colonies on Endo's media, these cultures which gave the presumptive test for B. coli and in some case the completely confirmed test, were tested as to their reactions with methyl-red broth, adonite and uric acid broth; the cultures appear to fall in 19 groups. The reactions of 159 of the 394 with a number of the commonly used sugars and alcohols were determined; if these results be regarded as sufficient basis for subdivision the 19 varieties may be increased by subdivisions.

Chloramine and Crenothrix.—Experiments undertaken to determine the stability of chloramine solutions showed chloramine most stable in dilute solutions. Its effectiveness as a germicide was demonstrated. Results obtained indicated, too, that the acute troubles arising from crenothrix in iron-bearing waters may be eliminated by the germicidal action of chloramine, thus reducing the problem of treatment to one of iron removal without complications.

Some spore-bearing colon—aerogenes forms.—Five spore-bearing organisms were isolated and described.

The quality of water in the Sangamon River.—A biological and chemical survey of the Sangamon, with special reference to the region between Decatur and Springfield, was made. The river above Decatur was found to be suitable for an abundance of our common game fish up to the limit of its capacity at low water. The stream was greatly polluted immediately below Decatur as evidenced by the disappearance of the normal fauna, by the dropping off of dissolved oxygen, by the increase of the ammonia content of mud from the bottom, and rise of the oxygen consuming power of the water. These conditions fluctuated with change of temperature and seasons. The worst conditions, between Decatur and Springfield, occur in the upper part of the river during hot dry summers, and in the lower part of the river, in the early spring following a severe winter.

Experiments with Miles Acid Process of treatment for sewage disposal.—Two concrete tanks with sloping bottoms were used As sewage was pumped into the two tanks sulfur dioxide (SO_2) was added to one of them by introducing it into the influent pipe with the sewage. After a sedimentation period of three hours the supernatant liquid from both tanks was drawn off and the tanks refilled.

Turbidity of the sedimentation effluent from the tanks was noted, chemical analyses of the dried sludge were made. It was found that by the Miles Acid Process the fat content of the sludge was increased materially over that of the sedimentation sludge, also that the cost of the SO_2 treatment on sewages with high alkalinity is prohibitive.

A water works laboratory.—A list of apparatus has been prepared for the guildance of city officials and other water works officials who contemplate the installation of small laboratories to control and supervise the' sanitary quality of the water furnished. The list includes apparatus necessary in making the determinations of Color, Turbidity, Alkalinity, Chloride, and Free Chlorine, and bacteriological tests including total number of bacteria developing on nutrient agar, and the fermentation test. The State Water Survey Division feels that the proper use and interpretation of such tests would very much improve the results of any water purification plant, and that only in exceptional cases would additional chemical or bacteriological tests be necessary.

Departures from standard methods.—A study was made to determine the optimum concentration of lactose, the quantity of beef extract and of peptone to be used in lactose broth. One per cent lactose, as prescribed by Standard Methods, inhibits B. coli and one-tenth of one per cent gives optimum results, peptone serves as a buffer and beef extract may be used but need not be considered an indispensible component of culture broth. Gentian violet at a concentration of 1:250,000 eliminates false presumptive tests and helps to give an early knowledge of the presence of B. coli.

Swimming pool data.—A brief summary of the results obtained for both the men's and women's pools at the University of Illinois is given. Bleaching powder, in addition to filtration and recirculation is used for the women's pool and gives better results than filtration and recirculation followed by exposure to ultra violet rays in use at the men's pool. The results compare favorably with those obtained for other pools.

ABSTRACTS OF REPORTS.

The following pages contain abstracts of detailed reports of investigations of water supplies made during 1918 and 1919, information in regard to yields of wells secured during previous visits and by letter, and references by number and page to preceding bulletins for abstracts of reports made in former years. Abstracts of reports made in former years may be found in Bulletins **9**, 15-33; **10**, 89-185; **11**, 28-141; **12**, 28-147; **13**, 30-143; **14**, 22-74; **15**, 20-99. References to abstracts in previous reports are given in parentheses after the title of each investigation. Depths of wells are given in feet from the surface of the ground unless otherwise specified. Estimates of capacity, yield, daily consumption, consumption per capita, discharge of sewage, and similar amounts are rounded off to avoid expression of fictitious accuracy.

ABINGDON. Water supply.—(Bull. **11**, 28.) A public supply is secured from a well 1,350 feet deep terminating in St. Peter sandstone. The well is 9 inches in diameter to a depth of 600 feet and 6 inches in diameter at the bottom. It is cased to rock at a depth of about 40 feet. Equipped with an air lift, with air pipe extending to a depth of 275 feet, 145 feet below the static water level, the yield was 153 gallons a minute. The water has a slight hydrogen sulfide odor as it comes from the well. Analysis 27136.

ALBION. Proposed water supply.—(Bull. **10**, 89; **15**, 20.)

ALEDO. Water supply.—(Bull. **10**, 90.) Visited July 4, 1918. Water for a municipal supply is secured from a deep well, equipped with an air lift of 240 gallons a minute capacity. The average daily consumption is 120,000 gallons. The well was drilled to a depth of 3,165 feet, but on account of the high mineral content of the water it was filled to within about 1,450 feet of the surface. A triplex pressure pump, a centrifugal fire pump, and a 150,000-gallon elevated steel tank have been installed.

The water is of good sanitary quality. It has a mineral content of 1,750, a total hardness of 350, and a content of iron of 0.2 parts per million. Analyses 27444, 39700.

ALEDO.—Sewage disposal.—(Bull. **13**, 30.)

ALEXIS. Water supply.—(Bull. **13**, 30.) A public water supply is secured from a well 1,204 feet deep, terminating in St. Peter sandstone. The well is 10 inches in diameter at the top and 4 inches at the bottom and is cased to a depth of 600 feet. It is equipped with a deep-well pump of 100,000 gallons a day capacity with working barrel at a depth of 140 feet. Analysis 32069.

ALGONQUIN. Water supply.—(Bull. **13**, 30.) Water from springs collected in tiles furnishes the public supply. A measurement made some years ago indicated a yield of 700,000 gallons a day. Analysis 30577.

ALGONQUIN. Sewerage—(Bull. **13**, 31.)

ALPHA. Water supply.—(Bull. **14**, 23.) Analysis 36310.

ALTAMONT. Water supply.—(Bull. **11**, 28; **15**, 21.) Water for a public supply is secured from three wells from 131 to 225 feet in depth. The deepest well yielded little water until blasted at a depth of about 150 feet. Before blasting water stood at a depth of 100 feet, and after blasting it stood at a depth of about 50 feet when not pumping. This well is cased to a depth of 110 feet. In 1913 with working barrel of pump at a depth of 100 feet a yield of 10 gallons a minute was secured. A well drilled to a depth of 320 feet was abandoned as salty water was encountered. Analyses 25364, 37748, 37749.

ALTON. Water supply.—(Bull. **9**, 15; **10**, 90; **11**, 29; **12**, 28; **13**, 31; **15**, 21.)

ALTON. Proposed hospital. Water supply.—An investigation of possible sources of water supply for a proposed State hospital for insane was made in 1912. Springs in a distance of 150 feet along the foot of a bluff on Edward Rogers farm, near the east bank of Wood River about one mile north at East Alton had a flow estimated at 120,000 gallons a day. Analysis 24150. Cleveland, Cincinnati, Chicago and St. Louis Railway secured about 70,000 gallons a day from two wells at East Alton, each 40 feet deep, one 6 inches and the other 8 inches in diameter. Analysis 24100. Beal Bros, at East Alton obtained water from two wells 52 feet deep, one 6 and the other 8 inches in diameter. Pumps were operating at a combined rate of 125,000 gallons a day. Analysis 24180.

ALTON. Proposed additional sewers.—(Bull. **12**, 29.)

Nuisance complaint.—(Bull. **12**, 30.)

AMBOY. Water supply.—(Bull. **11**, 29.) A public water supply is secured from a well 2,400 feet deep terminating in Potsdam sandstone. The well is cased 30 feet to rock and between depths of 1,200 and 1,400 feet. It is said that water was encountered in sandstone at a depth of 280 feet, that between depths of 1,200 and 1,400 feet water drained from the well, and that an ample supply was obtained at a depth of 1,630 feet. It is thought that the lower part is closed off and that water is obtained from a depth of 280 feet. Analysis 26573.

ANNA. Water supply.—(Bull. **9**, 15; **11**, 30; **15**, 22.) A public water supply is secured from a well 650 feet deep, the upper 100 feet 12 inches and the lower part 8 inches in diameter. When not pumping, water stands 90 feet below the ground surface. The well is equipped with an air shaft, with air pipe extending to a depth of 350 feet. The well has been tested and yielded about 300,000 gallons a day. Analysis 27187.

ANNA. Sewerage.—(Bull. **9**, 15; **11**, 30.)

ANNA. State Hospital. Water supply.—(Bull. **9**, 15; **10**, 91; **12**, 30; **13**, 31.

Proposed sewage treatment.—(Bull. **12**, 32.)

ARCOLA. Water supply.—(Bull. **10**, 91.) Visited January 10, 1918. A public water supply is obtained from three wells which penetrate a water-bearing stratum of fine sand between depths of 95 and 101 feet. The static water level is at a depth of 50 feet. The wells are equipped with deep-well pumps which discharge into a surface reservoir from which the water is pumped by two electrically-driven triplex pumps. The average daily water consumption is estimated at 24,000 gallons. There is chance for pollution at the tops of the wells, and analysis showed some contamination of the supply. The water has a mineral content of 735, a total hardness of 280, and a content of iron of 4.0 parts per million. Analyses 24444, 38817. Water from a well 375 feet deep located near the southern limits of the city has a high salt content.

AREA. Water supply.—(Bull. **15**, 22.) A public water supply is obtained from a 6-inch well 242 feet deep, cased 235 feet to rock. When not pumping water stands about 40 feet below the ground surface. A 48-hour test at time of completion showed that at least 75 gallons a minute could be secured. Analysis 38336.

ARLINGTON HEIGHTS. Water supply.—(Bull. **12**, 32.) Visited April 23, 1918. A public water supply is obtained from a well 10 inches in diameter and 140 feet deep, cased to limestone at a depth of 117 feet. Watei stands at a depth of 40 feet when not pumping and is lowered about 20 feet by pumping. The well pump is said to operate 7 or 8 hours a day at a rate of 350 gallons a minute.

The water is of good sanitary quality. It has a mineral content of 727, a total hardness of 325, and a content of iron of 0.1 parts per million. Analyses 28648, 39338.

ARTHUR. Water supply.—(Bull. **10**, 94; **12**, 33.) Analyses 24455, 27245.

ASHLAND. Proposed water supply. Visited September 17, 1919. Water for private supplies is obtained from wells 25 to 50 feet deep. A well 50 feet deep on the Smith farm, 1½ miles southwest of Ashland was pumped for several hours and rate of inflow is reported as 90 gallons a minute. Four miles southwest of Ashland are several springs with a total yield said to be about 4,000 gallons an hour. In boring for oil several years ago on the farm of Louis Savage, 5½ miles northwest of Ashland, fresh water was recorded at depths of 25 and 438 feet. Water was recorded in "salt sand" at depths from 530 to 565 feet, and in limestone at depths from 625 to 632 feet

A water supply from wells in drift would be the cheapest supply to develop if sufficient, water could be secured. Before any considerable expenditure is made it would be advisable to test the yield of the well on the Smith farm or other wells in drift.

ASHLEY. Public wells.—(Bull. **13**, 32.)

ASHTON. Water supply.—(Bull. **13**, 32.) Water for a public supply is obtained from a well 545 feet deep, cased to rock at a depth of 180 feet with 12-inch pipe. In rock the well is 8 inches in diameter. St. Peter sandstone is entered at a depth of 415 feet. The static water level in 1915 was at a depth of 16 feet. The well is equipped with a deep-well pump with a working barrel placed at a depth of 85 feet. When pumping with a displacement of 160 gallons a minute water was evidently drawn down to the pump cylinder. Analysis 30850.

ASHTON. Sewage-treatment plant.—(Bull. **13**, 33.)

ASSUMPTION. Water supply.—(Bull. **11**, 31; **12**, 33; **15**, 22.) Analysis 25886.

Sewerage.—(Bull. **11**, 32.)

ASTORIA. Water supply.—(Bull. **11**, 32; **15**, 23.) Water for a public supply is obtained from a well 1,658 feet deep, cased to a depth of 230 feet. When not pumping, water stands about 200 feet below the ground surface. The well is equipped with an air lift, with an air pipe extending to a depth of 360 feet. The capacity is given as 38 gallons a minute. • Analysis 25736.

ATKINSON. Proposed water supply.—(Bull. **13**, 33.)

ATLANTA. Water supply.—(Bull. **11**, 33.) Visited August 19, 1919. Water for a public supply is obtained from. 2 wells 151 feet deep spaced 30 feet apart. One is 10 inches and the other 8 inches in diameter. The lower 12 feet of the wells is in water-bearing gravel. Deep-well pumps with cylinders at a depth of 132 feet are operated 12 hours a day to supply a demand of about 50,000 gallons. The deep-well pumps now discharge into the surface reservoir, from which water is pumped into the distribution system.

Sanitary analyses showed some contamination of the supply. Mineral analysis 27189.

AURORA. Water supply.—(Bull. **9**, 16; **11**, 34 **12**, 33; **15**, 23.) Visited March 4, 1919. Water for a public supply is obtained from 8 wells which penetrate Potsdam sandstone. Five wells, each about 2,250 feet deep are located on the east bank of Fox River about 1½ miles north of the center of the city. These are equipped with air lifts and yield about 1,600,000 gallons a day. Analyses 27198, 30996, 30999. Well No. 6, located in the southern part of the city, is 18 inches in diameter at the top, 15 inches in diameter at the bottom, and 2,200 feet deep. A test of this well with centrifugal pump 320 feet below the ground surface and with 40 feet of 9-inch suction pipe attached was reported giving a yield of 800 gallons a minute against a total head of 416 feet and 630 to 650 gallons a minute against a total head of 497 feet. Analysis 30997. Well No. 7, located in the southwestern part of the city is 18 inches in diameter at the top, 15 inches in diameter at the bottom, and 2,263 feet deep. The yield of the well is about 1,000 gallons a minute to about 900 gallons when pumping continuously for several hours. Analysis 31000. Well No. 8, near the center of the city is similar to well No. 7, and is 2,330 feet deep.

AURORA. Alleged pollution of Indian Creek.—(Bull. **14**, 23.)

AVERYVILLE. Proposed sewerage.—(Bull. **12**, 34.)

AVISTON. Copper-sulfate treatment of reservoir.—(Bull. **11**, 34.)

AVON. Water supply.—(Bull. **13**, 33.) Visited July 3, 1918. Water for fire protection purposes is taken from two ponds as described in Bulletin 13. Two wells formerly in use have been abandoned.

BARRINGTON. Water supply.—(Bull. **12**, 34.) Visited April 23, 1918. Water for a public supply is obtained from a well 305 feet deep. The well is cased to rock at a depth of 200 feet with 12-inch pipe and is 10 inches in diameter in rock. It is equipped with an air lift with the bottom of the air pipe at a depth of 114 feet. The air lift operates 15 hours a day. The yield is given as 308 gallons a minute with a lowering of the water level of 3 feet to a depth of 58 feet below the ground surface. Analysis 39343.

BARRINGTON. Proposed sewerage.—(Bull. **10**, 94.)

BARRY. Water supply.—(Bull. **12**, 35.) Water for a public supply is obtained from a spring. Water was formerly obtained from a well 2,510 feet deep. The well is cased with 7-inch pipe to a depth of 300 feet and is 2 inches in diameter at the bottom. During a test the yield was about 35 gallons a minute for 40 hours. The well supply was abandoned on account of the high mineral content. Analyses 18825, 22152.

BATAVIA. Water supply.—(Bull. **9**, 16.) Visited January 30, 1918. Water for a public supply is obtained from a well 2,000 feet deep equipped with a 12-inch centrifugal pump placed at a depth of 70 feet with 30 feet of suction pipe attached. The well is 12 inches in diameter at the top, 8 inches at the bottom, and is cased to a depth of 40 feet. The capacity is 1,143 gallons a minute, and the pump operates 10 hours a day.- The water level, when not pumping, is at a depth of 6 feet and is lowered to a depth of 40 feet by pumping. Analyses 31679, 38931. A well 1,279 feet deep equipped with an air lift with air pipe extending to a depth of 230 feet is available. It is 10 inches in diameter at the top and 4 inches at the bottom. The yield is 600 gallons a minute, and water is lowered to a depth of 40 feet.

BEARDSTOWN. Water supply.—(Bull. **11**, 35.) Water for a public supply is secured from 16 wells, each 6 inches in diameter and 85 feet deep, which penetrate a sand and gravel deposit. Water is drawn from the wells by suction. Part of the supply was formerly obtained from shallower wells, 2 inches in diameter. Analysis 17868.

BEECHER. Water supply.—(Bull. **15**, 24.) Water for a public supply is obtained from a 10-inch well 165 feet deep, cased to rock at a depth of 90 feet. When not pumping, water rises to within 16 feet of the ground surface. A pump draws water from the well by suction. It operates 3 hours a day at a rate of 200 gallons a minute. Analysis 38536.

BELLEVILLE. Water supply.—(Bull. **11**, 36.) Water for a public supply was secured, until 1908, partly from wells in rock about 400 feet deep located near the southern limits of the city. Analysis 17167. The yield was insufficient, and wells were developed in drift in Mississippi River bottom lands at Edgemont. Analysis 17398. The supply being rather hard and becoming insufficient, filtered Mississippi River water is now obtained from the plant at East St. Louis.

BELLEVILLE. Sewage disposal.—(Bull. **12**, 35; **13**, 34.)

Scott Field, Aviation Cantonment. Water supply.—(Bull. **15**, 25.)

BELLWOOD. Water supply.—(Bull. **11**, 37; **12**, 36.) Water for a public supply is obtained from a well 1,538 feet deep, 12 inches in diameter at the top, and 8 inches at the bottom. When not pumping water stands 75 feet below the ground surface. Upon completion of the well a test was run pumping at the rate of about 200 gallons a minute for 75 hours. Analysis 28011.

BELVIDERE. Water supply.—(Bull. **11**, 36.) Water for a public supply is obtained from three 8-inch wells. The first well, 8 inches in diameter at the top, was drilled to a depth of 1,950 feet. Later the lower part was reamed to 8 inches, the loosened material partly filling the well. A second well is 1,861 feet deep, and a third well is 1,803 feet deep. When the first well was drilled in 1891 it overflowed. In 1901 when the second well was drilled water rose to within 3. feet of the surface, and in the third well when it was drilled in 1908, water rose to within 8 feet of the surface. Water is drawn from the wells by suction and in 1914 yielded about 400 gallons a minute. Analysis 26349.

BELVIDERE. Alleged pollution of Kishwaukee River by gas-house wastes.—(Bull. **11**, 36; **13**, 34.)

BEMENT. Water supply.—(Bull. **10**, 95; **15**, 26.) Visited June 29, 1918. Water for a public supply is obtained from two 6-inch wells spaced about 6 feet apart. The wells are 137 and 140 feet deep. When not pumped for some time water stands about 20 feet below the ground surface. When pumping one well, water in the other stands about 70 feet below the ground surface. Pump cylinders are at a depth of 119 feet, and water is not drawn down to the bottom of the cylinder at maximum rate of pumping which is probably about 50 gallons a minute from one well. The consumption averages about 70,000 gallons a day. Analyses 23163, 39683. Several wells have been drilled in an attempt to secure an increase in supply. Considerable difficulty has been encountered due to very fine sand. Water from wells 200 and more feet deep is very highly mineralized. In 1917 a well was drilled to a depth of 275 feet, the upper 139 feet 12 inches in diameter, and the lower part of the well 6 inches in diameter. The well is cased to rock at a depth of 211 feet. The static water level is at a depth of about 25 feet. The well yielded 82 gallons a minute continuously for 30 minutes without lowering the ground water below a depth of 68 feet. Analysis 37776. The Wabash Railroad Company formerly secured a supply from a dug well 150 feet deep. Analysis 22079. This has been abandoned and drilled wells in drift located near the west corporation limits are in use.

BENLD. Proposed water supply.—(Bull. **12**, 36; **15**, 27.)

BENSON. Water supply.—(Bull, **13**, 35.) Analysis 31553.

BENTON. Proposed improvement of water supply.—(Bull. **9**, 16; **10**, 95; **11**, 38; **12**, 36.)

Sewage treatment.—(Bull. **10**, 96; **12**, 37.)

BERWYN. Water supply.—(Bull. **13**, 35.) Visited August 5, 1918. Water is obtained from the Chicago municipal supply. It was until recently secured from 2 wells, one 1,600 and the other 1,605 feet deep. Both are 16 inches in diameter at the top, one 5 inches in diameter and the other 8 inches in diameter at the bottom. Early in 1912 the water level was about 113 feet below the top, but during the year there was a gradual fall of 73 feet after which the water level remained about constant. The older well was equipped with an air lift with air pipe extending to a depth of 297 feet. The yield was about 320 gallons a minute. The newer well was equipped with a deep well pump, yielding 100 gallons a minute. It is doubtful if a yield of 600,000 gallons a day could be secured continuously from the two wells. Analysis 28751.

BLOOMINGTON. Water supply.—(Bull. **10**, 96; **12**, 37; **14**, 26; **15**, 28.)

BLUE ISLAND. Water supply.—(Bull. **12**, 37; **13**, 37.) Water for a public supply was secured until 1915 from wells drilled to St. Peter and

Potsdam sandstones. A 1,659-foot well drilled in 1910 penetrated St. Peter sandstone between depths of 910 and 1,055 feet and entered Potsdam sandstone at a depth of 1,475 feet. The water level when not pumping was at first at a depth of 172 feet and in 1914 at a depth of 230 feet. 'The water level is probably affected by the other wells as the three wells are located about 125 feet apart at corners of a triangle. The wells equipped with air lifts were capable of yielding slightly less than 1,000,000 gallons a day. Analysis 27770. In 1914 an odor of gas developed in the water and oil gathered on the surface of the water when standing. In the following year arrangements were made to secure water from the Chicago municipal supply.

BLUE ISLAND. Pollution of Stony Creek and Calumet Lake.—(Bull. **13**, 37.)

BLUE MOUND. Water supply.—(Bull. **12**, 38; **15**, 28.) Visited July 24, 1918. Water for a municipal supply is secured from two wells in gravel, 6 inches in diameter and 55 feet deep, located one-half mile south of the village. The wells were pumped at a rate of 50 gallons per minute for 24 hours. The consumption averages between 15,000 and 18,000 gallons a day. Analysis 39817.

BLUFFS. Jacksonville Water Works Company Wells.—In 1905. wells were drilled 1¾ miles west of Bluffs on low land 2½ miles east of Illinois River, to secure a supply of water for the city of Jacksonville. Fourteen wells, 10 inches in diameter, equipped with 20-foot strainers were sunk to rock at a depth of 68 to 70 feet. Water was drawn from the wells by suction. When pumping 5,000,000 gallons of water a day it is said that the water level outside of the well casings was lowered 57 inches, and the water level in the wells was never lowered below 15 feet 5 inches from the ground surface. Analyses 13570, 14072, 17070, 17147, 17148.

BOURBONAIS. Water supply.—(Bull. **15**, 28.) Visited August 7, 1918. Water for a public supply is obtained from a 10-inch well 181 feet deep, cased to rock at a depth of 12 feet. Its yield as equipped is estimated at 72 gallons a minute. The static water level is at a depth of 16 feet. Another well is being drilled 10 feet south of the present well. Analysis 39360.

BRACEVILLE. Water supply.—(Bull. **12**, 39; **15**, 28.) Analysis 37274.

BRADFORD. Water supply.—(Bull. **15**, 29.) Water for a public supply is obtained from a well 2,079 feet deep. The well is said to penetrate St. Peter sandstone between depths 1,625 and 1,713 feet and to enter Potsdam sandstone at a depth of 1,979 feet. It is cased to a depth of 1,730 feet. Water rises to within 160 feet of the top of the well and is said to be not appreciably lowered by six hours continuous pumping at 130 gallons a minute. The pump cylinder is at a depth of 360 feet. Analysis 37908.

BRADLEY. Water supply.—(Bull. **14**, 26.) Analysis 36022.

Proposed sewerage.—(Bull. **11**, 38.)

BRAIDWOOD. Water supply.—(Bull. **12**, 39.) Water for a public supply is obtained from one dug well 20 feet deep and nine 2-inch driven wells twelve feet deep. The static water level is at a depth of 8 feet. The demand is about 8,000 gallons a day. The yield is limited in dry seasons. Analysis 27861.

BREESE. Water supply.—(Bull. **9**, 16; **11**, 39; **12**, 40; **13**, 38; **15**, 29.)

Microscopic survey of the water supply.—(Bull. **15**, 30.)

Catholic Institute. Sewage disposal.—(Bull. **15**, 31.)

BROOKFIELD. Water supply.—(Bull. **13**, 38.)

BROOKPORT. Water supply.—(Bull. **11**, 40; **13**, 38; **15**, 31.) Analysis 30945.

BUCKLEY. Water supply.—(Bull. **13**, 39.) Analysis 30593.

BUDA. Water supply.—(Bull. **13**, 40.)

BUNKER HILL. Proposed water supply.—(Bull. **13**, 40; **15**, 31.)

BUREAU. Water supply.—(Bull. **13**, 41.) Water for a public supply is obtained from two wells about 305 feet deep, which penetrate 135 feet of drift. One is 4 inches and the other 5 inches in diameter. The static water pressure at the ground surface in 1915 was 30 pounds, and water flowed directly into the distribution system. Analysis 23738.

BUSHNELL. Water supply.—(Bull. **12**, 40.) Water for a public supply is obtained from two wells penetrating St. Peter sandstone, each about 1,350 feet deep. One is cased to a depth of 900 feet. With pump suction at a depth of 115 feet it has yielded as high as 140,000 gallons a day for a month. The water has a marked corrosive action. Pipes removed from the well were eaten through at the joints, and one piece that had been in the well for eleven months was very noticeably pitted. Analysis 39210.

BUSHNELL. Sewerage.—(Bull. **9**, 17; **12**, 40.)

BYRON. Water supply.—(Bull. **11**, 40.) Analysis 26379.

CAIRO. Water supply.—(Bull. **10**, 96; **11**, 40; **12**, 42; **13**, 41; **15**, 32.)

CALUMET RIVER. Pollution.—(Bull. **12**, 42.)

CAMBRIDGE. Water supply.—(Bull. **10**, 96.) Visited March 27, 1919. Water for a public supply is obtained from two wells 35 feet apart, the older one 1,380 feet and the other 1,377 feet deep. The lower 50 feet is in St. Peter sandstone. The older well is 10 inches in diameter at the top, 4 inches at the bottom, and cased to a depth of 250 feet. The static water level is at a depth of about 150 feet. It is equipped with a deep-well pump of 80 gallons a minute capacity with cylinder placed at a depth of 250 feet. The new well is 10 inches in diameter at the top and 8 inches at the bottom. It is equipped with a deep-well pump of 175 gallons a minute rated capacity. Analysis 23597.

CAMP GRANT. Water supply—(Bull. **15**, 33.) Analysis 39082.

CAMP POINT. Proposed water supply.—(Bull. **11**, 41.)

CAMPUS. Water supply.—(Bull. **14**, 27.) Analysis 35952.

CANTON. Water supply.—(Bull. **11**, 41; **12**, 43; **15**, 33.) Water for a public supply is obtained from two wells about 50 feet apart on low ground in the southwest part of the city. The wells are 8 inches in diameter at the top and 6 inches at the bottom. One is 1,646 and the other 2,042 feet deep. St. Peter sandstone is entered at a depth of 1,405 feet. The older, shallower well when drilled had a static pressure at the ground surface of 15 feet and flowed about 260 gallons a minute. Water now stands about 50 feet below the ground surface. The water forms a heavy scale in boilers and has a decided corrosive action. Feed water pipes require renewal about once a year and many valves on the distribution system have become coated with scale until they cannot be fully closed. Analyses 14625, 14746.

CANTON. Sewage-disposal nuisance.—(Bull. **9**, 17.)

CAPRON. Water supply.—(Bull. **14**, 27.) Water for a public supply is obtained from a well 680 feet deep, 8 inches in diameter at the top and 5 inches at the bottom, cased to rock at a depth of 400 feet. The static water level of the well was at a depth of 10 feet in 1900 and 15 feet in 1916. The well is equipped with a deep-well pump, of 70 gallons a minute displacement with bottom of suction pipe at a depth of 54 feet. It has been in continuous service for 24 hours without drawing air. Analysis 35084.

CARBONDALE. Water supply.—(Bull **11**, 42; **15**, 34.) Visited May 7, 1918. Water for a public supply is obtained from five wells from 400 to 640 feet deep equipped with deep well pumps. Considerable trouble has been experienced with various makes of meters on account of the action of the water on the meter parts. There is some chance of pollution of the supply at the wells, especially when working on the wells, and at the reservoir which is not covered and is located near a public road. Chlorine treatment apparatus should be installed. (A chlorine treating apparatus has' since been installed.) Analyses 14722, 27095, 27204. Water from a well of the Southern Illinois State Normal School in the southern part of the city is less highly mineralized. Analysis 39420.

CARBON HILL. Water supply.—(Bull. **12**, 44.) Visited December 9, 1919. Water for a public supply is obtained from an 8-inch well originally 1,900 feet deep, cased to a depth of 150 feet. When drilled about 1893 water flowed from the well directly into the distribution system. It now rises to about 20 feet below the ground surface. Part of the supply may come from abandoned coal workings. Analysis 27638.

The water was not of good sanitary quality due, probably, to contaminating matter flowing into the top of the well.

CARLINVILLE. Water purification.—(Bull. **10**, 97; **12**, 44.)

CARLYLE. Water supply.—(Bull. **9**, 17; **11**, 43; **13**, 41; **15**, 34.) Visited July 16, 1918. Water for a public supply is secured from Kaskaskia River. Test wells have been sunk to rock at a depth of 30 feet near the river bank. In 1913 water stood about 12 feet below the ground surface. After pumping continuously for five days, when pumping at 28 gallons a minute from one well, water receded to a depth of about 24 feet. A sample was collected on the fifth day of pumping. Analysis 26004.

CARLYLE. Sewerage.—(Bull. **12**, 45.)

Microscopic and sanitary survey of water supply.—(Bull. **15**, 34.)

CARMI. Water supply.—(Bull. **11**, 44.)

CARPENTERSVILLE. Water supply.—(Bull. **13**, 42; **15**, 35.) Water for a public supply is obtained from a dug well 17 feet deep. Water overflowed at the top until an overflow was provided at a depth of 6 feet. Pumping with a pump of 250 gallons a minute capacity water has been lowered to within 4 feet of the bottom of the well, but could not be lowered below that level. Analysis 37359.

CARROLLTON. Water supply.—(Bull. **11**, 44; **15**, 35.) Visited October 30, 1919. Water for a public supply is obtained from a spring 4½ miles northwest of the city with a yield said to be 600,000 gallons a day. The springs are at the northern end of a narrow range of land on which limestone and flint rock outcrop. It is probable that water from this ridge and from other surrounding land flows through rock fissures to the spring. Diversion of a stream which flows close to the springs has been proposed. Should water in the springs show signs of contamination at any time it is recommended that samples from the stream and from the springs be analyzed to determine if pollution is from the stream. Analyses 24589 and 38721.

CARTERVILLE. Proposed water supply.—(Bull. **12**, 45.)

CARTHAGE. Water supply.—Visited January 23, 1918, and August 27, 1919. Water for a public supply is obtained from two wells, one about 847 feet, and the other about 1,000 feet deep. In the monograph, Illinois Glacial Lobe, Leverett states that water veins were struck in limestone at depths of 750' and 865 feet, and in St. Peter sandstone at 975 feet. Each well is equipped with an electrically-driven deep-well pump with cylinder at a depth of 110 feet. A gasoline engine is available for use in emergency.

Water is pumped from the wells into the distribution system to which an elevated wooden tank is connected. About 250 service connections are in use and the consumption is estimated at 50,000 gallons a day.

The water is highly mineralized and not in general use for drinking, except by a few who have become accustomed to its taste. Analyses 23424, 38860.

It is desired to secure water of a better quality. Water from limestone immediately underlying drift which is 200 feet or slightly more in depth, is in use at Carthage College and at the Court House. This water is of better quality than the city supply. From present information it cannot be said that an adequate public supply could be developed from this source. A public water supply may be developed by impounding and filtering a surface water and preliminary plans have been prepared.

CARTHAGE. Sewage disposal.—(Bull. **10**, 99.)

CARY. Water supply.—(Bull. **14**, 28.) Water for a public supply is obtained from a 10-inch well 300 feet deep, cased to rock at a depth of 154 feet. The static water level is at a depth of about 12 feet. During a 30-hour test in 1913 with a discharge of 110 gallons a minute, water was drawn down to the pump cylinder at a depth of 80 feet. Analysis 35078.

CASEY. Water supply.—(Bull. **10**, 100; **13**, 43; **14**, 28.) Visited July 23, 1919. Water for a public supply is obtained from three 8-inch wells in the bottom lands of North Fork about five miles east of the city. Two are 80 feet deep, and the other one is 131 feet deep. Several strata of sand and gravel were encountered. During tests one of the shallower wells was pumped for 68 hours at a rate of from 147 to 227 gallons a minute without drawing the water level down to the pump cylinder at a depth of 69 feet, and the deeper well was pumped continuously for 53 hours at a rate of about 130 gallons a minute. A horizontal pump driven by an oil engine draws water from the wells and forces it through a pipe line to the city. A pond formerly the source of supply is used as an emergency supply. Analyses 35355, 35380, 41499.

CEDAR POINT. Water supply.—(Bull. **11**, 45.) The source of the public water supply is a well 1,750 feet deep, cased to a depth of 900 feet. Water is obtained from Trenton-Galena limestone and St. Peter sandstone. The sandstone is penetrated between depths of 1,610 and 1,749 feet. The static water level when well was drilled in 1912 was at a depth of 90 feet. During a test the well was said to yield 183 gallons a minute. Analysis 24723.

CENTRAL CITY. Water supply.—(Bull. **14**, 29.)

CENTRALIA. Water supply.—(Bull. **10**, 102; **11**, 45; **12**, 46; **13**, 43; **14**, 30; **15**, 35.)

Sewerage.—(Bull. **10**, 102; **12**, 46.)

Microscopic survey of reservoir.—(Bull. **14**, 29.)

CERRO GORDO. Water supply.—(Bull. **12**, 46.) Visited June 29, 1918. Water for a public supply is obtained from two wells 150 feet deep which penetrate a stratum of water-bearing gravel. The wells are about 10 feet apart. It is stated that pumping from one of the wells, 8 inches in diameter, a 34,000-gallon tank was filled in eight hours. The distribution system includes about 4 miles of mains, 40 hydrants, and 150 service connections. All services are meteres. The consumption averages about 50,000 gallons a day.

The water is of fair sanitary quality. It has a mineral content of 590, a total hardness of 350, and a content of iron of 2.2 parts per million. Analyses 22137, 39684.

CHADWICK. Water supply.—(Bull. **11**, 46.) Water for a public supply is obtained from an 8-inch well 600 feet deep. Limestone is encountered at a depth of from 60 to 70 feet. The well is equipped with a deep-well pump of 40 gallons a minute capacity with cylinder placed at a depth of 300 feet. Analyses 14556, 27135.

CHAMPAIGN. (see Urbana).

CHARLESTON. Water supply.—(Bull. **10**, 103; **11**, 46; **12**, 47; **13**, 43.) Visited June 25, 1918. Water for a public supply is taken from the Embarrass River at a point about two miles east of the city. A filtration plant has been built but is not now in operation. A $20,000 bond issue for improvements was recently voted. The consumption of water is estimated at about 900,000 gallons a day. The elevated tank is not being used because the mains near the pumping station, it is said, cannot carry the necessary pressure. The filter plant should be put in good repair, records of location of all parts of the distribution system should be maintained, and people should be urged to boil the water before drinking it, until 'a water of good quality is furnished.

CHATSWORTH. Water supply.—(Bull. **9**, 17; **14**, 30.) Analysis 35958.

CHENOA. Water supply.—(Bull. **9**, 17; **12**, 48; **15**, 36.)

CHERRY. Water supply.—(Bull. **13**, 43.) Analysis 31776.

CHESTER. Water supply.—(Bull., **9**, 18; **11**, 47.)

CHIGAGO HEIGHTS. Water supply.—(Bull. **11**, 47; **15**, 36.) Visited March 5, 1918. Water for a public supply is secured from 5 wells in limestone, each 200 to 475 feet in depth. No water is encountered below a depth of 200 feet. Pumps are placed at depths of from 118 to 140 feet with suction pipes from 18 to 24 feet in length attached. The pump in the largest well, 24 inches in diameter, discharges 1,400 gallons a minute. The depth from pumping station floor to water level in a test well was 48 feet in 1910; 69 feet in April, 1915, when rate of pumping was approximately 2,500,000 gallons a day; 115 feet in January, 1918, when rate of pumping was about 5,000,000 gallons a day, and 100 feet on March 5, when rate of pumping was 3,000,000 gallons a day. A 15-inch well is under' construction and will be drilled to Potsdam sandstone.

The water is of good sanitary quality. It has a strong gaseous taste and odor caused by bitumen or possibly by wastes which enter fissures in rock. Mineral analyses 19908, 24968.

CHICAGO HEIGHTS. Sewerage.—(Bull. **11**, 48; **15**, 36.)

CHILLICOTHE. Water supply.—(Bull. **12**, 49.) Analysis 29444.

Pollution of Illinois River by Chicago Drainage Canal.—(Bull. **9**, 19; **11**, 50.)

CHRISMAN. Water supply.—Visited December 11, 1919. A public water supply was installed by the municipality in 1905. Water is obtained from a 10-inch well 132 feet deep in drift. The well is equipped with an air lift and yields 50 gallons a minute. Originally the well was equipped with a deep-well pump of 120 gallons a minute capacity. The yield would decrease rapidly from a maximum of 65 gallons a minute, and it was necessary to remove and clean the well screen frequently. The air lift discharges into a small pit from which water is pumped into the distribution system. A 34,500-gallon steel tank is connected to the mains. Possibly the flow of the well could be increased by cleaning. Flushing with water or air could be attempted to relieve clogging of the screen.

The water contains considerable iron. The quality could be improved by filtration. Gravity filters would be better than pressure filters. Until a treatment plant is installed the mains should be flushed regularly.

CHRISMAN. Proposed sewerage.—(Bull. **11**, 50; **13**, 44.)

CISSNA PARK. Water supply.—(Bull. **13**, 44.) Water for a public supply is obtained from two 5-inch flowing wells about 25 feet apart one 150 feet and the other 237 feet deep. Water-bearing sand and gravel strata are encountered at depths of 42 feet, 145 feet and 230 feet. The wells are cased to the bottom. The yield is not known' but is more than sufficient to supply demands of 60,000 gallons a day. Analysis 30633.

CLINTON. Water supply.—(Bull. **12**, 50; **15**, 37.) Water for a public supply is obtained from two wells 340 deep in drift. One is 10 inches and the other 12 inches in diameter. The combined yield is estimated at 1,500 gallons a minute with a lowering of the water level of 10 feet. Analysis 38379. Until 1913 water was secured from wells in drift, some 65, and others 285 feet deep. Analysis 24309.

COAL CITY. Water supply.—(Bull. **12**, 50; **13**, 38.) Visited December 9, 1919. Water for a public supply is obtained from an 8-inch well 350 feet deep, cased to a depth of 285 feet. When drilled in 1892 water overflowed. The water level when not pumping was at a depth of 30 feet in 1914 and 33 feet in 1919. There are 400 service connections, 6 of which are metered.

The water is of good sanitary quality. Mineral analysis 27631.

COLFAX. Water supply.—(Bull. **15**, 38.) Visited July 6, 1918. Water for a public supply is obtained from a 10-inch well 105 feet deep in drift. A 6-inch well 105 feet deep is available for use in emergencies. The larger well is equipped with a deep-well pump of 125 gallons per minute capacity with cylinder placed at a depth of 72 feet. The consumption is about 40,000 gallons a day. The water level is 15 feet below the ground surface when not pumping and is lowered 7 feet by pumping.

The water is of good sanitary quality. It has a mineral content of 740, a total hardness of 320, and a content of iron of 2.7 parts per million. Analyses 37556, 39699.

COLFAX. Proposed sewerage.—(Bull. **11**, 51.)

COLLINSVILLE. Water supply.—(Bull. **10**, 104.) Visited July 19, 1918. Water for a public supply is obtained from 8 wells 70 to 90 feet deep in bottom lands of Mississippi River about 2 miles west of the city. Water is obtained from a sand and gravel stratum. The maximum consumption is about 500,000 gallons a day.

Analysis of a sample of water showed some contamination. The water has a mineral content of 460, a total hardness of 380, and a content of iron of 1.0 part per million. Analysis 39786.

COLLINSVILLE. Typhoid fever.—(Bull. **12**, 51.)

Sewage disposal.—(Bull. **10**, 104; **11**, 51; **12**, 50; **13**, 45; **14**, 31.)

COLUMBIA. Proposed water supply.—(Bull. **10**, 105; **11**, 51; **12**, 51; **13**, 46; **14**, 31.) Hill's spring, about 3 miles southwest of Columbia was once suggested as a source of public supply. The yield after a long continued dry spell was 100,000 gallons a day. Analysis 24371. A test well in the southwestern portion of the village 5% inches in diameter, 45 feet deep, entering water-bearing gravel to a depth of 2 feet, yielded about 10 gallons a minute for 2½ hours. Water level was drawn down to the bottom of the well. Analysis 25192.

COLUMBIA. Proposed sewerage and sewage treatment.—(Bull. **13**, 46.)

COMPTON. Water supply.—(Bull. **15**, 38.) Analysis 37764.

COOK. County Poor Farm. Sewage disposal.—(Bull. **11**, 52.)

CREAL SPRINGS. Water supply conditions.—(Bull. **11**, 52.)

CRESCENT CITY. Water supply.—(Bull. **13**, 47.) Analysis 30611.

CRESTON. Water supply.—Visited June 5, 1919. A public water supply was installed in 1906. Water is obtained from a well 582 feet deep, cased to a depth of 400 feet. The static water level is 140 feet below the ground surface. The well was tested for 22 hours, pumping at a rate of 130 gallons a minute. It is equipped with a deep-well pump driven by a gas engine which also operates a dynamo. The deep-well pump discharges directly into the distribution system which covers practically the entire built-up area. A steel pressure tank 36 feet long by 9 feet in diameter is connected to the distribution system. There are about 60 service connections.

The water was of good sanitary quality at the time of visit. It has a mineral content of 290, a total hardness of 217, and a content of iron of 1.9 parts per million. Analyses 38024, 41156.

CRETE. Water supply.—(Bull. **13**, 48.) Analysis 30855.

Proposed sewerage.—(Bull. **13**, 48.)

CRYSTAL LAKE. Water supply.—(Bull. **9**, 19; **11**, 52; **15**, 39. Analysis 26326.

CUBA. Water supply.—(Bull. **12**, 51; **13**, 48; **15**, 39.) Water for a public supply is obtained from a well 1,768 feet deep, 12 inches in diameter to a depth of 1,000 feet and 10 inches in diameter below 1,000 feet, cased to a depth of 317 feet. The well penetrates St. Peter sandstone for 298 feet. The static water level is at a depth of 103 feet. The well was pumped continuously for 34½ hours. During 1½ hours when the rate was measured it varied from 69 to 164 and averaged 118 gallons a minute. When pumping 164 gallons a minute the water level in the well was lowered 39 feet. Analyses 28983, 32623.

CUBA. Proposed sewerage.—(Bull. **13**, 49.)

CULLOM. Water supply.—(Bull. **14**, 32.) Water for a public supply is obtained from a well about 1,700 feet deep which penetrates St. Peter sandstone between depths of 1,280 and 1,470 feet. The static water level is at a depth of 70 feet. A salt water in small quantity is said to enter the well at a depth of 600 or 700 feet. The bottom of Niagara limestone is at a depth of 700 feet. Analysis 35953.

DANVERS. Water supply.—(Bull. **12**, 51; **13**, 50.) Analysis 27545.

DANVILLE. Water supply.—(Bull. **9**, 19; **12**, 52.)

Microscopic survey of reesrvoir.—(Bull. **14**, 32; **15**, 39.)

DECATUR. Water supply.—(Bull. **10**, 106; **11**, 53; **12**, 55; **15**, 40.)

Sewage disposal. (Bull. **10**, 107; **11**, 253; **12**, 55; **15**, 40.)

Microscopic survey of reservoir.—(.Bull. **14**, 33.)

DEER CREEK. Water supply.—(Bull. **10**, 107; **11**, 53; **14**, 33.) Analysis 36135.

DEKALB. Water supply.—(Bull. **13**, 56.) Water for a public supply is obtained from deep wells. One well, cased with 15-inch pipe to a depth of 150 feet and 8 inches in diameter below that depth, is about 1,300 feet deep and terminates in Potsdam sandstone. It has yielded 500 gallons a minute lowering the water level from a depth of 104 feet down to the pump cylinder at depth of 160 feet. Analysis 29497.

DEKALB. Sewage disposal.—(Bull. **13**, 57.)

Pollution of Kishwaukee River.—(Bull. **13**, 57.)

DELAND. Proposed water supply.—(Bull. **12**, 55; **13**, 58.)

DELAVAN. Water supply.—(Bull. **12**, 56.) Visited November 5, 1919. Water for a public supply is obtained from 2 wells, one 10-inch and one 8-inch, about 20 feet apart, 160 feet deep in drift. The 10-inch well was drilled in 1917, and a 6-inch well formerly used was abandoned. The pump in the 10-inch well operates occasionally at a rate as high as 190 gallons a minute, and the water level is not drawn down to the pump cylinder which is at a depth of 140 feet.

The water is of fair sanitary quality. It has a mineral content of 370, a total hardness of 310, and a content of iron of 1.6 parts per million. Analyses 21721, 42044.

DEPUE. Water supply.—(Bull. **13**, 59.) Analysis 31419.

Proposed sewerage.—(Bull. **13**, 59.)

DESPLAINES. Water supply.—(Bull. **13**, 60; **15**, 41.) Water for a public supply was for many years obtained from three 8-inch wells 130 feet deep in drift, located on the east bank of DesPlaines River. Equipped with air lift the yield was 300 gallons a minute in 1915. Analysis 20941. Water is now obtained from a well dug 4 feet in diameter to a depth of 112 feet, from which depth pipes have been driven to the water-bearing stratum.

DESPLAINES. Sewerage.—(Bull. **10**, 66; **11**, 54; **13**, 61.)

DIXON. Water suppiy.—(Bull. **11**, 58; **13**, 61.) Water for a public supply is obtained from 4 wells 300 to 400 feet apart on the gank of Rock River. The wells vary in depth between 1,637 and 1,810 feet penetrating St. Peter and Potsdam sandstones. Three are. cased to a depth of 50 feet, and the other to a depth of 400 feet. The total natural flow of the four was estimated in 1915 at 700,000 gallons a day. One well, 10 inches at the top and 6 inches in diameter at the bottom flowed 200,000 gallons a day. Analysis 31647.

DOWNERS GROVE. Water supply.—(Bull. **13**, 61.) Water for a public supply is obtained from 2 wells one 10 inches in diameter and about 240 feet deep, the other 10 inches in diameter at the top, 6 inches at the bottom, and 2,250 feet deep. The 240 foot well yields 125 gallons a minute with bottom of suction pipe on pump cylinder at a depth of 160 feet. The static water level is at a depth of 80 feet. The deeper well is equipped with a pump of 175 gallons a minute, rated capacity with cylinder at a depth of 210 feet. Analysis 30918.

DOWNERS GROVE. Sewerage and sewage disposal.—(Bull. **13**, 62.)

DUQUOIN. Water supply.—(Bull. **9**, 19; **11**, 58; **13**, 62.) Analyses 28955, 28956.

Sewage disposal.—(Bull. **12**, 56; **13**, 63.)

DWIGHT. Water supply.—(Bull. **12**, 57.) Visited December 11, 1919. Water for a public supply is obtained from 3 wells, 136 feet deep in drift. Two are 6 inches and the other 8 inches in diameter. The static water level is at a depth of 34 feet. The wells are equipped with deep well pumps with cylinders at a depth of 126 feet. They are operated 10 to 12 hours a day and average amount pumped is 219,000 gallons a day. The amount of water pumped is measured by meter and averages 220,000 gallons a day. There are 500 service connections, 225 of which are metered. Analyses 14337, 23563.

The Keeley Institute secures water from a well 1,077 feet deep caused to rock at a depth of 450 feet. St. Peter sandstone lies between depths of 795 and 1,046 feet. The static water level is at a depth of 88 feet. Analyses 24479, 39478.

DWIGHT. Sewerage and sewage treatment.—(Bull. **12**, 57.)

EARLVILLE. Water supply.—(Bull. **9**, 20; **15**, 41.)

EAST DUBUQUE. Water supply.—(Bull. **11**, 60.) Visited December 19, 1919. Water for a public supply was secured until 1914 from a well 940 feet deep. When drilled in 1885 it was said to have a flow of 420 gallons a minute. Analysis 17958. The casing corroded and tools were lost in the well. The well was then reamed and drilled to a depth of 1,343 feet and cased to a depth of 426 feet. It is 4 inches in diameter at the bottom. In 1914 the yield was said to be about 300 gallons a minute, and at present it is about 160 gallons a minute. Analysis 29258.

EAST DUNDEE. Water supply.—(Bull. **9**, 20; **15**, 41.)

EAST MOLINE. Water supply.—(Bull. **14**, 33.) Analysis 35516.)

EAST PEORIA. Water supply.—(Bull. **11**, 61; **12**, 58; **14**, 34.) Analysis 36134.

EAST ST. LOUIS. Water supply.—(Bull. **11**, 61; **13**, 63.)

Pollution of Cahokia Creek.—(Bull. **13**, 63.)

EAST ST. LOUIS. Well water supply in industrial district.—(Bull. **15**, 42.) Water is secured by many industrial plants from wells in sand and gravel in bottom lands, of Mississippi River. The static water level is from 8 to 40 feet below the ground surface in different wells. The General Chemical Company in 1917 had two 10-inch wells 98 feet deep, spaced 12 feet apart. The yield of each well was 300 gallons per minute and 100,000 gallons a day was pumped. Analysis 36718. The Aluminum Ore Company had four 16-inch wells, 130 feet deep. The yield of a well when drilled is 1,000 gallons a minute and decreases to 500 gallons per minute. Two million gallons a day is pumped. Analysis 36719. The Commercial Acid Company had 3 wells 110 feet deep; 8, 12, and 16 inches in diameter. The yield per well was from 900 to 1,500 gallons per minute. The water level was lowered 26 feet by pumping. Analysis 36720:

EAST WENONA. Water supply.—(Bull. **13**, 65; **14**, 34.)

EDWARDSVILLE. Water supply.—(Bull. **12**, 58.) Analysis 27760.

Sewage disposal.—(Bull. **12**, 59.)

EFFINGHAM. Water supply.—(Bull. **10**, 108; **11**, 63; **13**, 65.)

Disposal of wastes from catsup factory.—(Bull. **9**, 20; **10**, 108.)

ELBURN. Water supply.—(Bull. **15**, 43.) Analysis 38032.

ELDORADO. Proposed water supply and sewerage.—(Bull. **9**, 20; **15**, 43.)

ELGIN. Water supply.—(Bull. **9**, 20; **14**, 34.) Analyses 12909, 31184, 31187.

Factory water supplies.—(Bull. **14**, 35.)

Elgin National Watch Company, water supply.—(Bull. **14**, 35; **15**, 43.)

Proposed sewage treatment.—(Bull. **9**, 163; **12**, 60.)

State Hospital. Water supply and typhoid fever.—(Bull. **10**, 109.)

ELMHURST. Water supply.—(Bull. **11**, 64; **12**, 61.) Visited December 13, 1918. Water for a public supply is obtained from a spring known as Mammoth Spring, located about three miles south of the city. Analyses 14890, 18632, 23616, 24972. The Water Works is owned and operated by the Elmhurst Spring Water Company whose franchise expires in the near future. The city has drilled a well 958 feet deep. During a test it was pumped for several hours at a rate of 500 gallons a minute. The water level when not pumping was at a depth of 35 feet and is said to be lowered little by pumping. During the past summer water from this well was used at times of great demand. The city has equipped the well with a centrifugal pump of 250 gallons a minute capacity, built a concrete reservoir of 150,000 gallons, installed a motor-driven centrifugal pump of 600 gallons a minute, erected a 100,000 gallon elevated steel tank, and started drilling a second well. A distribution system is to be installed.

ELMHURST. Sewage.—(Bull. **11**, 64.)

Sewage pollution of Salt Creek.—(Bull. **12**, 61.)

ELMWOOD. Water supply.—(Bull. **12**, 62; **15**, 44.) Water for a public supply is obtained from a well originally 1-,487 feet deep, at present possibly filled to a depth of about 600 feet. A yield of 150,000 gallons a day for 5 days has been secured. Analysis 27967.

EL PASO. Water supply.—(Bull. **10**, 109; **15**, 44.) Analysis 24565.

Sewerage.—(Bull. **10**, 110.)

Disposal of corn-canning wastes.—(Bull. **13**, 66.)

EUREKA. Water supply.—(Bull. **9**, 21; **12**, 62.) Analyses 29271, 30106.

Disposal of cannery wastes.—(Bull. **12**, 235.)

Proposed sewerage.—(Bull. **13**, 67.)

EVANSTON. Water supply.—(Bull. **9**, 21; **10**, 110; **13**, 67.)

FAIRBURY. Water supply.—(Bull. **9**, 22; **12,** 63; **15**, 44.) Visited February 7, 1918. Water for a public supply is obtained from a well 2,000 feet deep. The static water level is at a depth of 87 feet. Pumping 5 minutes at a rate of 120 gallons a minute lowered the water to the pump cylinder (depth 252 feet?) The well is said to be cased for 60 feet at a depth of about 1,500 feet to exclude salt water. A new well has been drilled to a depth of 2,172 feet but has not been equipped. The drillers record St. Peter sandstone between depths of 1,350 and 1,603 feet, below which is a few feet of shale underlain by limestone. This well is cased to rock and in shale. The static water level is at a depth of 109 feet. Pumping 24 hours at an average rate of 87 gallons a minute lowered the water to the pump cylinder at a depth of 200 feet. The water consumption averages about 90,000 gallons a day.

The water from the 2,000-foot well is of good sanitary quality. It has a mineral content of 1,295, a total hardness of 155, and a content of iron of 0.1 parts per million.

FAIRFIELD. Water supply.—(Bull. **12**, 65; **15**, 45.) Analysis 27570.
Sewerage.—(Bull. **12**, 65.)

FARMER CITY. Water supply.—(Bull. **10**, 111; **15**, 45.) Water for a public supply is obtained from two 8-inch wells, 176 feet deep in drift. When drilled water rose to the ground surface. Each well is equipped with a deep-well pump of 100 gallons a minute capacity with cylinder in one at a depth of 80 feet, and in the other at a depth of 100 feet. Analysis 37313.

FARMER CITY. Sewerage.—(Bull. **10**, 111.)

FARMINGTON. Water supply.—(Bull. **12**, 65; **13**, 67.) Water from a public supply is obtained from a well 1,700 feet deep, 10 inches in diameter to a depth of 1,020 feet and 8 inches in diameter below that depth. The upper 1,260 feet is cased. Below that depth the well penetrates 310 feet of Trenton limestone and 130 feet of St. Peter sandstone. When not pumping water stands 202 feet below the ground surface. With the bottom of suction pipe on pump cylinder at a depth of 310 feet the pump operates about 12 hours a day at a rate of 70 gallons a minute. Analysis 41714. Until 1918 water was secured from a well 1,461 feet deep said to be cased to a depth of 1,145 feet. Analysis 27220.

FARMINGTON. Sewerage.—(Bull. **12**, 66; **13**, 68.)

FLANAGAN. Water supply.—(Bull. **15**, 45.) Analysis 37577.

FLOOD RELIEF WORK.—(Bull. **11**, 65, 431.)

FLORA. Water supply.—(Bull. **9**, 22; **12**, 67; **15**, 46.) Water for a public supply is obtained from wells in rock which penetrate a water bearing stratum between depths of about 110 and 160 feet. The maximum capacity of a well is about 1,000 gallons an hour. Analyses 37657, 37658. Wells formerly in use obtained water from the same water-bearing stratum. Analysis 27566.

FLORA. Sewerage.—(Bull. **12**, 68.)
Stream pollution.—(Bull. **12**, 68; **15**, 46.)

FOREST PARK. Water supply.—('Bull. **10**, 112.) Analysis 27119.

FORREST. Water supply.—(Bull. **14**, 39.) Water for a public supply is obtained from two mine shafts, 7 feet by 14 feet, 80 feet deep. Water stands 8 feet below the ground surface when not pumping and 17 feet below the surface after long continued pumping. The amount pumped is estimated at 4,700 gallons a day. Analysis 35940.

FORRESTON. Water supply.—(Bull. **11**, 65.) Analysis 26274.

FORT SHERIDAN. Water supply.—(Bull. **9**, 23; **10**, 111; **13**, 68.)

FOX RIVER WATERSHED.—(Bull. **9**, 147; **11**, 66.)

FREEBURG. Water supply.—(Bull. **11**, 66.) Analysis 24726.
Microscopic and sanitary survey of the public water supply.—(Bull. **15**, 50.)

FREEPORT. Water supply.—(Bull. **10**, 113; **13**, 68.) Visited August 21, 1918. A public water supply is obtained from twenty-eight 6-inch wells 35 to 45 feet deep, and one 16-inch well 316 feet deep which penetrates St. Peter sandstone. One other well penetrating this sandstone has been drilled. Water is treated with two grains per gallon of hydrated lime and filtered to remove iron. The lime acts almost instantly. No crenothrix or sand incrustation was found in the filters. Analyses 19438, 19439, 19441.

PULTON. Water supply.—(Bull. **11**, 67.) Visited December 17, 1919. Water for a public supply is obtained from an 8-inch well 1,500 feet deep, cased to a depth of 387 feet. When drilled in 1908 the natural flow was about 270 gallons a minute. In 1912 it had decreased to 80 gallons a minute. Equipped with an air lift with air pipe extending to a depth of 208 feet, the yield in 1913 was given as 1,200 gallons a minute. At time of visit it was 1,090 gallons a minute, and the flow when air lift was not operating was 44 gallons a minute. The water consumption is from 180,000 to 200,000 gallons a day. There is a strong odor of hydrogen sulphide in the vicinity of the well. Analysis 20651.

A well 1,246 feet deep cased with 6-inch pipe to a depth of 160 feet and 5 inches in diameter below the casing was formerly in use. Leverett states that sulphurous water was struck at about 475 feet, another flow was obtained from the Potsdam at 940 to 1,050 feet, the pressure at the ground surface in 1899 was 60 feet, and the flow was estimated at 300 gallons a minute.

FULTON. Sewerage. (Bull. **11**, 68.)

GALENA. Water supply.—(Bull. **11**, 69; **12**, 68.) Visited December 18, 1919. Water for a public supply is obtained from a well approximately 1,530 feet deep, cased with 12-inch pipe to rock at a depth of 60 feet. The bottom of the well is 8 inches in diameter. In 1913 the natural flow of the well was reported as 480 gallons a minute, and the pressure at the ground surface as 30 feet. The casing is now in poor condition and the yield is estimated at 250 gallons a minute. Analysis 25062.

It is proposed to drill another well of about the same size and depth as the existing well and to case to a depth of 500 feet. In the Galena limestone in this vicinity there are many crevices and caves. It would be advisable to drill the new well 16 inches in diameter through drift and into limestone, and fill the space outside of the well casing with cement. Casing the well through strata containing crevices and caves in which water flows freely from the well and through all water-bearing strata in which the pressure is not sufficient to raise water to the ground surface will increase the yield. The well should be cased through strata yielding a poor quality of water. A very thin pipe with space outside filled with cement should not be depended upon for casing to any great depth on account of the probability of having very little cement in places. Casing partly or entirely through Galena limestone and possibly casing through St. Peter sandstone may prove advantageous. Closing off the flow from the well when it is not needed will decrease the rate of lowering of the ground water level and be of advantage, provided the well is cased to prevent the water flowing from the well to the surface of the ground, or through crevices which might be enlarged by the flow.

GALENA. Sewage disposal.—(Bull. **12**, 68.)

GALESBURG. Water supply.—(Bull. **9**, 23; **10**, 114; **12**, 69; **13**, 71.) Visited July 2, 1918. Water for a public supply is obtained from wells about 70 feet deep in a sand and gravel deposit near Cedar Fork and from wells in St. Peter sandstone. Analyses 26929, 28653, 33638, 33639, 33640, 33641. A well recently completed is 1,252 feet deep and is cased to St. Peter sandstone. It is 10 inches in diameter at the bottom. The well was shot with two 200-pound charges of 100 per cent gelatin. The static water level is at a depth of 183 feet. Equipped with an air lift with air pipe extending to a depth of 566 feet, the well yielded 540 gallons a minute with a lowering of the water level of 118 feet. Analyses 38986 and 39697. Another well is being drilled. The consumption is about 900,000 gallons a day.

GALESBURG. Sewage disposal.—(Bull. **9**, 23; **10**, 114; **12**, 70.)

Pollution of Cedar Creek.—(Bull. **9**, 23; **10**, 114; **12**, 70, 196-224; **13**, 72.)

GALVA. Water supply.—(Bull. **10**, 115.) Visited July 5, 1918. Water for a public supply is obtained from two wells, one 1,477 and the other 1,525 feet deep. Both are cased to St. Peter sandstone. The static water level in 1916 was at a depth of about 250 feet and was lowered from 35 to 40 feet when pumping both wells at a total rate of 125 gallons a minute. Another casing is to be installed in the 1,477-foot well. Analyses 23584, 39702.

GALVA. Sewerage.—(Bull. **10**, 115.)

GENESEO. Water supply.—(Bull. **10**, 116.) Visited July 5, 1918. Water for a public supply is obtained from springs. There is chance of contamination of the supply at times of high water. At the time of visit it was of good sanitary quality. It has a mineral content of 390 and a total hardness of 340 parts her million. It contains no iron. Analyses 23609, 39701.

GENESEO. Pollution of Geneseo Creek by city sewage.—(Bull. **10**, 117; **11**, 70; **12**, 70.)

GENEVA. Water supply.—(Bull. **9**, 23.) Visited January 30, 1918. Water for a public supply is obtained from a well 850 feet deep. The demand averages a little over 300,000 gallons a day. Analyses 22901, 38886. Near the pumping station is a spring with a yield said to be 400,000 gallons a day. The use of water from the spring for a city supply is considered. Analysis 38885.

GENEVA. Sewage treatment.—(Bull. **12**, 70.)

Illinois State Training School for Girls. Plans for sewage treatment. —(Bull. **12**, 71.)

GENOA. Water supply.—(Bull. **11**, 70.) Analysis 26371.

Sewage disposal.—(Bull. **12**, 71; **13**, 72.)

GEORGETOWN. Proposed water supply.—(Bull. **9**, 24; **10**, 117.) A well 32 feet deep had a natural flow in 1912, 2 feet above the ground surface, of about 4,000 gallons a day. Pumping a well 600 feet distant at a rate of 36 gallons a minute caused a cessation of flow in that well. Analysis 23513.

GEORGETOWN. Proposed sewerage and sewage treatment.—Bull. **12**, 72.)

GIBSON CITY. Water supply.—(Bull. **10**, 118.) Visited February 5, 1918. Water for a public supply is obtained from three 7-inch wells 55 feet deep, spaced about 100 feet apart. Pumps set 8 feet below ground surfaca draw water from the wells at a rate of about 450 gallons a minute 12 hours a day.

The water is of good sanitary quality. It has a mineral content of 260, a total hardness of 170, and a content of iron of 1.0 part per million. Analyses 21802, 38909.

GIBSON CITY. Disposal of cannery wastes.—(Bull. **12**, 73.)

Typhoid fever.—(Bull. **10**, 118; **13**, 73.)

GILLESPIE. Proposed water supply.—(Bull. **15**, 52.)

Sewerage.—(Bull. **13**, 73.)

GILMAN. Water supply.—(Bull. **11**, 71.) Visited October 16, 1918. Water for a public supply is obtained from wells about 120 feet deep in drift. The wells have a slight flow at connections with a reservoir 4 feet below the ground surface. One 6-inch well equipped with an air lift with air pipe extending to a depth of 80 feet yields when pumped for a short time, 100 gallons a minute. Analysis 36194.

GIRARD. Proposed water supply.—(Bull. **11**, 71; **15**, 52.) A test in 1913 of a well 14% feet in diameter and 25 feet deep which was proposed for a public water supply indicated with short periods of pumping, a maximum yield of 100 gallons a minute. Analysis 26124.

GLASFORD. Water supply.—Visited February 7, 1918. The installation of a public water supply was completed in 1917. Water is obtained from a well 1,669 feet deep, 10 inches in diameter to a depth of 1,130 feet and 8 inches in diameter at the bottom. It is cased to a depth of 620 feet. The lower 55 feet is in St. Peter sandstone. The static water level is at a depth of 60 feet. The well is equipped with an air lift which discharges into an elevated tank. Water was pumped at a rate of 140 gallons a minute during a five-hour test. The distribution system includes three miles of 4, 6, and 8-inch cast-iron main; 22 valves; and 26 hydrants. Leakage on the distribution system was reduced to 45 gallons per inch mile per day. A 50,000-gallon steel tank is connected to the distribution system. The cost of the waterworks was about $22,000.

The water is of good sanitary quality. It has a mineral content of 1,630 a total hardness of 295, and a content of iron of 2.2 parts per million. Analysis 38936.

GLENCOE. Water supply and sewerage.—(Bull. **9**, 24.)

GLEN ELLYN. Water supply.—(Bull. **12**, 75.) Water for a public supply is obtained from an 8-inch well 310 feet deep, the lower 196 feet in rock. The static water level in 1914 was at a depth of 43 feet. Equipped with an air lift with air pipe extending to a depth of 185 feet the well yielded 275 gallons a minute with a lowering of the water level of 13 feet. Analysis 28349.

GLEN ELLYN. Sewage disposal.—(Bull. **12**, 74.)

GLEN VIEW. Water supply.—(Bull. **14**, 40.) Visited August 14, 1918. Water for a public supply is obtained from a well 1,251 feet deep, 12 inches in diameter at the top and 6 inches at the bottom. About 70 service connections have been installed. Analysis 39977.

GRAFTON. Pollution of Illinois River.—(Bull. **11**, 72.)

GRAND RIDGE. Water supply.—(Bull. **11**, 72; **13**, 74.) Water for a public supply is obtained from a 10-inch well 160 feet deep in drift When completed in 1915 the well was pumped for 22 hours at a rate of 70 gallons a minute. Analysis 30896.

GRANITE CITY. Water supply.—(Bull. **11**, 72; **13**, 74.)

Proposed improved sewerage.—(Bull. **13**, 75.)

GRANT PARK. Water supply.—(Bull. **15**, 53.) Water for a puhlic supply was obtained from an 8-inch well in limestone 147 feet deep cased to a depth of 75 feet. The static water level was at a depth of 30 feet. As equipped the well yielded about 78 gallons a minute. Analysis 38537. Recently the well has been drilled to a depth of 251 feet.

GRANVILLE. Water supply.—(Bull. **13**, 75.) Visited May 6, 1918. Water for a public supply is obtained from a well 1,742 feet deep, 8 inches in diameter at the top and 4½ inches at the bottom. The well is in limestone between depths of 1,389 and 1,650 feet and in sandstone below a depth of 1,650 feet. It is cased to a depth of about 1,310 feet. The static water level is at a depth of 125 feet. A deep-well pump rated at 90 gallons a minute capacity with cylinder at a depth of 180 feet is operated from 8 to 10 hours a day.

A sample of water collected at the time of visit was not of good sanitary quality. A sample collected later was of good quality. The water has a mineral content of 975, a total hardness of 260, and a content of iron of 1.2 parts per million.

GRAYSLAKE. Water supply.—Visited April 14, 1919. The installation of a public water supply was completed in 1915. Water is obtained from a well 12 inches in diameter at the top, 6 inches at the bottom, and 1,039 feet deep. It is cased to rock at a depth of 246 feet. The well is equipped with an electrically-driven deep-well pump which discharges directly into the distribution system. The distribution system includes 3.2 miles of 8, 6 and 4-inch mains. A 60,000-gallon elevated steel tank is located at the rear of the pumping station. The cost of the system was about $25,000.

Wells at the Wisconsin Condensed Milk Company plant, located 500 feet from the village well, enter rock at a depth of 230 feet and St. Peter sandstone at a depth of 890 feet. One well, 1,040 feet deep, thought to be 12 inches in diameter at the bottom, equipped with a centrifugal pump 240 feet below the ground surface with 35 feet of suction pipe attached yields 230 gallons a minute. Another well, 100 feet distant, is 1,600 feet deep.

The public water supply is of good sanitary quality. An odor of hydrogen sulphide is noticeable near the well. The water has a mineral content of 450, a total hardness of 295, and a content of iron of 0.2 parts per million. Analyses 29996, 40919.

GRAYSLAKE.' Sewage disposal.—(Bull. **12**, 75; **13**, 76.)

GRAYVILLE. Water supply.—(Bull. **10**, 119.)

GREAT LAKES. Naval Training Station. Water supply.—(Bull. **9**, 28; **11**, 34; **13**, 76.)

GREENUP. Water supply.—(Bull. **10**, 119; **11**, 74; **13**, 76.) Analysis 29714.

GREENVIEW. Water supply.—Bull. **11**, 75.) Visited November 6, 1919. Water for a public supply is obtained from a well 8 feet in diameter at the top, 6 feet at the bottom and 40 feet deep, lined with iron. The static water level is at a depth of 12 feet. A 4-inch perforated pipe 40 feet long extends through gravel from the bottom of the dug well. The person now in charge of the pumping station doubts the existence of this pipe. The maximum yield of the well is about 12,000 gallons a day. An electrically-driven deep-well pump has been installed. About 50 service connections are in use. Analysis 26804.

GREENVILLE. Water supply.—(Bull. **15**, 53.) Water for a public supply is obtained from seven 8-inch wells 47 feet deep in drift. Well pumps are operated about 7 hours a day and the yield of each well averages 20 gallons a minute. Two of the wells yield very little water. Analysis 37302.

GREENVILLE. Sewerage and sewage disposal.—(Bull. **11**, 75; **12**, 76; **13**, 77.)

GROSS POINT. Water supply.—(Bull. **15**, 54.)

HAMILTON. Water supply.—(Bull. **10**, 120; **11**, 76; **13**, 77.) Visited October 23-26, 1919. Water from above dam of the Mississippi River Power Company flows by gravity to the filtration plant. The water is treated with alum, settled, filtered, and pumped into the distribution system to which a 100,000-gallon storage tank is connected. The filtration plant includes two settling or coagulating basins of about 60,000 gallons capacity each, two filters of 500,000-gallon daily capacity each, two electrically-driven triplex pumps, one of 600 and the other of 300 gallons a minute capacity, a clear water basin of 10,000 gallons capacity, two chemical solution tanks, pipes, valves, and other accessories.

The rate of filtration is practically determined by the capacity of the pumps on account of the limited capacity of the clear water basin. By pumping with the larger pump and using both filter beds, a satisfactory rate of filtration can be maintained. The water was treated with three grains per gallon of alum and all of the turbidity and practically all of the color was removed. The removal of bacteria was not as good as it should have been.

The plant was not in good repair. An alum solution pipe was broken, and the alum solution flowed into one corner of one of the settling basins instead of being mixed with the raw water.

The length of time of a washing is limited by the amount of water in the clear water basin, as it is necessary in washing to take water from the mains and from the basin at as rapid a rate as possible to make the wash effective. A valve between the settling basins and the east filter bed was broken, and it was impossible to shut the water out of this filter without shutting it off from the other filter. With neither filter operating, water in the clear water basin is exhausted very rapidly during washing and the washing is inadequate.

Wasting filtered water would be desirable at times as the filters are operated intermittently and practically clear settled water is at times admitted from the settling or coagulating basins to the filters. On account of a broken valve it was impossible to *filter to waste.*

The depth of water in the clear well could hot easily be determined as a float on the gauge had been broken. The sand in the filter beds was more or less packed in places. The loss-of-head guages and rate controllers were not operating. A mechanical agitator in one of the alum mixing tanks could not be operated.

The broken solution pipe, broken valves, loss of head guages, rate controllers, and alum solution agitator should be repaired. To insure water of good quality at all times it should be sterilized with liquid chlorine or calcium hypochlorite. The clarity and color of samples of water from each filter and from the mains should be compared with distilled water as a check on operating results.

HARMON. Water supply.—(Bull. **10**, 121; **14**, 41.) Water for a public supply is obtained from a 5-inch well 532 feet deep, equipped with a deep-well pump which discharges probably 28 to 30 gallons a minute. The static water level is at a depth of 7 feet. With pump cylinder at a depth of 60 feet air was drawn into the pump and with cylinder at a depth of 90 feet no air was drawn. Analysis 36191.

HARRISBURG. Water supply.—(Bull. **9**, 24; **10**, 121; **11**, 76; **12**, 76.)

Pollution of public water supply by improper sewage disposal.—(Bull. **11**, 77; **13**, 79.)

Microscopic and sanitary survey of water supply.—(Bull. **15**, 54.)

HARVARD. Water supply.—(Bull. **12**, 78.) Water for a public supply is obtained from two wells, one 741 feet deep, 8 inches in diameter to a depth of 100 feet, below which it is 6 inches in diameter, the other 1,600 feet deep, 10 inches in diameter to a depth of 120 feet, and 8 inches in diameter below that depth. The static water level is at a depth of 30 feet. The wells are equipped with deep-well pumps which operate about 9 hours a day. The pump in the shallower well delivers 110 gallons a minute, and the pump in the deeper well delivers 150 gallons a minute. The water level is lowered to 60 feet below the ground surface. Analysis 23565.

HARVARD. Sewage disposal.—(Bull. **10**, 122; **12**, 79.)

HARVEY. Water supply.—(Bull. **13**, 81.) Water for a public supply is obtained from four wells each about 1,600 feet deep. One of smaller diameter has a very small yield. In March, 1913, water stood 120 feet below the ground surface and in June, 1915, the distance was 155 feet. No. 2 well equipped with air lift with air pipe extending to a depth of 360 feet, yielded 186 gallons a minute. Well No. 3, 16 inches in diameter at the top and 6 inches at the bottom, equipped with an air lift with air pipe extending to a depth of 460 feet, yielded 325 to 350 gallons a minute. Well No. 4, the same size as No. 3 equipped with a deep-well impeller pump, yielded approximately 100 gallons a minute. Well No. 1 was originally 2,100 feet deep, but was plugged at 1,600 feet to exclude salt water. Analyses 18165, 31509.

HARVEY. Investigation of nuisance.—(Bull. **10**, 123.)

HAVANA. Water supply.—(Bull. **12**, 79.) Analysis 29175.

Pollution of Illinois River by Chicago Drainage Canal.—(Bull. **11**, 77.)

HEBRON. Water supply.—Visited April 16, 1919. A public water supply was installed by the municipality in 1905. The waterworks includes a brick pumping station, a well in drift equipped with a deep-well pump, a 37,000-gallon reservoir, two steel pressure tanks, an 8 by 8-inch triplex pump, an air compressor, a 25-horsepower kerosene engine, and a distribution system which reaches practically the entire built-up portion of the village. The well is 8 inches in diameter at the top, 6 inches at the bottom, and 272 feet deep. The static water level is at a depth of 61 feet. The well pump operates 4 or 5 hours a day at a rate of about 78 gallons a minute.

The water is of good sanitary quality. It has a mineral content of 270, and a total hardness of 210 parts per million. Analysis 40946.

HENNEPIN. Water supply.—(Bull. **15**, 55.) Analysis 38602.
Pollution of Illinois River by Chicago Drainage Canal.—(Bull. **9**, 24.)

HENRY. Water supply.—(Bull. **12**, 80.) Analysis 28976.
Pollution of Illinois River.—(Bull. **11**, 77.)

HERRIN. Water supply.—(Bull. **10**, 125; **13**, 82.) Analysis 24270.
Proposed sewerage.—(Bull. **10**, 125.)

HEYWORTH. Proposed water supply.—(Bull. **14**, 42.)

HIGH LAKE. Proposed water supply.—(Bull. **9**, 24.)

HIGHLAND. Proposed water supply.—(Bull. **10**, 126; **13**, 83.)
Proposed sewerage.—(Bull. **13**, 83.)

HIGHLAND PARK. Water supply and sewerage.—(Bull. **9**, 24; **10**, 126.)
Sewage treatment.—(Bull. **9**, 24; **13**, 83.)

HILLSBORO. Water supply.—(Bull. **10**, 127; **12**, 81; **13**, 84; **15**, 56.) Two wells on the Glenn farm were once considered as a possible source of public water supply. A small quantity of fresh water was encountered in sandstone at depths of from 64 to 74 feet and 490 to 540 feet. Sandstone which yielded salt water was entered at a depth of 670 feet. The shallower well, 757 feet in depth, was said to yield 150 gallons a minute during **a** 55-hour test. Analyses 21028, 23350.

HILLSBORO. Sewage pollution of Middle Fork of Shoal Creek.—(Bull. **12,** 83.)

HINCKLEY. Water supply.—(Bull. **11**, 78.) Water for a public supply is obtained from a 12-inch well 708 feet deep, cased to rock at a depth of 100 feet. It penetrates St. Peter sandstone. When completed in 1913 water rose to within 4 feet of the ground surface, and was drawn down 24 feet by pumping one hour at a rate of 250 gallons a minute. Analysis 27577.

HINSDALE. Water supply.—(Bull. **11**, 78; **13**, 84.) Water for a public supply is obtained from a 12-inch well, 200 feet deep. It has yielded as much as 600,000 gallons in a day, and for **a** short time at a rate of 1,350,000 gallons a day. The water is softened before delivering to consumers. Analysis 21794.

HOLLYWOOD. Water supply—(Bull. **13**, 86.)

HOMER. Pollution of private wells.—(Bull. **12**, 84; **13**, 86.)

HOMEWOOD. Water supply.—(Bull. **12,** 84.) Analysis **39136.**

HOOPESTON. Water supply.—(Bull. **10**, 128.) Visited September 2, 1919. Water for a public supply is obtained from three 10-inch wells **118** feet deep in drift, and one 8-inch well originally 2,100 feet deep which **was** plugged at a depth of 360 feet. One 10-inch well is equipped with an **air** lift with air pipe extending to a depth of 80 feet. The other wells **are** equipped with deep-well pumps. The largest pump with cylinder at a depth of 65 feet discharges 320 gallons a minute. During August, 1919, the average amount of water pumped daily was 618,000 gallons. Analyses 23286, 23287.

HOOPESTON. Flooding of cellars by sanitary sewage.—(Bull. **14**, 42.)
Sewage disposal.—(Bull. **11**, 78; **14**, 42.)

HUNTLEY. Water supply.—(Bull. **15**, 56.) Water for a public supply is obtained from three 6-inch wells 68 to 98 feet deep in drift. The **static** water level is at a depth of 15 feet. Water is drawn from the wells at a rate of 175 gallons a minute by a pump placed three feet below the ground surface. Analysis 38795.

ILLINOIS RIVER. Examination of Illinois River between the cities of Morris and Peoria.—(Bull. **14**, 44.)

IPAVA. Water supply.—(Bull. **12**, 85; **15**, 57.) Analysis 29194.

JACKSONVILLE. Water supply.—(Bull. **10**, 89; **12**, 85; **15**, 57.) Water for a public supply has been obtained partly from a stream, the south branch of Mauvaise Terre Creek, and partly from wells. There are five wells each about 70 feet deep in bottom land of Mauvaise Terre Creek within a distance of 420 feet. During a dry period the wells yielded from 16 to 104 gallons a minute each, and a total of 450,000 to 500,000 gallons a day. Water was drawn down to within a few feet of the bottom of the wells and at a distance of 2,000 feet water stood 24 feet below the elevation of the ground surface at the wells. Analyses 28596, 28597, 28599, 37038, 37039, 37040, 37041, 37042. Water from a sand stratum in the creek valley at a depth of 140 to 146 feet was much more highly mineralized. Analysis 38335. A supply was developed at Bluffs *(see* Bluffs), by a private company but water was never furnished from this supply. Water secured from wells in the city 3,000 feet deep was highly mineralized.

The State Department of Public Health, and the State Geological Survey and State Water Survey Divisions of the Department of Registration and Education, during 1917 and 1918, made an investigation of water resources in the vicinity of Jacksonville. An abstract of information secured is given in Bulletin 15. Tests made did not prove that water of good quality could be secured in sufficient quantity from wells in the vicinity of Jacksonville to supply the demands of the city. It was recommended that a supply be secured by filtering water impounded from a stream, and that an engineer be employed to take charge of the entire project.

An engineer was employed by the city and a dam has been built near the southeastern limits of the city which forms an impounding reservoir on the south branch of Mauvaise Terre Creek.

JACKSONVILLE. Water supply of Jacksonville schools.—(Bull. **15**, 61.) Sanitary inspection of Chautauqua ground.—(Bull. **12**, 87.) Illinois School for the Deaf. Water supply.—(Bull. **13**, 86.)

JERSEYVILLE. Water supply.—(Bull. **12**, 88.) Water for a public supply is obtained from a well 1,542 feet deep, cased to a depth of 1,367 feet. The well is 12% inches in diameter at the top and 8 inches at the bottom. It was practically dry between depths of 896 and 1,040 feet. The flow is from St. Peter sandstone. The static water level was originally at a depth of 117 feet. The water level in 1914 was estimated to be 140 feet below the ground surface when not pumping, and less than 280 feet below ground surface when pumping. A yield as high as 148 gallons a minute is said to have been secured. Analyses 17687, 24046, 27771.

JOHNSTON CITY. Proposed improved water supply.—(Bull. **11**, 79; **14**, 44; **15**, 62.) Visited May 6, 1918, and December 3, 1919. Water for a public supply is obtained from Lake Creek. The supply is not adequate and is of very poor quality. Officials of the city, officials of the Central Illinois Public Service Company, the owners of the plant, and the consulting engineer of the company were seen. The consulting engineer recommended the construction of a reservoir south of Marion, a filter plant, and a pipe line from the reservoir to Marion and Johnston City together with reservoirs for storage of water.

City officials believe that a plan by which a temporary water supply could be installed immediately should be followed. The use of water from an abandoned mine, Oak Ridge Mine, and the use of water from an impounding reservoir to be formed by a dam on a branch 8f Lake Creek were suggested. Water from the Oak Ridge Mine has a hardness of 737 parts per million, contains 5 parts per million of iron and 1.0 part per million of manganese. Analysis 41854. On standing, a black precipitate forms which would separate out and would stain porcelain fixtures, and white goods washed in it. It would be necssary to filter the mine water to remove these substances before using it for a water supply.

A reservoir of probably 100,000,000 gallons capacity could be formed on a drainage of 0.9 square miles located near the city. A run-off of 6 inches would about fill the. reservoir and allowing one-third for evaporation would furnish 300,000 gallons a day for 200 days. Another drainage area about one-half this size which would furnish half as much water is located near the city.

The procedure as recommended by the consulting engineer of the company is ideal for the permanent solution of the Johnston City and Marion water problems if the necessary money can be obtained. With the cooperation and support of the two cities, the money might be raised. If the company cannot arrange to secure funds, the financing of such a system could be carried out by the cities forming a sanitary district.

If the larger scheme cannot be carried out in the near future, the use of water from Lake Creek and use of water from reservoirs on branches of Lake Creek, or water from Oak Ridge Mine, at times when the flow in Lake Creek is insufficient should be considered. It would be necessary to filter the supply. Pressure filters are on hand but they are too small.

It is hoped that the city officials and the Central Illinois Public Service Company may agree on the general propositions:

1. Whether the large permanent scheme shall be adopted. The time for carrying it out to be determined at once.
2. Whether a temporary scheme to supply Johnston City shall be adopted, if the larger scheme will require too much time.

JOLIET. Water supply.—(Bull. **11**, 79.) Visited April 24, 1918. Water for a public supply is obtained from wells. At the main pumping station, water is drawn by suction from 6-inch wells 40 feet deep in drift and pumped by air lift from six wells 1,200 feet deep and the others from 1,600 to 1,700 feet in depth. The deep wells are cased to a depth of 400 feet. Analysis 39357.

A well on Canal Street 8 inches in diameter at the bottom, 1,575 feet deep, is cased with 10⅝-inch casing to a depth of 893 feet. Casing was put in in an attempt to exclude oil encountered in shale at a depth of 220 feet. The casing did not exclude all oil, and an aerator was constructed to remove the odor from the water. Equipped with a deep-well pump the well yielded 800,000 gallons a day. Analysis 39359.

A well on VanBuren Street is 1,547 feet deep, cased with 14-inch pipe to a depth of 328 feet. The well is 8 inches in diameter at the bottom. The normal water level when drilled in 1913 was 63 feet below the ground surface. Pumping at a rate of 650,000 gallons, a day the level was lowered to 240 feet. Analysis 39358.

A well on DesPlaines Street is 1,575 feet deep, cased with 14-inch pipe to a depth of 300 feet, also cased between depths of 600 and 824 feet and from 1,200 feet to below 1,300 feet. It is 5 inches in diameter at the bottom. The static water level in 1914, was 64 feet below the ground surface when not pumping and was drawn down to 180 feet when pumping at a rate of 650,000 gallons a day. Analysis 31692.

Electrically-driven centrifugal pumps are being installed at the main pumping station. A 4,500,000-gallon concrete reservoir was constructed in 1917. The water consumption is approximately 4,500,000 gallons a day.

JOLIET. lllnois State Penitentiary. Water supply.—(Bull. **11**, 81.)
Contamination of wells by gas liquors.—(Bull. **15**, 63.)

JONESBORO. Proposed water supply.—(Bull. **15**, 64.)

KANKAKEE. Water supply.—(Bull. **11**, 83; **13**, 88.) Analyses 14265, 14266.

KANKAKEE. State Hospital. Water supply.—Visited March 5, 1918. At the Kankakee State Hospital water is obtained from two wells, one 1,812 and the other 1,892 feet deep. Water from the deeper well was said to be- preferred. The yield of this well, equipped with an air lift with air pipe extending to a depth of 260 feet was said to be 800,000 gallons a day. Analyses 18776, 39036.

KANSAS. Water supply.—(Bull. **13**, 88.) Visited January 8, 1918. Water for a public supply is obtained from an 8-inch well 80 feet deep in drift, equipped with an electrically-driven deep-well pump. The static water level is at a depth of 14 feet. During a 48-hour test water was drawn for the greater part of the time at a rate of 55 gallons a minute. There are 50 service connections, all of which are metered. The plant cost approximately $15,000.

The water is of fair sanitary quality. It has a mineral content of 450, a total hardness of 340, and a content of iron of 3.0 parts per million. Analysis 38810.

KEITHSBURG. Water supply.—(Bull. **12**, 89.) Analysis 27965.

KEMPTON. Water supply.—(Bull. **14**, 45.) Water for a public supply is obtained from a well 404 feet deep. The static water level is thought to be at a depth of 80 feet. Pumping at a rate estimated at 8 gallons a minute, it is thought that the water level is at times drawn down to the pump cylinder at a depth of 318 feet. Analysis 35950.

KENILWORTH. Water supply.—(Bull. **9**, 24; **13**, 88.)

KEWANEE. Water supply.—(Bull. **10**, 130.) Water for a public supply is obtained from wells from 1,400 to 1,500 feet deep which penetrate St. Peter sandstone. A 30-hour test on a well was reported to have yielded 150 gallons a minute with a lowering of the water level from 246 feet to 494 feet below the ground surface. Pumping at the rate of 90 gallons a minute was reported as lowering the water level 42 feet. Analyses 14430, 24003, 24348, 25117, 25118. A well 2497 feet deep was completed in 1919. Analyses 41510, 41643.

KINCAID. Water supply—(Bull. **15**, 64.) Analysis 38725.

KIRKWOOD. Water supply.—(Bull. **10**, 131; **15**, 65.) Water for a public supply is obtained from a well in rock 127 feet deep. On a 24-hour test it yielded from 30 to 54 gallons a minute. Analyses 17953, 37606.

KNOXVILLE. Water supply.—(Bull. **9**, 25; **10**, 131; **12**, 90; **13**, 88.)

Water for a public supply is obtained from a well 1,350 feet deep, cased to a depth of 1,066 feet. The lower 170 feet is in St. Peter sandstone. When the well was installed it was pumped for 32 hours at a rate of 150 gallons a minute. Analyses 22862, 23591, 23592.

KNOXVILLE. Sewage disposal.—(Bull. **12**, 90.)

LACON. Water supply.—(Bull. **12**, 91.) Analysis 27430.

LADD. Water supply.—(Bull. **11**, 84; **12**, 91; **13**, 88.) Visited May 7, 1918. Water for a public supply is obtained from a 6-inch well 187 feet deep. No important changes have been made since 1915. In 1913 the supply was thought to be contaminated by seepage into a collecting reservoir or through a connection with a private mine supply. Different mineral content of water from well and reservoir is shown by analyses. Analyses 24755, 24756, 30879, 39454.

LAGRANGE. Water supply.—(Bull. **13**, 89.) Visited August 5, 1918. Water for a public supply is obtained from wells, each about 2,000 feet deep, which terminate in Potsdam sandstone. The capacity of one well, 16 inches in diameter at the top and 6 inches in diameter at the bottom, cased to a depth of 180 feet, and equipped with a pump placed at a depth of 90 feet with suction pipe 30 feet long, was said to be 1,020 gallons a minute in 1915. Analyses 15475, 17115, 39919.

LAGRANGE. Sewage-treament plant.—(Bull. **10**, 134.)

LAGRANGE PARK. Water supply.—(Bull. **13**, 90.)

LAHARPE. Water supply.—(Bull. **12**, 92.) Analysis 27583.

LAKE BLUFF. Water supply and sewerage.—(Bull. **9**, 25; **10**, 135.)

LAKE FOREST. Water supply.—(Bull. **9**, 25; **12**, 93; **13**, 90.)

Sewage disposal.—(Bull. **9**, 25; **11**, 85.)

LAKE ZURICH. Water supply.—(Bull. **13**, 90.) Analysis 30607.

LAMOILLE. Water supply.—(Bull. **14**, 46.) Water for a public supply is obtained from a well in drift 268 feet deep, 8 inches in diameter at the top and 6 inches at the bottom. The static water level is at a depth of 137 feet. Pumping 1½ hours at a rate of 30 gallons a minute lowered the water level 3½ feet. Analysis 35619.

LANARK. Water supply.—(Bull. **11**, 85.) Analysis 26312.

LAROSE. ' Proposed water supply.—(Bull. **13**, 91; **15**, 65.) A 4-inch well, 28 feet deep, obtaining water from an 8-foot stratum of gravel was said to have been pumped at a rate of 24 to 25 gallons a minute without appreciably lowering the water level. Analysis 30103.

LASALLE. Water supply.—(Bull. **11**, 86.) Visited May 7, 1918. Water for a public supply is obtained from three dug wells, 38 to 40 feet deep, located on bottom land near Illinois River. The static water level varies with the stage of the river. Approximately 2,300 service connections are in use of which all but 6 are metered. The consumption averages about 1,500,000 gallons a day. Analysis 39458.

LASALLE. Investigation of the pollution of two deep wells.—(Bull. **9**, 25.)

LAWRENCEVILLE. Water supply.—(Bull. **9**, 25; **11**, 86; **12**, 93; **13**, 91.) Analyses 29295, 36068.

Pollution of Embarrass River and Indian Creek by oil.—(Bull. **14**, 46.)

LEAF RIVER. Proposed water supply.—(Bull. **12**, 94.)

LE CLAIRE. Typhoid fever.—(Bull. **11**, 87.)

LEE. Water supply.—Visited June 4, 1919. A public water supply was installed by a private company. In 1904 the village acquired possession of the waterworks and drilled a well 335 feet deep in drift, which has since been the source of supply. The upper part of the well is 6 inches and the lower part is 4½ inches in diameter. It is equipped with a deep-well pump with cylinder at a depth of 234 feet. At the normal rate of operation the displacement is 46 gallons a minute. The pump discharges directly into the the distribution system to which a steel pressure tank is connected. Nearly all residents use water from the public supply.

The water is of good sanitary quality. It has a mineral content of 274, a total hardness of 150, and a content of iron of 0.4 parts per million. Analysis 41149.

LELAND. Water supply.—(Bull. **12**, 95; **13**, 91.) Analysis 28448.

LEMONT. Water supply.—(Bull. **14**, 49.) Water for a public supply is obtained from two wells, one 4 inches in diameter, 1,300 (?) feet deep, and the other 12 inches in diameter at the top, 6 inches at the bottom, and over 2,000 feet deep. The natural flow from the shallower well was sufficient to supply demands for some time. This well, equipped with air lift pipe extending to a depth of 100 feet, furnishes 35 or 40 gallons a minute. The deeper well is equipped with a deep well pump of 160 gallons a minute capacity with cylinder at a depth of 85 or 90 feet. Analyses 36036, 36031.

LENA. Water supply.—(Bull. **11**, 88.) Analysis 26416.

LEONORE. Water supply.—(Bull. **15**, 65.) Analysis 38595.

LEROY. Water supply.—(Bull. **10**, 136; **15**, 66.) Water for a public supply is obtained from three wells, from 79 to 81 feet deep, in drift. One is 8, another 10, and one 12 inches in diameter. The wells are equipped with deep-well pumps with bottoms of suction pipes at depths of 62, 76, and 75 feet respectively. The yields are given as 100, 200 and 360 gallons a minute respectively. When not pumping, water stands at a depth of 25 feet.

LEWISTOWN. Water supply.—(Bull. **12**, 95; **15**, 66.) Analysis 27446.

LEXINGTON. Water supply.—(Bull. **12**, 96; **15**, 66.) Analysis 27569.

LIBERTYVILLE. Water supply.—(Bull. **10**, 137; **15**, 66.) Analysis 38318.

LINCOLN. Sewerage.—(Bull. **12**, 96.)

State School and Colony. Water supply.—(Bull. **12**, 97; **13**, 92.)

Sewage disposal.—(Bull. **12**, 97.)

Sanitary condition of water supply.—(Bull. **14**, 50.) Analyses 16757, 21825, 36312.

LITCHFIELD. Water supply.—(Bull. **9**, 26; **10**, 141; **11**, 89; **13**, 92.) Analysis 21701.

Typhoid fever conditions.—(Bull. **11**, 90.)

LITTLE YORK. Water supply.—(Bull. **13**, 92; **15**, 67.) Visited July 3, 1918. Water for a public supply is obtained from a 6-inch well 400 feet deep in drift. The well yields about 35 gallons a minute.

The surroundings are not in good sanitary condition. A sample of water was not of good quality. The water has a mineral content of 1,530 a total hardness of 95 and a content of iron of 0.4 parts per million. Analysis 39773.

LOCKPORT. Water supply.—(Bull. **13**, 93.) Water for a public supply is obtained from a well 1,650 feet deep, 10 inches in diameter at the top and 5 inches in diameter at the bottom. It was drilled to a depth of 1,922 feet, and was plugged at a depth of 1,650 feet to exclude salt water. St. Peter sandstone was encountered between depths of 630 and 860 feet and Potsdam sandstone was entered at a depth of 1,310 feet. When drilled in 1896,water flowed from the well at a rate of 275 gallons a minute. In 1915, equipped with air lift, it yielded 160 gallons a minute with a lowering of the water level of about 100 feet Analysis 30866.

LOCKPORT. Inspection of private well.—(Bull. **13**, 93.)

Pollution of Illinois River by Chicago Drainage Canal. (Bull. **9**, 26.)

LOMBARD. Water supply.—Visited December 13, 1918. A public water supply was installed in 1910. Water is obtained from an 8-inch well 93 feet deep, the upper 60 feet in drift. The static water level is at a depth of 12 feet. An electrically-driven centrifugal pump of 450 gallons a minute capacity with suction pipe extended to a depth of 41 feet below the ground surface is operated 1½ hours a day. A 60,000-gallon elevated steel tank is connected to the distribution system. Analysis 38895.

LONDON MILLS. Water supply.—(Bull. **13**, 94.)

LOSTANT. Water supply—(Bull. **11**, 90.) Visited May 6, 1918 Water for a public supply is obtained from a well 5 feet in diameter, 70 feet deep in drift. The static water level is at a depth of 35 feet. About three days of intermittent pumping was required to fill an elevated tank of 50,000 gallons capacity. Forty-three service connections are in use and the consumption averages about 2,600 gallons a day.

The water is of good sanitary quality. It has a mineral content of 555, a total hardness of 153, and a content of iron of 0.1 parts per million. Analysis 39439.

LOUISVILLE. Water supply.—(Bull. **14**, 50.)

LOVINGTON. Water supply.—(Bull. **12**, 97; **15**, 67.) Analysis 27063.

LOW POINT. Water supply.—(Bull. **15**, 68.) Analysis 37925.

LYONS. Water supply.—(Bull. **13**, 94; **14**, 50.) Visited August 6, 1918. Water for a public supply is obtained from a well 1,650 feet deep. Water may be secured from Berwyn at times when the demand is greater than the yield of the well.

The water is of good sanitary quality. It has a mineral content of 580 and a total hardness of 415 parts per million. It contains no iron.

McHENRY. Water supply.—(Bull. **9**, 27.) Visited August 22, 1918. Water for a public supply is obtained from a 6-inch flowing well 71 feet deep. The lower 16 feet is in coarse gravel. An odor of hydrogen sulphide is noticeable in the vicinity of the well. Analysis 40039.

McLEAN. Proposed water supply.—(Bull. **13**, 94.)

McLEANSBORO. Water supply.—(Bull. **10**, 147; **12**, 98; **13**, 95.)

MACKINAW. Water supply.—(Bull. **12**, 98.) Visited November 3, 1919. The waterworks is now municipally owned. The supply is obtained from two wells in drift, spaced 10 feet apart, each 172 feet deep. One well is 4 inches and the other is 5 inches in diameter. The static water level is at a depth of 46 feet. The wells are equipped with deep-well pumps with cylinders at a depth of 157 feet. The pump in the larger well is of 60 gallons a minute capacity and is generally operated 9 or 10 hours a day.

The distribution system has been extended and now includes 2.75 miles of mains, 26 fire hydrants, and 180 service connections.

The water is of good sanitary quality. It has a mineral content of 536, a total hardness of 455, and a content of iron of 1.7 parts per million. Analysis 28505.

MACOMB. Water supply.—(Bull. **9**, 26; **12**, 99.)

MACON. County Almshouse. Sewage disposal.—(Bull. **11**, 90.)

MALTA. Water supply.—(Bull. **15**, 68.) Water for a public supply is obtained from a 10-inch well 795? feet deep. It is equipped with a deep well pump of 92 gallons a minute capacity with the bottom of suction pipe on the cylinder at a depth of 148 feet. It operates about 3 hours a day. The static water level is at a depth of 100 feet. Analysis 38022.

MANHATTAN. Water supply.—(Bull. **15**, 68.) Analysis 38552.

MANSFIELD. Proposed water supply.—(Bull. **12**, 100.)

MANTENO. Water supply.—(Bull. **12**, 100.) Visited March 5, 1918. Water for a public supply is obtained from wells 60 to 426 feet deep described in Bulletin 12. A test well was drilled north of the existing wells at a location selected by a water witch and was tested by pouring water into it. Analysis 27332.

MAPLE PARK. Water supply.—(Bull. **13**, 95.) Analysis 31118.

MARENGO. Water supply.—(Bull. **11**, 91.) Water for a public supply is obtained from a well 20 feet in diameter 14 feet deep. The static water level is at a depth of 7 feet. The maximum yield during dry periods is about 100,000 gallons a day. Analysis 26351.

MARION. Water supply.—(Bull. **10**, 142; **12**, 101; **13**, 95; **14**, 51; **15**, 69.) Water for a public supply is obtained from wells from 700 to 960 feet deep which enter rock at a depth of 50 feet. The yield of a well is said to be about 60 gallons a minute when first drilled, but the yield decreases. Analyses 23352, 26018, 2601,9, 26020, 26021, 26022, 38028. An investigation of water supply conditions with the object of improving; the supply is being made by the Central Illinois Public Service Company.

MARION. Sewage disposal.—(Bull. **12**, 101; **13**, 96; **14**, 51.)

MARISSA. Proposed water supply.—(Bull. **12**, 102.)

MARK. Water supply.—(Bull. **13**, 96.)

MAROA. Water supply.—(Bull. **10**, 143.) Visited August 18, 1919. Water for a public supply is obtained from three wells, each about 85 feet deep in drift. One was 8 inches and the other two 6 inches in diameter. They have been recased with pipe about inches smaller. The distribution system includes 2.5 miles of mains, 32 fire hydrants, and 232 service connections. All services are metered. About 160,000 gallons of water is pumped daily, a large part of which is thought to be lost by leakage.

The water is of good sanitary quality. Mineral analysis 22085.

MARSEILLES. Water supply.—(Bull. **9**, 26; **13**, 96.) Water for a public supply is obtained from two wells, spaced about 1,000 feet apart, 8 inches in diameter at the top, and 6 inches in diameter at the bottom, one 600 and the other 800 feet in depth terminating in the lower magnesian formation. Water from St. Peter sandstone has been cased off. In 1915 the 600-foot well, equipped with air lift with air pipe extending to a depth of 100 feet, yielded 67 gallons a minute continuously and the deeper well had a natural flow of 45 gallons a minute. Analysis 30868, 31623.

MARSEILLES. Pollution of Illinois River by Chicago Drainage Canal. —(Bull. **9**, 26.)

MARSHALL. Water supply.—(Bull. **12**, 102.) Visited January 7, 1918. Water for a public supply is obtained from a well in drift 6 feet in diameter and 27.5 feet deep located on bottom land of Big Creek. The static water level is at a depth of 12 feet. The amount of water pumped is estimated at 450,000 gallons a day. Analysis 38796. Water was formerly obtained from drilled wells 40 to 55 feet deep. Analysis 36284.

MARSHALL. Typhoid fever.—(Bull. **12**, 103.)

MARTINSVILLE. Proposed water supply.—Visited July 23, 1919. Three sources of supply for a public water supply might well be considered; 1. Wells in bottom land of North Fork; 2. Wells other than in bottom land; and 3. Streams.

The city of Casey secures water for a public supply from wells in bottom lands of North Fork located 2 miles from the city of Martinsville. With the exception of a high content of iron the water is of good quality.

Several deep wells have been drilled for water by private parties and many wells have been drilled for oil in the vicinity. Water is secured at depths of from 80 to 300 feet. Oil sand is encountered in places at a depth of less than 500 feet and salt water ,is also encountered at about the same depth and in deeper strata. The village of Westfleld secures a maximum of 8,000 gallons a day from an 8-inch well 155 feet deep.

A public water supply should be developed. Test wells should be drilled in bottom lands of North Fork near Martinsville to determine if sufficient water for a public supply may be obtained from such source. Tests should be made of yield of any existing wells in the city thought to have a yield of 20 gallons a minute or more with continuous pumping. Water from test wells or other wells which indicate large yield should be analyzed to determine the quality of the water.

MASCOUTAH. Water supply.—(Bull. **12**, 103.) Visited July 17, 1918. Water for a public supply is obtained from 9 drilled wells from 35 to 40 feet deep in drift. The static water level is 12 feet below the ground surface. The total maximum yield is about 50 gallons a minute. Analyses 19906, 39783. The original dug well has been abandoned.

MASON CITY. Water supply.—(Bull. **12**, 104.) Visited November 5, 1919. Water for a public supply is obtained from. 2 wells, one 200 and the other 198 feet deep in drift. One well is 10 inches in diameter at the top and 6 inches at the bottom. The other well is 12 inches in diameter. The static water level is at a depth of 60 feet. The wells are equipped with steamhead deep-well pumps which operate 10 to 12 hours a day. The consumption during last summer averaged 260,000 gallons a day.

The water is of good sanitary quality. It has a mineral content of 285, a total hardness of 270 and a content of iron of 0.8 parts per million. Analyses 21714, 42053.

MATTESON. Water supply.—(Bull. **12**, 105; **14**, 51.) Water for a public supply is obtained from a 10-inch well 282 feet' deep. It enters a rock at a depth of 82 feet. The static water level is at a depth of 14 feet. The well was tested by pumping for 8 hours at a rate of 200 gallons a minute. Analyses 29110,. 36185.

MATTESON. Proposed sewerage.—(Bull. **12**, 105.)

MATTOON. Water supply.—Visited June 24, 1918. A public water supply was installed in 1885 by the Mattoon Clear Water Company. Water is obtained from wells 60 to 90 feet deep which penetrate sand and gravel overlaid by blue clay. This supply is not adequate to meet all demands and in 1908 a supply, now owned by the city was installed to supply water for industrial purposes.

The well supply furnishes water to 1,367 consumers and supplies a demand of about 450,000 gallons a day. The distribution system includes 21.25 miles of mains and 235 fire hydrants. Many of the wells are constructed according to a patent by which the water bearing stratum may be operated under a vacuum. One well is arranged so that the space between the casing and a drop pipe serves as an air chamber. Analyses 33932, 34218, 39660, 39665.

The municipal plant includes an impounding reservoir on Little Wabash River about 7 miles southwest of Mattoon, a pipe line to the city, pumping stations at the impounding reservoir and in the city, a storage reservoir in the city, and a distribution system. The discharge from tile drainage of about 5 square miles of land is collected. When this is sufficient to supply demands it is not necessary to pump from the impounding reservoir.

MATTOON. Pollution of public water supply by improper disposal of city wastes.—(Bull. **10**, 144; **12**, 105.)

Proposed sewerage.—(Bull. **11**, 92.)

Microscopic survey of reservoir at Paradise near Mattoon.—(Bull. **14**, 52.)

MAYWOOD. Water supply.—(Bull. **10**, 146.) Analyses 28366, 39137.

MELROSE PARK. Water supply.—(Bull. **10**, 148.) Visited January 31, 1918. Water for a public supply is obtained from two wells, one 1,620 and the other 1,571 feet deep which enter the Potsdam formation. The 1,571-foot well is 15 inches in diameter at the top and 8 inches at the bottom. The deeper well is 15 inches in diameter at the top and 4% inches at the bottom. When drilled in 1898, the static water level was at a depth of 30 feet, and it yielded 600 gallons a minute. In 1918 the static water level was at a depth of 110 feet. The wells are operated by air lift and centrifugal pumps are used for high service. All equipment is electrically-driven. Analysis 21797.

MELVIN. Water supply.—(Bull. **13**, 97.) Analysis 30591.

MENARD. Southern Illinois Penitentiary. Water supply.—(Bull. **11**, 92.)

MENDOTA. Water supply.—(Bull. **11**, 93.) Analysis 31143.

Sewerage.—(Bull. **11**, 94.)

Treatment of gas-house wastes.—(Bull. **12**, 106; **13**, 97.)

MEREDOSIA. Pollution of Illinois River.—(Bull. **11**, 94.)

METAMORA. Water supply.—(Bull. **13**, 98.) Water for a public supply is obtained from a well 8 feet in diameter, 72 feet deep in drift. The static water level is at a depth of 30 feet. The well is pumped for two hours at a rate of 53 gallons a minute two or three times a week and the water level is lowered 20 feet.

METROPOLIS. Water supply—(Bull. **9**, 27; **11**, 94; **13**, 99; **15**, 69.) Analysis 18647.

MILAN. Water supply.—(Bull. **14**, 52.) Visited July 4, 1918. Water for a public supply is obtained from a 5-inch well 1,157 feet deep which penetrates St. Peter sandstone. When drilled in 1895 the pressure at the ground surface with no flow was 67 feet, and the discharge at the ground surface was 350 gallons a minute. In 1916 the flow at the ground surface during a test was 100 gallons a minute. Well casings are said to corrode in a few years. Analysis 39935.

MILFORD. Water supply.—(Bull. **11**, 95; **15**, 70.) Analysis 37411.

Sewerage.—(Bull. **11**, 95.)

Corn-canning wastes.—(Bull. **12**, 106.)

MILLEDGEVILLE. Water supply.—(Bull. **14**, 52.) Analysis 35532.

MINIER. Water supply.—(Bull. **14**, 53.) Analysis 36133.

MINONK. Water supply.—(Bull. **12**, 107; **15**, 70.) Analysis 28647.

Disposal of sewage.—(Bull. **12**, 107; **13**, 100.)

MINOOKA. Water supply.—(Bull. **11**, 95.) Visited December 8, 1919. Water for a public supply is obtained from a well 621 feet deep, cased to rock at a depth of about 124 feet. The well at the bottom is 6 inches in diameter. The static water level was at a depth of 00 feet in 1913 and is now at a depth of 78 feet. The well is equipped with a deep-well pump of 65 gallons a minute rated capacity with the bottom of suction pipe on the pump cylinder at a depth of 148 feet. Analysis 31690. A well 2,100 feet deep was formerly in use. When drilled in 1886 the static pressure at the ground surface was 90 feet and the flow at the ground surface was 100 gallons a minute. The flow is now 32 gallons a minute. Analysis 31633.

MINOOKA. Sewerage.—(Bull. **11**, 96.)

MOKENA. Water supply.—(Bull. **13**, 100.) Analysis 30861.

MOLINE. Water supply.—(Bull. **13**, 100.) Analyses 14366, 14367. .

Additional sewerage.—(Bull. **11**, 96.)

Sanitary survey of Mississippi River.—(Bull. **9**, 27.)

MOMENCE. Water supply.—(Bull. **11**, 97.) Visited August 24, 1918. Water for a public supply is obtained from four 8-inch wells from 85 to 135 feet in depth cased to rock. Analysis 40062. The wells are sometimes pumped 24 hours a day to supply demands.

The water is of good sanitary quality. It has a mineral content of 500 and a total hardness of 420 parts per million. It contains no iron.

MOMENCE. Sewerage.—(Bull. **11**, 97.)

MONEE. Water supply.—(Bull. **13**, 103.) Water for a public supply is obtained from two wells, one 6 inches in diameter and 166 feet deep, and the other 10 inches in diameter and 169 feet deep, cased to rock at a depth of 90 feet. The 166-foot well was pumped for three days at a rate of 60 gallons a minute. Analyses 30842, 30843.

MONEY CREEK TOWNSHIP. Typhoid fever.—(Bull. **13**, 104.)

MONMOUTH. Water supply.—(Bull. **10**, 149; **15**, 70.) Water for a public supply is obtained from three wells about 1,200 feet deep terminating in St. Peter sandstone. Pumping one well in 1910 at a rate of about 370 gallons a minute lowered the water level to 210 feet below the ground surface. Analyses 19141, 19249, 38284.

MONTGOMERY. Sewage disposal.—(Bull. **12**, 108.)

MONTICELLO. Water supply.—(Bull. **10**, 150; **12**, 109; **15**, 71.) Visited June 29, 1918. Water for a public supply is obtained from 4 wells from 209 to 309 feet in depth. The static water level is at a depth of about 25 feet. A 10-inch well with pump cylinder at a depth of 100 feet was pumped for 45 minutes at a rate of 167 gallons a minute. A 12-inch well 209 feet deep is equipped with a deep-well pump which operates at a displacement of about 380 gallons a minute. There are about 670 service connections and the consumption is about 200,000 gallons a day. Analyses 22075, 29331, 36982.

MORRIS. Water supply.—(Bull. **12**, 109.) Visited December 8, 1919. Water for a public supply is obtained from two wells 800 feet deep which penetrate St. Peter sandstone. Both are cased to rock at a depth of about 40 feet. The static water level is at a depth of 53 feet. An average demand of 270,000 gallons a day is supplied by one well, equipped with a centrifugal pump placed at a depth of 150 feet. The waterworks is now operated by the municipality. The distribution system includes more than 16 miles of mains and 1,100 service connections almost all of which are metered. Analyses 31600, 42262.

The water is of good sanitary quality. It has a mineral content of 400 and a total hardness of 300 parts per million. It contains no iron.

MORRIS. Pollution of Illinois River by Chicago Drainage Canal.—(Bull. **9**, 27.)

MORRISON. Water supply.—(Bull. **12**, 110.) Visited December 17, 1919. Water for a public supply is obtained from a spring and from two wells spaced 31 feet apart. One well 2,048 feet deep 12 inches in diameter at the top, and 6 or 6½ inches in diameter at the bottom, is cased to a depth of 437 feet and between depths of 751 feet and 916 feet, shutting off water from St. Peter sandstone. In 1914 the well flowed 85 gallons a minute into a collecting reservoir. The well is equipped with an air lift with air pipe extending to a depth of 175 feet. It yields from 750 to 800 gallons a minute. Analysis 28568.

A well was drilled in 1897 to a depth of 1,640 feet, the bottom in Potsdam sandstone. In 1910 it was 900 feet deep, about to the bottom of St. Peter sandstone. It is equipped with an air lift with 184 feet of air pipe and discharges 600 gallons a minute. The yield is limited by the capacity of a pipe from the well to the collecting reservoir. The spring yields sufficient water to supply the demand of 300,000 gallons a day during the winter. More than nine-tenths of the population use water from the public supply.

MORRISONVILLE. Water supply.—(Bull. **11**, 98.) Visited December 20, 1919. Water for a public supply is obtained from two wells about 500 feet apart, 16 feet in diameter and 35 feet deep. The maximum yield is probably less than 25,000 gallons a day. Analysis 24919.

MORTON. Water supply.—(Bull. **13**, 106.) Analyses 31620, 31621.

MORTON GROVE. Water supply.—(Bull. **14**, 54.) Water for a public supply is obtained from a well 1,468 feet deep, cased to a depth of 1,100 feet. The well is 10 inches in diameter to a depth of 125 feet and 8 inches in diameter at the bottom. It is equipped with a pump of 225 gallons a minute capacity with the bottom of the suction pipe on the cylinder at a depth of 128 feet. The static water level is at a depth of 74 feet. Analysis 36063.

MOUND CITY. Water supply.—(Bull. **13**, 106; **15**, 71.) Water for a public supply is obtained from a well 630 feet deep, cased with 8-inch pipe to a depth of 450 feet. In 1900 when the well was drilled there was a natural flow of 85,000 gallons a day. The maximum yield secured during pumping tests has been from 650,000 to **700,000** gallons a day. Analysis 30935.

MOUND CITY. Proposed sewerage.—(Bull. **13**, 107.)

MOUNDS. Water supply.—(Bull. **9**, 27; **11**, 98; **15**, 71.) Analyses 24815, 25109.

Sewerage and sewage-treatment plant.—(Bull. **13**, 107.)

MOUNT CARMEL. Water supply.—(Bull. **9**, 27; **12**, 111; **13**, 108.) Analysis 25692.

MOUNT CARROLL. Water supply.—(Bull. **11**, 100.) Analyses 18346, 26306.

MOUNT MORRIS. Water supply.—(Bull. **11**, 100.) Water for a public supply obtained from a well 500 feet deep, 10 inches in diameter at the top and 6 inches at the bottom which is drilled through St. Peter sandstone and terminates in limestone. The static water level is at a depth of 153 feet. The well is equipped with an air lift which operates 10 hours a day. The yield is 60 gallons a minute, and the water level is lowered 57 feet. Analysis 27327.

MOUNT OLIVE. Water supply.—(Bull. **10**, 151.) Analysis 21705.

MOUNT PULASKI. Water supply.—(Bull. **11**, 101; **12**, 113.) Water for a public supply is obtained from 3 wells each 32 feet deep in drift. Two of the wells are 8 feet and one is 10 feet in diameter. Water rises to within 6 feet of the ground surface. Pumping from the wells for two hours each day supplies a daily demand of about 30,000 gallons. An 8-inch well 52 feet deep in drift is available but seldom used. Analysis 25667.

MT. PULASKI. Sewerage.—(Bull. **12**, 113.)

MOUNT STERLING. Water supply.—(Bull. **11**, 102.) Visited January 23, 1918. Part of the water used for a public supply is obtained from ponds and part from a well 2,235 feet deep. The distribution system includes about 3 miles of 4, 6, and 8-inch pipe; 38 hydrants and 140 service connections. Analysis 38856.

MOUNT STERLING. Proposed sewerage.—(Bull. **11**, 101.)

MOUNT VERNON. Water supply.—(Bull. **10**, 152; **11**, 102; **12**, 113; **13**, 109.) Analyses 21908, 22993, 23143, 23145.

Microscopic survey of reservoir.—(Bull. **14**, 54.)

MOWEAQUA. Water supply—(Bull. **11**, 99.) Analysis 25670.

MURPHYSBORO. Water supply.—(Bull. **10**, 155; **11**, 103; **12**, 114; **13**, 109; **15**, 72.)

Microscopic survey of the source of the water supply.—(Bull. **15**, 74.)

NAPERVILLE. Water' supply.—(Bull. **13**, 109.) Water for a public supply is obtained from two wells, one 1,425 and the other 1,375 feet in depth. The deeper well, drilled in 1904 is 10 inches in diameter at the top and 6 inches in diameter at the bottom. It is cased to a depth of 118 feet and between depths of 773 and 939 feet. St. Peter sandstone is entered at a depth of 646 feet, and Potsdam sandstone is entered at a depth of 1,265 feet. When completed the water level was 51 feet below the ground surface and was lowered 28 feet by pumping at a rate of 108 gallons a minute. Analyses 22303, 30619.

NAUVOO. Water supply.—(Bull. **10**, 157.)

NEOGA. Water supply.—(Bull. **13**, 110.) Visited August 20, 1918. Water for a public supply is obtained from a well 15 feet in diameter, 16 feet deep. When the water level was lowered 2.5 feet water flowed into the well at a rate of 88 gallons a minute. It is thought that the daily consumption will soon amount to 100,000 gallons a day. It is recommended that test wells be drilled to a depth of 100 feet to determine the amount of water available from such source. Analyses 29699, 38814.

NEOGA. Proposed sewerage.—(Bull. **13**, 110.)

NEW ATHENS. Proposed water supply.—(Bull. **10**, 158.)

Microscopic and sanitary survey of the water supply.—(Bull. **15**, 74.)

NEW WINDSOR. Typhoid fever.—(Bull. **11**, 103.)

Proposed water supply.—(Bull. **11**, 104.)

NEWTON. Water supply.—(Bull. **10**, 159; **13**, 111.) In order to determine the amount of ground water available in bottom lands of Embarras River an 8-inch well was sunk to rock at a depth of 24 feet. The maximum yield was 11 gallons a minute. Analysis 31231.

NEWTON. Microscopic and sanitary survey of the water supply.—(Bull. **15**, 75.)

NILES CENTER. Water supply.—(Bull. **15**, 76.) Analysis 38315.

NOKOMIS. Water supply.—(Bull. **11**, 105.) Analysis 24913.

Proposed sewerage and sewage treatment.—(Bull. **12**, 114.)

NORMAL. Water supply.—(Bull. **10**, 159; **14**, 55.) Water for a public water supply is obtained from four wells. Two wells, one 6 and the other 8 inches in diameter, 180 feet deep, are each equipped with deep-well pumps of 250 gallons a minute capacity. A 12-inch well 204 feet deep, and a 15-inch well 215 feet deep, are generally used. Each is equipped with a centrifugal pump of 600 gallons a minute capacity. The static water level is at a depth' of 135 feet. About 700,000 gallons is pumped daily. Analyses 23299, 32849, 32851.

NORTH CHICAGO. Sewerage.—(Bull. **9**, 28; **11**, 105; **12**, 115; **13**, 112.)

NORTH CRYSTAL LAKE. Water supply.—(Bull. **12**, 116.) Analysis 26365.

OAKLAND. Water supply.—(Bull. **12**, 116.) Visited June 27, 1918. Water for a public supply is secured from two 6-inch wells 10 feet apart, one 95 and the other 115 feet deep, cased to rock at a depth of 45 feet. The static water level is at a depth of 30 feet. The wells are equipped with electrically-driven deep-well pumps. The average daily water consumption is 8,600 gallons.

A sample of water collected was not of good sanitary quality. The water has a mineral content of 545, a total hardness of 268, and a content of iron of 0.8 parts per million. Analyses 21929, 39675.

OAK PARK. Water supply.—Water for a public supply, from Lake Michigan, is purchased from the city of Chicago. Wells formerly in use secured water from Potsdam sandstone. Flows of about 300 gallons a minute have been secured from individual wells. Analyses 17804, 17805.

OAK PARK. Typhoid fever.—(Bull. **13**, 112.)

OBLONG. Proposed water supply.—(Bull. **13**, 112.)

ODELL. Water supply.—(Bull. **12**, 116; **13**, 113.) Water for a public supply is obtained from a well 1,360 feet deep, cased to St. Peter sandstone at a depth of 1,000 feet The water is aerated to remove hydrogen sulphide. Analysis 24969.

ODELL. Test of operation of apparatus for removal of hydrogen sulfide from the water supply. (Bull. **14**, 56.)

O'FALLON. Water supply.—(Bull. **15**, 76.) Visited July 19, 1918. Water is secured from a well 8 feet square and 50 feet deep, the lower part in fine sand. A cover has been placed on the well, and a drain from a pump pit which formerly entered the well has been closed. Analysis 39788.

OGLESBY. Water supply.—(Bull. **11**, 115; **13**, 118; **15**, 77.) Water for a public supply is obtained from a well 14 inches in diameter at the top, 8 inches at the bottom, and 1,645 feet deep. In 1915 the static water level was at a depth of 105 feet. A pumping test lasting 13 hours showed a yield of 350 gallons a minute. Since that test the pump cylinder has been lowered to a depth of 280 feet below the ground surface and when pumping 175 gallons a minute in 1917 water stood 188 feet below the ground surface. Analysis 37098.

OHIO. Water supply.—(Bull. **14**, 57.) Water for a public supply is secured from two wells about 38 feet apart, one 385 and the other 388 feet deep. When pumping 30 gallons a minute from one well in 1916 water stood in the other well at a depth of 260 feet. Analysis 35618.

OLNEY. Water supply.—(Bull. **11**, 106.)

Sewerage and sewage disposal.—(Bull. **12**, 117.)

Microscopic and sanitary survey of the water supply.—(Bull. **15**, 78.)

ONARGA. Water supply.—(Bull. **11**, 107; **15**, 79.) Visited August 13, 1918. Water for a public supply is obtained from three 6-inch wells from 105 to 115 feet in depth. The distribution system has been extended by the addition of one mile of mains.

The water is of good sanitary quality. It has a mineral content of 930, a total hardness of 600, and a content of iron of 1.7 parts per million. Analyses 13946, 39950.

ONARGA. Proposed sewerage.—(Bull. **12**, 118.)

OREGON. Water supply.—(Bull. **11**, 107.) Water for a public supply is obtained from a 10-inch well 1,610 feet deep. Pumping from the well in 1913 with pumps of 1,100,000 gallons a day capacity lowered the water 5 feet. Analyses 14431, 26429.

OREGON. Pollution of creek by wastes from a silica sandwashing plant. —(Bull. **13**, 113.)

OSWEGO. Water supply.—(Bull. **15**, 79.) Aanlysis 31106.

OTTAWA. Water supply.—(Bull. **9**, 28.) Visited October 15, 1918. Water for a public supply is obtained from four wells equipped with air lifts which discharge into two collecting reservoirs. Water is pumped from the reservoir into the distribution system by either of two compound duplex steam pumps. A standpipe located on high ground near the southern limits of the city is connected to the distribution system. The wells are 6 inches in diameter and 1,200 feet deep. One was drilled to a depth of 1,449 feet but the lower part was plugged off as the water was salty. Air pipes extend to a depth of 200 feet The air lifts in all four wells operate 18 hours a day to supply a daily demand of 800,000 gallons.

It would be of advantage to secure information in regard to water levels when pumping from different wells in order to secure information in regard to size and spacing of wells for future development.

PALATINE. Water supply.—(Bull. **12**, 119; **15**, 79.) Analyses 17941, 37351.

Sewage treatment.—(Bull. **10**, 161; **12**, 119.)

PANA. Water supply.—(Bull. **9**, 29; **10**, 161; **13**, 114.) Water for a public supply is secured from an impounding reservoir. Water was formerly secured from wells penetrating about 15 feet of loam and 35 feet of water-bearing sand. Analysis 22086.

PANA. Pollution of a tributary of Beck Creek.—(Bull. **13**, 115.)

Sewage disposal.—(Bull. **12**, 120; **13**, 115.)

Typhoid fever epidemic—(Bull. **12**, 120; **14**, 57.)

PARIS. Water supply.—(Bull. **10**, 164.) Analysis 22890.

PARK RIDGE. Water supply.—Water for a public supply, from Lake Michigan, is purchased from the city of Chicago. Waterworks were installed in 1890 and until recently the supply was taken from wells. In 1890 the static water level of a well 1,580 feet deep was 15 feet above the ground surface. Two wells one 1,425 and the other 1,806 feet deep, furnished the supply for a number of years. Analysis 30005.

PARK RIDGE. Typhoid fever.—(Bull. **13**, 116.)

PAW PAW. Water supply.—(Bull. **14**, 59.) Water for a public supply is obtained from a well 1,018 feet deep, cased to rock at a depth of 454 feet and in St. Peter sandstone from a depth of 885 feet to the bottom. Analysis 33304.

PAXTON. Water supply.—(Bull. **10**, 165; **15**, 79.) Analysis 37140.

PEARL. Water supply.—(Bull. **12**, 120.) Visited July 20, 1918. Water for a public supply is obtained from a spring with a flow, at time of measurement, of 72,000 gallons a day. A pump operated by a gasoline engine has been installed for use at times when the hydraulic ram, which is regularly used does not supply sufficient water. The distribution system includes 1.6 miles of mains from one-half to three inches in diameter and 80 service connections. Analysis 39792.

PEARL. Pollution of Illinois River.—(Bull. **11**, 108.)

PEARL CITY. Water supply.—(Bull. **14**, 60.) Analysis 35546.

PECATONICA. Water supply.—(Bull. **11**, 108; **13**, 116; **15**, 80.) Analysis 26343.

PEKIN. Water supply.—(Bull. **10**, 166.) Visited October 29, 1919. Water for a public supply is obtained from wells in sand, each about 60 feet deep from the bottom of a pit which is twenty feet below the ground surface. Wells within a radius of about 12 feet are pumped fifteen hours a day to supply a demand of 800,000 gallons. The water level is lowered about one foot. Analyses 14548, 25282, 25625, 36259, 40586.

PEKIN. Pollution of Illinois River by Chicago Drainage Canal.—(Bull. **11**. 108.)

PEORIA. Water supply. (Bull. **9**, 29; **11**, 109.) Visited February 26, 1918. Water for a public supply is obtained from wells in sand and gravel in low lands near Illinois River. The main well, 34 feet in diameter and 40 feet deep, from which the high service pumps draw, furnishes sufficient water to supply demands during wet months. In the main well, outside of a large strainer with which it is equipped are four auxiliary wells 4 by 5 feet extending to hardpan, a depth of 19 feet. Each is equipped with a motor-driven pump which discharges into a suction tank in the well. Connected to the main well is a reserve well 12 feet in diameter and 40 feet deep. This is located in pump house No. 2.

Well No. 7, located about 3 miles north of the pumping station is 90 feet deep and has a steel strainer 7 feet in diameter and 24 feet long. It is equipped with an 8-inch centrifugal pump driven by a 60-horsepower electric motor. Well No. 8 is similar to well No. 7 and is about 600 feet distant. Other wells available are very seldom used.

The main well yields from 4 to 5 million gallons a day, and wells No. 7 and 8 yield from 3 to 3½ million gallons a day each.

The main well and pumping station are located about 3 miles northeast of the center of the city. There are four vertical high service pumps, three of 7,200,000 gallons and one of 10,000,000 gallons daily capacity. A reservoir of about 19,000,000 gallons capacity is connected to the distribution system. Analyses 25987, 25988, 25989, 25990, 25991, 25992.

PEORIA. Microscopic survey of reservoir.—(Bull. **14**, 60.)

State Hospital. Water supply.—(Bull. **10**, 166.)

PEORIA HEIGHTS. Water supply.—(Bull. **9**, 29; **10**, 166; **11**, 109.)

PEOTONE. Water supply.—(Bull. **11**, 109.) Visited August 8, 1918. Water for a public supply is obtained from a 10-inch well 135 feet deep in drift. The well yielded 210 gallons a minute for 4 hours during a fire in 1913.

The water is of good sanitary quality. It has a mineral content of 600, a total hardness of 427 and a content of iron of 0.9 parts per million.

PERU. Water supply.—(Bull. **11**, 109; **13**, 116.) Water for a public supply is obtained from flowing wells from 1,200 to 1,500 feet deep. Records of one well show that salt water was encountered at depths of 595 feet and 700 feet, and St. Peter sandstone was entered at a depth of 1,360 feet. Each well is cased to a depth of 900 feet or more. When drilled one well 1,254 feet deep had a flow of 448,000 gallons a day and another of about the same depth, a flow of 280,000 gallons. The cholrine content in one well increased, probably on account of a leaky casing. Analyses 23735, 26735, 30894.

PETERSBURG. Water supply.—(Bull. **10**, 167; **14**, 61.) Analysis 24286, 21719.

PINCKNEYVILLE. Water supply. (Bull. **11**, 110.) Analysis 24720.

PIPER CITY. Water supply.—(Bull. **11**, 111; **12**, 122; **15**, 81.) Visited February 6, 1918. Water for a public supply is obtained from three wells 70 feet deep in drift, one 6-inches and two 8-inches in diameter. A demand of about 6,000 gallons is supplied by pumping from the wells for two or three hours a day. The supply is used by about one-third of the population.

The water is of good sanitary quality. It has a mineral content of 440, a total hardness of 380, and a content of iron, of 0.6 parts per million. Analysis 38926.

PITTSFIELD. Water supply.—(Bull. **11**, 111.) Visited July 20, 1918, and October 20, 1919. Water for a public supply is obtained from a deep well, originally 2,200 feet deep, and cased to a depth of about 275 feet. A few years ago a bar could be lowered to a depth of 600 feet. The water is not in general use for drinking. Analysis 39791. City officials wish to furnish a water of better quality.

Several private supplies are secured from wells in rock. One well, 6-inches in diameter, 98 feet deep with pump cylinder at a depth of about 60 feet, will furnish 75 to 100 pails of water and the water level is said to rise rapidly after this amount of water is withdrawn. The water is of much better quality than that from the city supply. Analysis 41968. A highly mineralized water is secured from a well 33 feet deep. At a school house a well thought to be 325 feet deep, yields less than 1,200 gallons a day.

In 1895 test wells were sunk in bottom lands of Bay Creek. They penetrate 8 feet of loam and about 20 feet of sand. Water was secured which was of good quality with the exception of a high content of iron. It may be possible to develop a public water supply from wells in bottom lands of Bay Creek, deep wells, such as the present city well, wells about 100 feet deep, springs or streams.

Test wells should be sunk in the bottom lands of Bay Creek and Panther Creek near their junction. When a good water bearing stratum is located, a well of at least 6 inches in diameter should be sunk to test for yield and quality of water.

A more thorough test of yield of well about 100 feet deep should be made, if there is any evidence of any such well yielding a fair quantity of water.

No large springs were seen during the visit and no springs of any considerable flow close to the city were reported. However, if it is thought that some springs might yield sufficient water, measurement of flow of such spring should be made and the expense involved would not be great.

Should supplies from other sources prove inadequate, a public water supply should be developed using water from a stream as the source of supply.

PITTSFIELD. Disposal of sewage at high school.—(Bull. **13**, 117.)

PLAINFIELD. Water supply.—(Bull. **11**, 112; **15**, 81.) Water for a public supply is obtained from a well 1,380 feet deep. Analysis 37339. Water was formerly obtained from a well 101 feet deep, cased with 9-inch pipe to rock at a depth of 20 feet and 6 inches in diameter in rock. The static water level was a depth of 18 feet. The well yielded 100 gallons a minute. Analysis 17878.

PLAINFIELD. Sewage disposal.—(Bull. **12**, 122.)

PLANO. Water supply.—(Bull. **9**, 29; **15**, 81.) Analysis 38019.-

Sewerage and sewage disposal.— Bull. **12**, 122.)

PLEASANT HILL. Typhoid fever.—(Bull. **11**, 113.)

POAG. Water supply.—Water for the public supply of Edwardsville is secured from a well located at Poag. The well is 28 inches in diameter and 70 feet deep in drift. It is cased with porous concrete. The well yields 600 gallons a minute for 18 or 20 hours a day and the water level is lowered 16 feet to a depth of 39 feet below the ground surface. Water was formerly secured from wells of small diameter in the same locality. Analyses 15373, 27760.

POLO. Water supply.—(Bull. **11**, 113.) Water for a public supply is secured from 2 wells, which enter Potsdam sandstone. One is 10 inches in diameter at the top, 4 inches at the bottom, and 2,100 feet deep; the other is 15 inches in diameter at the top, 8 inches at the bottom, and 1,200 feet deep. Both are cased to a depth of 200 feet. Water stood 70 feet from the ground surface in 1891 when the first well was drilled and in 1914 at a depth of 114 feet. The maximum yield of each well in 1914 with the bottom of suction pipe on the pump cylinder in the deeper well at a depth of 164 feet, and in the shallower well at 175 feet, did not exceed 160 gallons a minute. Analysis 26266.

PONTIAC. Water supply.—(Bull. **9**, 30; **11,** 113; **13,** 117.)

Sewage disposal.—(Bull. **12,** 123.)

Microscopic and sanitary survey of the water supply.—(Bull. **15**, 82.)

POPLAR GROVE. Water supply. A public water supply was installed by the municipality in 1915. Water is obtained from a 6-inch well 130 feet deep in drift. It is equipped with an electrically-driven, deep-well pump which discharges into the distribution system to which a steel pressure tank is connected. The distribution system covers practically the entire built-up portion of the village. Twenty-four service connections have been made. There are private wells in the village from which water is secured for industrial purposes entering the same water-bearing stratum. Two wells, one 115 and the other 125 feet deep, supply a demand durng the summer of perhaps 80,000 gallons a day.

The water is of good sanitary quality. It has a mineral content of 390, a total hardness of 360, and a content of iron of 0.3 parts per million. Analysis 40945.

PORTLAND. (see Oglesby):

PRINCETON. Water supply.—(Bull. **12,** 124.) Water for a public supply is obtained from wells. One well, 20 inches in diameter, 245 feet deep, in drift, was pumped for 7½ days in 1914. Pumping at a rate of 640 gallons a minute lowered the water level 5 feet. The well is equipped with a centrifugal pump of 620 gallons a minute capacity which operates about 6 hours a day. During pumping the water level is lowered about four feet to a depth of 162 feet.

For many years a suply was obtained from two wells, one 2,550 and the other 2,092 feet deep. The capacity of the 2,092-foot well with 4⅝-inch casing to a depth of 1,000 feet was given as 320 gallons a minute in 1899. Both wells yielded a total of 300 gallons a minute in 1914 and 150 gallons a minute in 1919. Analyses 19261, 22860, 22861.

PRINCETON. Sewage disposal.—(Bull. **12,** 125.)

PRINCEVILLE. Water supply.—(Bull. **11,** 116; **12,** 126; **15**, 83.) Analysis 37916.

PROPHETSTOWN. Water supply.—(Bull. **14**, 61.) Analysis 36193.

QUINCY. Water supply.—(Bull. **9**, 30; **11,** 116; **12,** 126.) Analysis 14271, 14272.

RANKIN. Water supply.—(Bull. **13,** 118; **14**, 62; **15**, 83.) Visited June 29, 1918. Water for a public supply is obtained from an 8-inch well 270 feet deep in drift. The static water level is at a depth of 35 feet. During a 15-hour test the maximum yield was from 60 to 70 gallons a minute and the water level was drawn down to a depth of 249 feet. The equipment includes a 5-inch by 6-inch triplex service pump, a 6½-inch by 8-inch triplex fire pump, a concrete reservoir 30 feet in diameter and ten feet deep, a steel pressure tank 8 feet in diameter and 36 feet long, and a distribution system. All pumps are electrically driven. The steel tank was tested at a pressure of 125 pounds. The distribution system includes 3.5 miles and 4, 6 and 8-inch pipe; 82 valves; and 41 hydrants. The leakage in the system, at first very great, was reduced to 143 gallons an hour at 125 pounds pressure, a rate of **140** gallons per mile per day per inch diameter of pipe. Analysis 34920.

RANKIN. Proposed sewerage.—(Bull. **11**, 117; **12**, 127.)

RANTOUL. Water supply.—(Bull. **10**, 168; **15**, 83.) Visited February 4, and April 15, 1918. Water for a public supply is obtained from three wells in drift. Two, spaced about 16 feet apart, are 10 inches in diameter and 120 feet deep and one, midway between the other two, is 10 inches in diameter and 141 feet deep. The water level when not pumping is 60 feet below the ground surface. The shallower wells yielded a maximum of about 250,000 gallons a day. The 140-foot well is equipped with a deep well-pump of 200 gallons a minute capacity with bottom of 30-foot suction pipe 123 feet below the ground surface. The water consumption in the city is about 120,000 gallons a day and at Chanute Field, which was also supplied, the demand was, at times, as great. Analysis 38907.

RANTOUL. Chanute Field. Water supply.—(Bull. **15**, 84.)

Sewerage.—(Bull. **15**, 84.)

RED BUD. Water supply.—(Bull. **12**, 127; **13**, 119.) Visited July 18, 1918. Water for a public supply is obtained from a well 294 feet deep which enters rock at a depth of 18 feet. The well is cased to a depth of 246 feet. It is equipped with a deep-well pump of 150 gallons a minute capacity with cylinder placed at a depth of 245 feet. The cylinder was lowered but brought back to the 245-foot depth. The yield does not exceed 50 gallons a minute. Analysis 39787.

The water is of good sanitary quality. It has a mineral content of 457, a total hardness of 233, and a content of iron of 0.3 parts per million.

REDDICK. Proposed water supply.—(Bull. **11**, 117.)

RIVERDALE. Water supply.—(Bull. **13**, 119.) Analyses 30853, 30854.

RIVER FOREST. Water supply.—(Bull. **10**, 169. Analyses 21792, 25995, 38534.

RIVERSIDE. Water supply.—(Bull. **11**, 118.) Analyses 26085, 26086.

ROANOKE. Water supply.—(Bull. **11**, 119; **13**, 120.) Water for a public supply is obtained from four 4-inch wells 30 feet deep in drift, located at the corners of a 30-foot square. Pumping from 45 to 50 gallons a minute from one well for one day lowered the water level in the other wells about 1 foot. Analyses 26788, 31555.

ROBERTS. Water supply.—(Bull. **13**, 120.)

ROBINSON. Water supply.—(Bull. **9**, 30; **12**, 127.) Analysis 22841.

ROCHELLE. Water supply.—(Bull. **11**, 120.) Visited June 2, 1919. Water for a public supply is obtained from two wells, one 1,026 and the other 1,980 feet deep. The 1,980-foot well equipped with an air lift with air pipe extending to a depth of 154 feet yields 280 gallons a minute. The static water level is 12 feet below the ground surface. The 1,026-foot well yields 500 to 700 gallons a minute. It is thought that the deeper well may be partly filled and that surface water may enter it. The total amount pumped per day from the two wells is estimated at from 600,000 to 800,000 gallons. Analyses 26387, 41220, 41221.

ROCHELLE. Sewerage.—(Bull. **11**, 120.)

ROCKDALE. Water supply.—(Bull. **13**, 125.) Water for a public supply is obtained from a 12-inch well 662 feet deep, cased to a depth of 260 feet. The upper 5 feet is in drift. The static water level is at a depth of 25 feet. The pump cylinder is placed at a depth of 50 feet. During a 24-hour test in 1915 the well yielded 160 gallons a minute. Analyses 29127, 30865.

ROCK FALLS. Water supply.—(Bull. **13**, 121.)

ROCKFORD. Water supply.—(Bull. **10**, 170.) Visited March 5, 1919. Water for a public supply is obtained from deep wells. Three wells drilled to Potsdam sandstone and five wells to St. Peter sandstone are connected by tunnels about 100 feet below the ground surface to a shaft in which pumps are located. With valves to 4 of the St. Peter wells closed, the yield with practically continuous pumping is from 2,600,000 to 2,900,000 gallons a day. Analyses 14176, 25189, 37400. Water is obtained also from 2 wells of large diameter, one of which is in the southeastern and the other in the northeastern part of the city. The two wells are similar in construction and each is equipped with an electrically-driven centrifugal pump. Each is capable of yielding for a few hours at a rate of over 2,000,000 gallons a day. The well in the northeastern part of the city is 22 inches in diameter at the top, 12 inches at the bottom and 1,502 feet deep. Pumping at a rate of 2,300,000 gallons a day for a few hours lowers the water level about 85 to 100 feet below the ground surface.

The average daily water consumption for the month of August, 1918, was 4,000,000 gallons. Increasing the supply by the installation of additional wells is recommended.

ROCKPORD. Water supply conditions at Camp Grant.—See Camp Grant.

ROCK ISLAND. Water supply.—(Bull. **9**, 30; **13**, 121.)

Disposal of gas wastes.—(Bull. **12**, 128, 225-8; **13**, 124.)

ROCK ISLAND. Arsenal. Water supply.—(Bull. **11**, 120; **13**, 125.)

ROODHOUSE. Water supply.—(Bull. **11**, 121.) Analysis 22157.

ROSEVILLE. Water supply.—(Bull. **15**, 85.) Visited July 3, 1918. Water for a public supply is obtained from a 6-inch well 1,350 feet deep, cased to a depth of 500 feet, and from a well penetrating an abandoned coal mine at a depth of 50 feet. Analyses 29784, 39695, 39696. The mineral content of the water from the deep well, comparatively low when not pumping, increases rapidly with pumping. Analyses 29191, 29491, 29783, 29784.

ROSEVILLE. Sewerage.—(Bull. **13**, 126.)

ROSSVILLE. Water supply.—(Bull. **10**, 172.) Analyses 20437, 20438, 23246.

RUSHVILLE. Water supply.—(Bull. **9**, 30; **12**, 128.) Analysis 24310.

ST. ANNE. Water supply.—(Bull. **13**, 126.) Analyses 17813, 30628.

Proposed sewerage.—(Bull. **11**, 122.)

ST. CHARLES. Water supply.—(Bull. **9**, 30; **12**, 129.) Visited August 11, 1919. Water for a public supply is obtained from 3 wells. One well, completed in February, 1919, is 20 inches in diameter at the top, 8 inches at the bottom, and 2,198 feet deep. Red marl was encountered at a depth of 830 feet, and 100 feet of casing was placed between depths of 830 and 930 feet. St. Peter sandstone lies between depths of 560 and 875 feet, and Potsdam sandstone was entered at a depth of 1,095 feet. Water was encountered at a depth of 65 feet, with a static head of about 40 feet; at a depth of from 85 to 90 feet, with a static head of about 20 feet; and at a depth of 335 feet, with a static head of about 10 feet. These waters were sealed off by the casing extending to a depth of 489 feet and below that depth the hole was dry until water from the St. Peter sandstone was encountered and rose to 31 feet from top of hole. Between depths of 1,180 and 1,185 feet the head dropped 3½ feet.

The well is equipped with a centrifugal pump with bottom of impeller at depth of 110 feet and 40 feet of suction pipe is attached to the bottom of the pump. On completion of the well it was tested by pumping 100,000 gallons into the reservoir and the yield was 555 gallons a minute. When not pumped for 48 hours water rises to within 14 feet of the ground surface. The pump is operated about 18 hours a day and the water level is lowered to more than 104 feet below the ground surface.

A second well is 8 inches in diameter and 350 feet deep. The static water level is 6 feet below the ground surface. The well yields about 120 gallons a minute with a pump cylinder 60 feet below the ground surface. Analysis 28354. A third well is 10 inches in diameter, 850 feet deep located on higher ground. The static water level is 40 feet below the ground surface and 40 feet above the water level in the 350-foot well. A deep-well pump of about 120 gallons a minute displacement with cylinder at a depth of 125 feet draws water down to within 10 or 15 feet of the cylinder. Analysis 28355.

ST. ELMO. Water supply.—(Bull: **10**, 174.)

ST. PETERS. Typhoid fever epidemic.—(Bull. **14**, 63.)

SALEM. Water supply.—(Bull. **11**, 123; **15**, 86.)

Sewerage.—(Bull. **11**, 123; **13**, 127; **15**, 87.)

Disposal of sewage from high school.—(Bull. **13**, 128.)

Microscopic and sanitary survey of reservoir.—(Bull. **15**, 86.)

SANDWICH. Water supply.—(Bull. **9**, 30; **12**, 130.) Analysis 23000.

Sewage treatment.—(Bull. **13**, 128.)

SANGAMON. County Poor Farm. Proposed sewage treatment.—(Bull. **11**, 123.)

SAN JOSE. Water supply.—(Bull. **12**, 131.) Visited November 5, 1919. Water for a public supply is obtained from two wells in drift equipped with deep-well pumps. A 6-inch well 105 feet deep was drilled in 1917. It is pumped 6 hours a day. The pump displacement is 90 gallons a minute. There are 75 service connections in use.

The water is of good sanitary quality. It has a mineral content of 526, a total hardness of 422, and a content of iron of 1.0 parts per million. Analyses 29169, 42051.

SAVANNA. Water supply.—(Bull. **11**, 124; **14**, 64.) Visited December 18, 1919. Water for a public supply is obtained from three flowing wells.

Well No. 1 was drilled in 1890. It is located on the same lot as the pumping station. It is 1,432 feet deep, 8 inches in diameter to a depth of 400 feet and 5 inches in diameter below that depth. The pressure at the ground surface was 30 pounds in 1890, 18 pounds in 1906, and 15 pounds in 1908. The yield through a pipe passing over the collecting reservoir wall, apparently recorded in 1908, was 260 gallons a minute.

Well No. 2 was drilled in 1908 about 1,700 feet distant from well No. 1, on ground 12 or 14 feet higher than at well No. 1. It is 1,443 feet deep, 13 inches in diameter at the top and 8 inches in diameter at the bottom. It is cased into stratum of sandstone which is encountered between depths of 348 and 468 feet and through 63 feet of shale limestone and marl which underlie this sandstone. In 1908 the static pressure was 14 pounds and the yield 500 gallons a minute.

Well No. 3 was drilled in 1917 about 300 feet distant from well No. 1 on ground about 7 feet lower than at well No. 1. It is 12 inches in diameter at the top, 8 inches in diameter at the bottom, and 1,852 feet deep. The well is cased with 12-inch pipe to a depth of 80 feet and from the ground surface to a depth of 880 feet with 8-inch pipe. The pressure at the ground surface outside of the 8-inch casing was 4½ pounds and inside the casing it was 11 pounds in 1917. The yield of the well, all from inside of the 8-inch casing was 312 gallons a minute in 1917.

Wells No. 1 and 2 supplied a demand of about 700,000 gallons a day in 1916. In 1919 the three wells yielded 959,000 gallons a day. Analysis 38519.

SEARS. Proposed water supply.—(Bull. **12**, 131; **13**, 129.)

SECOR. Water supply.—(Bull. **13**, 129.) Water for a public supply is obtained from 2 wells in drift, spaced 10 feet apart. One of the wells 8 inches in diameter, and 185 feet deep was pumped in 1915 for 32 hours at a rate of 60 gallons a minute. Analysis 31911.

SESSER. Proposed water supply.—Visited July 17, 1919. Water for a public supply may possibly be secured from wells in rock several hundred feet in depth, from wells in sand and gravel deposits, or from a stream. The amount of water used at residences may be estimated at about 25 gallons per person a day and water wasted, used in stores, offices, etc., and for public purposes will usually bring the total to at least 50 gallons per person per day. Allowance for mine, railroad or factory use should be made.

Water is secured at Carbondale from wells 400 feet deep in rock and at Marion from wells 700 feet or more in depth. These supplies are limited and the water is highly mineralized. A well was drilled at St. John's about 12 miles southwest from Sesser to a depth of 3,600 feet Water of good quality but in very limited quantity was reported at a depth of 311 feet. Salt water was encountered in various strata between depths of 520 and 2,271 feet. At a mine about a mile southeast of Sesser the depth to coal is 664 feet. The amount of water encountered in the mine is scarcely sufficient for use in sprinkling. At a mine a short distance north of the city a small quantity of water was encountered in sand rock at a depth of 160 feet. There is little probability that an adequate supply could be secured economically from deep wells in rock. Expenditure of money on such a project is not recommended.

Water is secured from sand and gravel deposits in bottom lands of streams at West Frankfort and at Valier. One well at West Frankfort, 24 inches in diameter with 18-inch screen, yielded 164 gallons a minute during a 24-hour test. Word has been received that the yield has greatly decreased. The yield of the well at Valier is now insufficient to supply the demands of the railroad company. A spring on the Moore farm is reported to have yielded 75 barrels of water a day. The tributary drainage area is small and it is doubtful if the spring would supply as much as 75 barrels of water a days for many days. Water from sand and gravel deposits may be too highly mineralized to be suitable for a public supply.

Water for a public supply can be secured from a stream. On a small drainage area it would be necessary to form a reservoir to store the water for use during times of small stream flow. If filtered in a carefully operated filtration plant the water would be suitable for domestic purposes. At McLeansboro, Harrisburg, Herrin and .Murphysboro filtered surface water is used. A reservoir from which water is used at a coal mine is reported to hold 70,000,000 gallons. It is more than sufficient to supply demands of the company. Whether or not the tributary drainage area is sufficient to supply a much greater demand is not known.

SHAWNEETOWN. Water supply conditions.—(Bull. **15**, 87.)

Flood conditions on Ohio River.—(Bull. **11**, 124.)

SHEFFIELD. Water supply.—(Bull. **12**, 131.) Analysis 28972.

SHELBYVILLE. Water supply.—(Bull. **11**, 125.) Visited July 15, 1918. Water for a public supply is obtained from wells in drift in bottom land near the bank of Kaskaskia River. A well 22 feet in diameter, 30 feet deep has an estimated capacity at 100,000 gallons a day. Two wells 12 feet in diameter were in process of construction. There are 936 consumers and the average daily consumption is over 300,000 gallons. Analyses 15895, 39029, 39741.

SHELDON. Water supply.—(Bull. **11**, 125.) Visited February 5, 1918. Water for a public supply is obtained from two wells, one 1,850 feet deep and the other, drilled in 1914, 6 inches in diameter and 130 feet deep in drift. The shallower well is equipped with an electrically-driven deep well pump. At the time of visit this well was furnishing the entire supply which was not sufficient to meet all demands.

The water from the 130-foot well is of good sanitary quality. It has a mineral content of 370, a total hardness of 150, and a content of iron of 0.3 parts per million. Water from the deep well is more highly mineralized but has a hardness of only 24 parts per million. Analyses 38916, 38917.

SHERMERVILLE. Water supply.—(Bull. **15**, 88.) Analysis 38339.

SILVIS. Water supply.—(Bull. **10**, 173.) Visited July 5, 1918. Water for a public supply is obtained from a flowing well 2,000 feet deep, cased to a depth of 900 feet. Analyses 24350, 39703.

SOMONAUK. Water supply.—(Bull. **13**, 129.) Water for a public supply is obtained from two 10-inch wells, one 190 feet deep in drift, and the other 500 feet deep, terminating in St. Peter sandstone. As equipped in 1915, the wells yielded 340 gallons a minute. Analysis 31758.

SOMONAUK. Stream pollution.—(Bull. **13**, 130.)

SOUTH BELOIT. Pollution of Turtle Creek.—(Bull. **13**, 130.)

SPARTA. Water supply.—(Bull. **12**, 132.) Waterworks were installed by the Sparta Gas and Electric Company, in 1908. The supply was secured from two small reservoirs and a well 400 feet deep. The well, cased with 5⅝-inch pipe, yielded 18,000 gallons a day. Analysis 32748. One well drilled to a depth of 450 feet yielded 3 gallons a minute. Analysis 24284. In 1915 an impounding reservoir and filtration plant was constructed.

SPARTA. Typhoid fever.—(Bull. **12**,, 132.)

Proposed sewerage.—(Bull. **14**, 64.)

SPRINGFIELD. Water supply.—(Bull. **9**, 31; **11**, 126; **11**, 208; **15**, 88.) Water for a public supply is obtained from a bed of gravel about 40 feet deep overlaid by about 10 feet of sandy loam. Part of the supply is collected in galleries about 20 feet below the ground surface. When the ground water is low, part of the supply is obtained from wells extending to the bottom of the water-bearing stratum. Analyses 23121, 36535.

SPRINGFIELD. Sanitary conditions of State Fair Grounds.—(Bull. **12**, 132.)

Pollution of Sangamon River.—(Bull. **13**, 131.)

SPRINGFIELD. Camp Lowden. Water supply.—(Bull. **15**, 89.)

SPRING VALLEY. Water supply.—(Bull. **11**, 126.) Analyses 23734, 26708.

Pollution of Illinois River.—(Bull. **11**, 126.)

STANDARD. Water supply.—(Bull. **15**, 89.) Analysis 38598.

STANFORD. Water supply.—(Bull. **13**, 131.) Analysis 31634.

STAUNTON. Water supply.—(Bull. **10**, 174; **13**, 132.) Analyses 13951, 21705.

Proposed sewerage and sewage disposal.—(Bull. **12**, 134.)

STEGER. Water supply.—(Bull. **12**, 134.) Visited August 7, 1918. Water for a public supply is obtained from a 12-inch well 318 feet deep, cased to a depth of 147 feet. Rock is encountered 94 feet below the ground surface. The water is of good sanitary quality. It has a mineral content of 47.0, a total hardness of 380, and a content of iron of 0.4 parts per million. Analyses 27338, 39933.

STERLING. Water supply.—(Bull. **11**, 127; **13**, 132.) Water for a public supply is obtained from four wells, from 1,334 to 1,829 feet in depth, spaced about 100 feet apart. The wells enter Potsdam sandstone. They had a natural flow in 1915 estimated at about 1,800,000 gallons a day. Analyses .25829, 25830, 30902.

STEWARD. Water supply.—(Bull. **15**, 90.) Analysis 37761.

STOCKTON. Water supply.—(Bull. **11**, 127.) Visited August 21, 1918. Water for a public supply is obtained from a well 1,500 feet deep, 12 inches in diameter at the top and 5 inches at the bottom, cased to a depth of 300 feet Rock is encountered at a depth of 50 feet and the well ends in Potsdam sandstone. Analysis 40017.

STOCKTON. Sewerage.—(Bull. **11**, 128.)

STONINGTON. Water supply.—(Bull. **11**, 128; **15**, 90.) Analysis 37390.

STRAWN. Water supply.—(Bull. **11**, 130; **13**, 134.) Analysis 30602.

Typhoid fever.—(Bull. **11**, 130.)

STREATOR. Water supply.—(Bull. **9**, 31; **11**, 128; **13**, 134.)

Pollution of Vermilion River.—(Bull. **13**, 134.)

Microscopic survey of reservoir.—(Bull. **15**, 90.)

STRONGHURST. Water supply.—(Bull. **12**, 135; **15**, 91.) Visited July 3, 1918. Water for a public supply is obtained from a well 1,009 feet deep. The lower 159 feet, in St. Peter sandstone, is 6 inches in diameter. The upper 323 feet and 500 feet overlying St. Peter sandstone is cased. The well is equipped with a deep well pump of 100 gallons a minute capacity. Analysis 39704.

SUBLETTE. Water supply.—(Bull. **15**, 91.) Analysis 37755.

SULLIVAN. Water supply.—(Bull. **11**, 130; **13**, 134; **14**, 65.) Water for a public supply is obtained from 3 wells. Two of the wells are about 300 feet deep and obtain their supply from sandstone. The maximum yield of a well does not exceed 22 gallons a minute. Analyses 22083, 28846, 29274.

SULLIVAN. Proposed sewerage.—(Bull. **13**, 135.)

Masonic Home. Proposed improved water supply.—(Bull. **14**, 66.)

SUMMIT. Water supply.—(Bull. **14**, 66.) Analysis 36061.

SYCAMORE. Water supply.—(Bull. **11**, 131.) Water for a public supply is obtained from two wells located 15 feet apart. Each well is 905 feet deep, is cased to rock at a depth of 244 feet, and is 8 inches in diameter in rock. They penetrate St. Peter sandstone. When drilled they were tested for 48 hours and each yielded about 500 gallons a minute. Analysis 26606.

TAMPICO. Water supply.—(Bull. **14**, 67.) Analysis 24750.

TAYLORVILLE. Water supply.—(Bull. **11**, 132.) Visited December 20, 1919. Water for a public supply is obtained from eight 8-inch wells 92 feet in drift. The static water level is 25 feet below the ground surface.

The water is of good sanitary quality. It has a mineral content of 800, a total hardness of 568, and a content of iron of 1.2 parts per million. Analyses 37391, 42306.

THOMSON. Water supply.—(Bull. **14**, 67.) Visited August 20, 1918. Water for a public supply is obtained from 2 wells in drift, one a 3-inch well 37 feet deep, the other an 8-inch well 40 feet deep. Analysis 40032.

TINLEY PARK. Water supply.—(Bull. **12**, 136.) Visited August 15, 1918. Water for a public supply is obtained from a well 915 feet deep, 12 inches in diameter at the top, and 6 inches in diameter at the bottom. The static water level is 12 feet below the ground surface. The well is equipped with an electrically-driven deep-well pump. It is said to deliver 250 gallons a minute with a draw-down of not more than 1 foot. About four-fifths of the population use water from the public supply. During the summer the consumption averages 90,000 gallons a day.

The water is of good sanitary quality. It has a mineral content of 490, a total hardness of 427, and a content of iron of 0.9 parts per million. Analysis 39976.

TISKILWA. Water supply.—(Bull. **9**, 31; **10**, 175.) Analysis 38945.

Microscopic and sanitary survey of the public water supply.—(Bull. **15**, 92.)

TOLEDO. Proposed water supply.—(Bull. **13**, 135.)

TOLONO. Water supply.—(Bull. **12**, 139.) Visited October 28, 1919. Water for a public supply is obtained from two wells spaced 37 feet apart. One well drilled in 1914 is 8 inches in diameter and 157% feet deep. Water is drawn from a 5-foot stratum of sand entered at a depth of 151 feet. The well is equipped with a deep-well pump of 125 gallons a minute capacity which operates 5 to 8 hours a day. The other well, occasionally used, is 145 feet deep. Gas is encountered at a depth of 103 feet and two wells formerly in use have been abandoned on account of a large yield of gas. The pump generally used is operated by a fuel-oil engine. Analyses 27026, 42010.

TOLUCA. Water supply.—(Bull. **11**, 132; **15**, 93.) Analysis 24718.

TOULON. Water supply.—(Bull. **11**, 133.) Water for a public supply is obtained from a well 1,445 feet deep, the lower 100 feet in St. Peter sandstone. It is 10 inches in diameter at the top and 6 inches at the bottom.

The upper 100 feet is cased. The static water level is 140 feet below the ground surface. The well is equipped with a deep-well pump which is operated 8 hours a day, at a rate of'120 gallons a minute. Analysis 26305.

TOULON. Sewage treatment plant.—(Bull. **12**, 140.)

TREMONT. Water supply.—(Bull. **12**, 140.) Visited November 4, 1919. Water for a public supply is obtained from a 6-inch well 132 feet deep in drift. The static water level is 92 feet below the ground surface. The well is equipped with an electrically-driven pump of about 70 gallons a minute capacity which operates 3 to 5 hours a day. There are 112 service connections of which 101 are metered. The consumption is about 15,000 gallons a day. Analysis 28494.

TRENTON. Water supply.—(Bull. **12**, 140.) Water for a public supply is obtained from two wells each about 235 feet deep, cased with 10-inch pipe to rock at a depth of 100 feet, and is 8 inches in diameter in rock. Pumped separately during a test one yielded 10 and the other 12 gallons a minute. Analysis 27361.

TROY. Proposed water supply.—(Bull. **14**, 68.)

TUSCOLA. Water supply.—(Bull. **12**, 141; **13**, 136.) Visited June 24, 1918. Water for a public supply is obtained from 2 wells spaced about 135 feet apart, one 287 feet deep cased with 8-inch pipe to a depth of 118 feet and the other 300 feet deep cased with 8-inch pipe to a depth of 128 feet. The wells were drilled by the city in 1916 and leased to the Central Illinois Public Service Company. The wells are equipped with electrically-driven deep-well pumps which discharge directly into the distribution system. When demands are less than the discharge from the wells the excess flows into a reservoir from which water is pumped by a compound duplex steam pump at times when the well pumps do not supply demands. During a test one well yielded 69 and the other 72 gallons a minute. Analyses 33934, 39632.

TUSCOLA. Proposed sewerage.—(Bull. **12**, 142.)

UNION. Water supply.—Visited April 18, 1919. A public water supply was installed in 1912. Water is obtained from a well 10 feet in diameter and 16 feet deep. The lower part of the well is in sand. Water is drawn from the well by a simple double-acting pump driven by a gas engine. A distribution system extends to practically all built-up parts of the village. A steel pressure tank is connected to the system.

South of a creek which flows through the village there is little sand and several wells have been drilled into limestone which is encountered at a little more than 100 foot depth. A private well east of the city 1,365 feet deep and 6 inches in diameter at the bottom is pumped 8 hours each day at a rate of 170 gallons a minute.

The city supply is of good sanitary quality. It has a mineral content of 532 and a total hardness of 445 parts per million. Analysis 40951.

URBANA. Water supply.—(Bull. **15**, 93.) Water supplies for Urbana and Champaign, the University of Illinois and other large water consumers are obtained from a water-bearing gravel stratum, the bottom of which at nearly all of the wells is at a depth of from 140 to 180 feet. Some wells of 8-inch diameter have a yield of 100 gallons a minute. A 36-inch well with a 24-inch screen at the University of Illinois, after 13 days continuous pumping, yielded 670 gallons a minute. By stopping the pump a few minutes the yield was considerably increased. The public supply is aerated, chlorinated, and filtered to remove the content of iron. Analyses 13869, 13872, 28684, 25731, 26760, 30484, 30486.

UTICA. Water supply.—(Bull. **11**, 134.) Analyses 26696, 26697.

VANDALIA. Water supply.—(Bull. **15**, 95.) Visited May 5-8, 1919. Water from the Kaskaskia River is now pumped directly into the distribution system and the city wishes to furnish a water of better quality. The total consumption is estimated at about 750,000 gallons a day.

The Zent spring located about three miles northwest of the center of the city was visited. The flow was about 77,000 gallons a day. The Ritter spring northwest of the city which was flowing at a rate of 90,000 gallons a day when measured in 1917 was flowing at a rate of about 150,000 gallons a day. Rainy weather preceding this visit would account for the increased flow. The flow of springs should be measured at least during one summer.

Little information is available in regard to yield of wells. A well has been drilled in bottom lands of the river but there is no information in regard to the yield. Private wells in the city supply small demands. In 1892-1893 a mine shaft was sunk about one-half mile north of the city to a depth of 420 feet. To keep the shaft dry water was pumped at a rate of 170,000 gallons a day. Test wells should be sunk in bottom lands north of the pumping station and the quantity and quality of water available should be determined. If an adequate supply cannot be secured from wells in bottom lands or from springs a test well should be sunk in the northwestern part of the city and the quantity and quality of water available should be determined.

If an adequate suply cannot be obtained from wells close to the city and measurements of flow of springs indicate sufficient yield the cost of furnishing water from springs should be compared to the cost of furnishing filtered river water. Analyses 22973, 41033, 41034.

VILLA GROVE. Proposed water supply.—(Bull. **12**, 142; **13**, 137.)

VILLA PARK. Water supply.—Visited December 13, 1918. Two public water supplies have been installed, one to supply water for domestic purposes to the southern part of the village and the other to supply the northern part. Both plants are privately owned. Each consists of a well equipped with a deep-well pump, a small pumping station, a limited distribution system, and an clevated wooden tank.

VIOLA. Water supply.—Visited July 3, 1918, and March 28, 1919. A public water supply was installed in 1916. The supply is obtained from a well 1,281 feet deep, 10 inches in diameter at the top and 6 inches at the bottom. St. Peter sandstone is entered at a depth of 1,113 feet. When drilled the static water level was at a depth of 175 feet, and pumping 160 to 180 gallons a minute for 10 hours would not draw the water level down below the pump cylinder which was at a depth of 225 feet. The well is equipped with an electrically-driven deep-well pump which discharges directly into the distribution system to which a 60,000 gallon elevated steel tank is connected. The distribution system includes 3.8 miles of 4, 6, and 8-inch mains, 39 fire hydrants, and 38 service connections. All services are metered. The cost of the waterworks was about $30,000. Analysis 39812.

VIRDEN. Proposed water supply.—(Bull. **11**, 135; **14**, 68; **15**, 96.)

WALNUT. Water supply.—(Bull. **14**, 68.) Analysis 35616.

WARREN. Water supply.—(Bull. **11**, 136.) Visited December 20, 1919. Water for a public supply is obtained from two 10-inch wells about 20 feet apart drilled into St. Peter sandstone. The wells are cased about 14 feet to rock. One well is 700 and the other 875 feet in depth. During a ten-hour test each well supplied 150 gallons a minute. Analyses 18196, 26414.

WARSAW. Water supply.—(Bull. **10**, 176; **11**, 136; **13**, 137.)
Sewerage.—(Bull. **10**, 177.)

WASHINGTON. Water supply.—(Bull. **14**, 69.) Analysis 29579.
Disposal of canning-factory wastes.—(Bull. **11**, 339-73.)

WATERLOO. Water supply.—(Bull. **10**, 178; **14**, 69.) Analysis 23332.
Microscopic and sanitary survey of reservoir.—(Bull. **14**, 69.)

WATERMAN. Water supply.—(Bull. **14**, 70.) Analysis 33294.

WATSEKA. Water supply.—(Bull. **10**, 179.) Visited February 16, 1918. Water for a public supply is secured from two wells 150 feet deep in drift, obtaining water from sand and gravel between depths of 125 and 150 feet. Water is drawn from the wells by suction. They will probably not deliver more than 200 gallons a minute. Analyses 15443, 21808, 38928.

WATSEKA. Iroquois County Poor Farm. Sewage disposal.—(Bull. **12**, 143.)

WAUKEGAN. Water supply.—(Bull. **9**, 31; **11**, 137; **13**, 139.) Visited May 12 to 16, 1919, to investigate the quality of water available from wells. Many wells at Waukegan are in sand and gravel overlying Niagara limestone or enter the limestone a few feet. A few wells enter St. Peter and Potsdam sandstone. Some of the wells located on low ground have a natural flow. The maximum yield of any of the wells is not known. At the United States Naval Hospital at Great Lakes are two 8-inch wells spaced about 75 feet apart. One well is 200 feet deep and enters limestone 20 feet. The other well is 220 feet deep and enters limestone 33 feet. Pumping the 220-foot well for 9 hours at a rate of 110 gallons a minute lowered the water level 35 feet to a depth of 60 feet below the ground surface. The water level in this well was lowered 14 feet when pumping the other well at a rate of 85 gallons a minute. Samples of water were collected from many of these wells. Analyses 29923, 29924, 41060, 41061, 41062, 41063, 41064, 41068, 41119, 41120, 41122, 41123, 41124, 41144, 41219.

Water of good sanitary quality, suitable for a public supply may be secured from wells. Water from some of the wells is softer than Lake Michigan water. Water from other of the wells is considerably harder than Lake Michigan water. The quantity of water that may be secured from wells cannot be estimated from the available information. Should the city deem it advisable to consider changing the source of public water supply, tests to determine the quantity and quality of water available should be made before much money is spent on the project. Unless data are secured showing that water comparable with filtered Lake Michigan water can be secured economically from wells no change in the source of supply should be made.

WAVERLY. Proposed water supply.—Visited November 26, 1919. It may be possible to secure sufficient water for a public supply from wells. Many private wells are from 20 to 30 feet deep. At the high school water is secured for 185 pupils from a well 10 feet in diameter and 38 feet deep. A well in the city park, dug to a depth of 40 feet and drilled an additional 30 feet is said to have a capacity of 50 barrels a day. A well two Blocks west of the public square, dug to a depth of 75 feet and drilled 300 feet, is said to have a capacity of 40 barrels a day but is said to go dry in times of drought.

Several oil and gas wells have been drilled in the vicinity. Sand is reported in a well two miles east of the city between depths of 24 and 34 feet, in a well three miles northwest of the city between depths of 70 and 88 feet, and in a well two miles southwest of the city to a depth of 55 feet. In the last two mentioned wells considerable water is said to have been encountered at a depth of 100 feet or more. In the well northwest of the city some oil was reported at a depth of 735 feet and a strong flow of salt water at a depth of 885 feet.

Water could be secured from a stream. There is no stream in the vicinity in which the flow is at all times sufficient to furnish a public water supply for the city. An impounding reservoir could be formed by building a dam across a valley of a stream. On small level drainage areas in the vicinity of Waverly the run-off may be practically zero for six or seven months. To furnish 2,000 people 75 gallons a day each for this period and allow 15,000,000 gallons for evaporation a reservoir of about 45,000,000 gallons capacity would be required. When the rainfall for winter and spring months is only 8 or 9 inches the corresponding run-off may be not more than 4 inches or 66,000,000 gallons per square mile. Where little is wasted and evaporation is not excessive this run-off from one square mile would supply from 2,000 to 2,500 people with 60 gallons of water a day throughout the year. Where land is hilly or a reservoir can be built to store water from one year to another one square mile drainage area will furnish a supply for many more people.

By building a dam across the valley of a stream which flows southeast through the central part of section 5, about 3 miles west of the city, an ample supply could be secured for a city many times the present size of Waverly.

A stream in section 10 a short distance west of the city apparently has sufficient drainage area and available site for reservoir of sufficient capacity to furnish a public supply. It would not be advisable to use' water from this stream unless all sewage from the city could be diverted from the stream.

Additional information should be secured in regard to wells in the vicinity. The prospect of securing sufficient water of good quality from wells is not promising and a large expenditure is not warranted.

Costs should be secured of diverting sewage from the drainage area adjoining the city on the north and west and of developing a supply from this drainage area and also of developing a supply from an area which does not receive drainage from the city.

WAYNESVILLE. Water supply.—Visited August 19, 1919. A public water supply was installed in 1895. Water is obtained from two 6-inch drilled wells 116 feet deep in drift. The wells are equipped with steam-head deep-well pumps with cylinders at a depth of 102 feet. The total yield of both wells is somewhat less than 110 gallons a minute. When pumping from one well the water level in the other, 22 feet distant, is 45 feet below the ground surface. The well pumps discharge directly into the distribution system to which a 48,000 gallon elevated steel tank is connected. There are 129 service connections, all metered. The consumption averages 24,000 gallons a day The water is of good sanitary quality. Analyses 41607, 41608.

WELDON. Water supply.—(Bull. **14**, 70.) Analysis 36121.

WENONA. Water supply.—(Bull. **13**, 139; **14**, 71.) Analysis 30117.
Proposed sewage.—(Bull. **13**, 139.)

WEST BROOKLYN. Water supply.—(Bull. **14**, 71.) Visited May 8, 1918. Water for a public supply is obtained from a well 358 feet deep in drift. The static water level is at a depth of 217 feet. Water is sometimes drawn down to the pump cylinder at a depth of 270 feet. For sometime water was obtained from a well 375 feet deep. Analysis 33322. There are 56 service connections all of which are metered. The water is of good sanitary quality. It has a mineral content of 385, a total hardness of 295, and a content of iron of 2.2 parts per million. Analysis 39450.

WEST CHICAGO. Water supply.—(Bull. **12**, 143.) Water for a public supply is obtained from 2 wells, one 775 feet deep and the other 322 feet deep. Both are cased with 12-inch pipe to rock at a depth of 90 feet and are 8 inches in diameter at the bottom. The static water level is at a depth of about 50 feet. Each well is equipped with a deep-well pump of 200 gallons a minute capacity with cylinder placed at a depth of 90 feet. Analysis 29269.

WEST DUNDEE. Water supply.—(Bull. **9**, 32.) Water for a public supply is obtained from springs with a yield of about 1,000,000 gallons a day. Analysis 37355.

WEST FRANKFORT. Water supply.—(Bull. **11**, 137; **12**, 144, **14**, 72.) Visited May 7, 1918. A public supply was completed in 1917. Water is obtained from 2 wells located about 350 feet apart in bottom lands of Middle Fork of Big Muddy River. One well is 24 inches in diameter and has an 18-inch screen. On April 9, 1916 when not pumping water stood 9 feet below the ground surface. Pumping for 20 hours at a rate of 164 gallons a minute the water level was lowered 43 feet. Each well is equipped with an electrically-driven deep-well pump which discharges through a pipe line into a concrete reservoir. Water is pumped from the reservoir into a distribution system by either of two electrically-driven centrifugal pumps. One pump is 2½-inch size and the other used at times of fires is 8-inch. A small steel pressure tank is connected to the distribution system. All excess water pumped, passes through a relief valve into the reservoir.

The water is of good sanitary quality. It has a mineral content of 1,105, a total hardness of 600, and a content of iron of 6.8 parts per million. Analysis 39452.

WESTERN SPRINGS. Water supply.—(Bull. **13**, 140.) Water for a public supply is obtained from a well 2,046 feet deep, 20 inches in diameter at the top and 7 inches at the bottom. The well is cased to a depth of about 1,785 feet. The various sized pipes used in casing are sealed one to another and are sealed to surrounding rock at depths of 1,337 and 1,785 feet. A deep-well pump with the cylinder at a depth of 250 feet and a duplex pump located in a pit draw' water from the well. The arrangements are said to be such that the deep-well pump draws water from below a depth of 1,785 feet, and the other pump draws water from above a depth of 1,337 feet. The total yield in 1915 was 600 gallons a minute. Analyses 30698, 30699.

WESTFIELD. Water supply.—Visited July 24, 1919. A public water supply was installed in 1913. Water is obtained from an 8-inch well 155 feet deep, located near the center of the village. The well is equipped with an electrically-driven deep-well pump with a cylinder about 12 feet above the bottom of the well. The pump is operated about two hours and then remains idle for an hour or two. It is said to yield about 9 gallons a minute. A 60,000 gallon elevated tank is connected to the distribution system. There are about 42 service connections. The amount of water available is not sufficient to supply all demands.

WEST HAMMOND. Water supply.—(Bull. **12**, 144.)

WESTVILLE. Proposed water supply.—(Bull. **15**, 97.) Visited September 19, 1919. A stratum of sand and gravel underlies the city and surrounding territory at a depth, in most places, of less than 40 feet. At some places in ravines this stratum outcrops and there is a slight flow of water from springs. The sand and gravel stratum is said to be thicker to the south and east of the city. The total yield of springs seen in one ravine was probably less than 10 gallons a minute.

In 1914 an attempt was made to develop a ground water supply and two 6-inch wells, each about 80 feet in depth were drilled, one in the eastern and the other in the western part of the city. The yield of these wells was very small. In 1916 three wells were drilled east of the city. The yield was very small and indicated that a public supply could not be developed from wells in that vicinity. In a drill hole two miles east of Westville water was encountered in gravel at a depth of about 70 feet. Salt water was encountered at a depth of 600 feet. There was little or no water between depths of 70 and 600 feet.

At the air shaft of Kelly Mine No. 4 about 1½ miles southeastward from the center of the city considerable water was encountered at a depth of about 40 feet. This water flows through a pipe which passes through a concrete lining of the shaft, into the mine from which it is pumped with other water. The yield of water from the shaft has been measured and at the time of measurement was 100 gallons a minute.

Samples of water collected from various sources show considerable variation in quality. The differences may be due to various strata through which the water flows or it may be due in part to the differences in length of time the water was in contact with certain strata.

The quality of water from Kelly Mine No. 4 is probably as good as could be secured from drift wells and is much better than samples of water collected from Kelly Mine No. 2. It is recommended that water from Kelly Mine No. 4 be used for a public water supply if 150,000 gallons or more of water can be secured per day, and if satisfactory arrangements can be made.

WHEATON. Water supply.—(Bull. **15**, 97.) Water for a public supply is obtained from 2 wells located about 20 feet apart. Each well is 10 inches in diameter and 175 feet deep. They penetrate about 110 feet of drift and 65 feet of Niagara limestone. The static water level is at a depth of about

26 feet. Water is pumped by either of two pumps of 750 gallons a minute capacity located in a shaft between the wells. When pumping the water level in the wells is about 66 feet below the ground surface. Analysis 21796, 39427.

WHEATON. Sewage purification.—(Bull. **10**, 180.)

WHITEHALL. Incrustation of mains and filtration of water supply.—(Bull. **11**, 138; **13**, 142.) Analysis 22166.

Sewerage.—(Bull. **11**, 139.)

WILMETTE. Water supply and sewerage.—(Bull. **9**, 31.)

WILMINGTON. Water supply.—(Bull. **15**, 98.) Analysis 38386.

WINCHESTER. Water supply.—(Bull. **11**, 139; **12**, 145; **14**, 73.) Visited July 23, 1918. Water for a public supply is obtained from two 8-inch wells 42 feet in drift located 100 feet apart in the valley of Big Sandy Creek. During a test each well yielded 50 gallons a minute. There are 147 consumers. The water is of good sanitary quality. It has a mineral content of 304, a total hardness of 284, and a content of iron of 2 parts per million.

WINNETKA. Water supply.—(Bull. **10**, 184; **11**, 140; **13**, 143.)

WINSLOW. Water supply.—(Bull. **15**, 98.) Visited August 22, 1918. Water for a public supply is obtained from an 8-inch well 200 feet deep located in an abandoned stone quarry near Indian Creek. The upper 40 feet is cased with an 8-inch pipe with cement grout poured around the pipe. Below a depth of 40 feet the well is in St. Peter sandstone. Water is drawn by suction with a pump of 200 gallons a minute displacement at the speed operated.

Samples of water collected have not been of good sanitary quality. At times the water has been turbid. The location of a ditch which formerly flooded the ground around the well has been changed and no turbidity has since been noticed. The water has a mineral content of 315 and a total hardness of 296 parts per million. It contains no iron.

WITT. Proposed water supply.—(Bull. **11**, 140.) Visited May 31, 1918. A 6-inch well 39 feet deep in bottom land of East Fork of Shoal Creek about 1½ miles northeast of the center of the city has been drilled. After pumping nearly continuously for 5 days and then pumping at a rate of 70 gallons a minute for 2 hours the water level in the well was 14 feet below the ground surface. One minute after stopping the pump, the water level rose 6½ feet and 20 minutes after pumping ceased water stood about 7 feet below the ground surface. Analysis 39546.

WOODHULL. Water supply.—(Bull. **14**, 74.) Water for a public supply is obtained from a well 1,394 feet deep, 12 inches in diameter at the top and 6 inches at the bottom. The lower 104 feet is in St. Peter sandstone. Analysis 35467.

WOOD RIVER. Water supply.—(Bull. **14**, 73.) Visited July 19, 1918. Water for a public supply is furnished by the Standard Oil Company. The water is secured from ten 20-inch and two 12-inch wells in sand and gravel. One 20-inch well 110 feet deep has yielded on test 2,100 gallons a minute. The estimated total yield is 25,000,000 gallons a day. Analysis 36723.

WOODSTOCK. Water supply.—(Bull. **9**, 32; **12**, 145.) Analysis 27284.

WYOMING. Water supply.—(Bull. **12**, 146.) Water for a public supply is obtained from a well 1,557 feet deep, 12 inches in diameter at the top, 8 inches in diameter at the bottom, and cased to a depth of 1,197 feet. The lower 50 feet is said to he in St. Peter sandstone. During a 10-hour test water was pumped at a rate of 200 gallons a minute. Analysis 29381.

YORKVILLE. Water supply.—(Bull. **9**, 32; **15**, 99.) Analysis 38013. Proposed sewerage.—(Bull. 11, 141.)

ZION CITY. Water supply and sewerage conditions.—(Bull. **9**, 32.)

THE HARDNESS OF ILLINOIS MUNICIPAL WATER SUPPLIES.

A previous report[5] published under the same title in 1908 gave information concerning the composition of the mineral matter the hardness and the amount of lime and soda ash required to soften the water of 98 municipal water supplies. The data given in that report has been found to be so useful that similar data for all of the public water supplies of the State has been collected. The water furnished to municipalities in Illinois is hard and therefore information concerning the degree of hardness and the amount of chemicals needed to soften it is of practical value. To soften a water is comparatively inexpensive whenever it is necessary to purify it for drinking purposes. Most of the water supplies of Illinois are from wells and to soften these waters would mean complete installations for the purpose, and municipalities and water companies hesitate to erect general softening plants on account of the expense. There is also a reluctance to treat all of a water supply when softened water is not needed for all purposes. The railroads have many softening plants and manufacturing establishments and even the small consumers would find it to their advantage to imitate the railroads. In most cases it will be found good practice to establish small softening plants rather than to treat the whole supply of a municipality, though a large general plant can be more easily operated than many small ones.

This report furnishes the chemical data necessary for treatment of the water with lime and soda ash. It is also possible from the data given to estimate the capacity required for Zeolite water softeners and also to estimate the amount of sodium chloride, common salt, which would be required for these processes.

The analyses given in the present report have been made of the most representative samples available. The majority of the samples have been collected by representatives of the State Water Survey Division. Others have been sent to the Division from the various towns by the waterworks men, city officials, or by other citizens. The samples are in all probability authentic. The Division would appreciate information concerning any experiments which show the data given to be inaccurate.

Well waters are usually constant in composition but it is possible that some change might have occurred owing to excessive pumping and the drawing of water from other strata, or to the caving in of deep wells shutting out the lower strata. Any information concerning cases of this kind will be appreciated.

Three hundred and forty-seven analyses from 338 different towns are reported in the table. It is hoped to publish these analyses in full in a bulletin of the State Water Survey, but it has not been possible to do so to date.

The mineral content given in the table shows. hypothetical combinations which have been calculated from the ionic content by calculating bases in the order, potassium, sodium, ammonium, magnesium, calcium, iron and aluminium, to the acid ions in the order, nitrate, chloride, sulfate and carbonate. By using this order the waters can be divided into several classes. To facilitate comparison three classes were made.

Class I. includes those waters which contain more than enough sodium to unite with all of the nitrate, chloride and sulfate ions. These waters would therefore contain sodium carbonate, and possibly the carbonates of magnesium, calcium and iron. The waters of this class will form a sludge or soft scale when used in boilers. They may have a high soap consuming power when used for laundry or in the lavatory. The hardness, which would necessarily consist of the carbonates of calcium and magnesium, will be almost entirely removed by boiling, or by-treatment with the necessary amount of lime. The relative cost of softening by boiling and by lime is given by Collott[3] as 50 to 1.

Class II. includes those waters which have sufficient sodium to unite with all the nitrate and chloride and with part of the sulfate ions present. These waters contain the sulfate of magnesium and sometimes the sulfates of calcium, iron and aluminium. The waters of this class will form a scale more or less hard, according to the proportion of sulfate present. Their soap consuming power may be high, and boiling will not remove all of the hardness. Boiling will remove the carbonate hardness, but the sulfate hardness will remain. Lime will remove the carbonates, but soda ash or caustic soda must be used to change the sulfates to sulfates of sodium.

Class III. includes those waters in which the sodium is not present in sufficient quantity to unite with all the nitrates and chlorides present. These waters will therefore contain magnesium chloride. The hardness may be due to chlorides, sulfates and carbonates of magnesium, calcium, etc. These waters will be corrosive will form a hard scale and pit when used in boilers. They will also consume a considerable quantity of soap, and the hardness will not all be removed by boiling. As in Class II, lime will remove the carbonates, but soda ash or caustic soda must be used for the mineral acid hardness.

It is noted that the waters of the first class are most common, there being 161 waters in this class. The second class is next in order with 147 waters, and the third class numbers 39.

Most of these waters will yield to treatment, the exception being those containing a large residue. These may be softened, but because of the necessary addition of sodium salts in the softening process, the foaming constituents will be increased so that they will be unsatisfactory for boiler uses. With the exception of the waters just mentioned, it is possible to so treat the Illinois waters that corrosion will be prevented and the scaling ingredients reduced to less than 85' parts per million (5 grains per gallon.)

The amounts of sodium carbonate (soda ash, Na_2CO_3) and lime (CaO) needed to treat the waters were calculated, using factors, as follows:

Magnesium chloride, $MgCl_2$, to Soda ash, Na_2CO_3	1.1130
Magnesium sulfate, $MgSO_4$ to Soda ash, Na_2CO_3	.8811
Calcium sulfate, $CaSO_4$ to Soda ash, Na_2CO_3	.7792
Sodium carbonate, Na_2CO_3 to Lime, CaO	.5287
Magnesium chloride, $MgCl_2$ to Lime, CaO	.5889
Magnesium sulfate, $MgSO_4$ to Lime, CaO	.4659
Magnesium carbonate, $MgCO_3$ to Lime, CaO	1.3300
Calcium carbonate, $CaCO_3$ to Lime, CaO	.5600
Parts per million to grains per gallon	.05833
Parts per million to pounds per thousand gallons	.008345

The amounts are calculated on the basis of pure soda ash and pure lime, and no account is taken of the residual carbonate of calcium and magnesium which can not be removed. Practice would probably show that the approximate cost is therefore a trifle high. The amount of sodium carbonate present has been included in the calculation of the lime needed for the waters of Class I. This is according to the laboratory experiments of Bartow and Lindgren.[1]

The results are given in parts per million, grains per gallon and pounds per thousand gallons. This will make it convenient for treatment on a large or small scale. Those desiring to soften water for use in the household, where the whole supply is not softened, may soften from a few gallons up by adding the calculated amount. We have tried the experiment with the water at the University of Illinois on a laboratory scale, using 30 liters of water; and on a household scale using 1,000 gallons of water.

Analyses of water from the streams used for municipal supplies have not been given owing to the variation of the mineral content of waters, due to variations in dilution at different seasons making it necessary to modify the treatment from day to day. Average analyses of water from the streams of the State are given in Water Supply Paper No. 239 of the U. S. Geological Survey.[2] Analyses were made during one year and the work was done with the cooperation of the Illinois State Water Survey, the State Geological Survey, and the Engineering Experiment Station of the University of Illinois.

The cost of treatment has been calculated on the basis of lime at $10.00 per ton, and soda ash at $40.00 per ton. The cost at any place can be readily calculated by noting the relationship to the values given of the actual cost on the spot.

An examination of the table shows that the majority (186) of the waters have a hardness of from three to six hundreds parts per million. Only one water, from Mount Olive, has a hardness of less than 100, only seven less than 200 and only thirty-eight less than 300. Compared with the water supplies in the East these waters are extremely hard. For example in Massachusetts[4] only sixteen well waters and one surface water used for municipal supplies has over 100 parts per million of residue and no water used for municipal supplies has a residue of more than 200 parts per million. In Illinois in addition to the waters already mentioned 58 have a residue between 600 and 1,000; 57 have a residue between 1,000 and 2,000; 11 between 2,000 and 3,000; 5 between 3,000 and 4,000; one between 4,000 and 5,000 and one has more than 5,000.

The use of the very highly mineralized waters seems impracticable and an attempt should be made to obtain better waters if any are available.

The Water Survey Division will be glad to assist water works officials and others who may wish to consider softening the municipal water supplies.

REFERENCES.

1. Bartow and Lindgren, Proc. Am. Water Works Assn. 27, 505 (1907 University of Illinois, State Water Survey Bull. 6.
2. Collins, W. D., The Quality of surface waters of Illinois, U. S. Geol. Sur. Water Supply Paper 239.
3. Collott, Water softening and purification, p. 3, London, 1908.
4. Mass. State Board of Health, Rep't., 1917, 45-53.
5. University of Illinois, Water Survey Bull. 7, 98 (1908).

TABLE SHOWING THE HARDNESS, AND THE AMOUNT OF LIME AND SODA ASH REQUIRED TO SOFTEN THE WATER FURNISHED TO THREE HUNDRED AND THIRTY-EIGHT ILLINOIS MUNICIPALITIES.

City, town and village.	Class.	Mineral content—parts per million.								Soda ash.			Lime.			Chemicals.	Remarks.
		Iron.	Res.	Na_2CO_3.	$MgCl_2$.	$MgSO_4$.	$MgCO_3$.	$CaSO_4$.	$CaCO_3$.	Parts per million.	Grains per gallon.	Pounds per 1000 gallons.	Parts per million.	Grains per gallon.	Pounds per 1000 gallons.	Approximate cost per 1000 gallons.	
Abingdon	II	0.3	1323	--------	--------	232.8	--------	1.8	223.7	206.5	12.0	1.71	233.7	13.5	1.94	.04390	1350-foot well.
Aledo	II	0.2	1755	--------	--------	110.5	16.7	--------	238.5	97.3	5.6	.81	207.2	12.0	1.72	.02480	1450-foot well.
Alexis	II	7.0	969	--------	--------	28.6	95.9	--------	158.1	25.2	1.4	.21	229.3	13.3	1.90	.01360	1204-foot well.
Algonquin	III	0.1	328	--------	0.9	56.2	69.6	--------	162.3	50.5	2.9	.42	210.0	12.2	1.75	.01715	Springs.
Alpha	I	0.2	1053	--------	--------	--------	71.0	--------	130.5	--------	--------	--------	166.7	9.6	1.38	.00690	1465-foot well.
Altamont	I	0.3	773	251.6	--------	--------	60.3	--------	74.6	--------	--------	--------	254.9	14.8	2.11	.01055	149-foot well.
	I	0.4	885	195.1	--------	--------	79.0	--------	93.9	--------	--------	--------	260.7	15.1	2.16	.01080	225-foot well.
Amboy	II	1.4	450	--------	--------	25.8	118.4	--------	211.7	22.7	1.3	.18	288.0	16.7	2.40	.01560	160-foot well.
Anna	III	0.0	383	--------	3.5	18.4	54.4	--------	204.7	20.0	--------	--------	197.6	11.4	1.64	.00820	650-foot well.
Antioch	I	0.2	325	1.6	--------	--------	76.2	--------	61.7	--------	--------	--------	136.7	7.9	1.13	.00565	217-foot well.
Arcola	I	4.0	735	165.9	--------	--------	62.7	--------	207.2	--------	--------	--------	287.1	16.7	2.39	.01195	100-foot well.
Area	I	0.3	380	40.9	--------	--------	37.7	--------	39.7	--------	--------	--------	93.9	5.4	.78	.00390	242-foot well.
Arlington Heights	II	0.1	750	--------	--------	215.5	--------	14.3	114.5	196.6	11.3	1.62	164.5	9.5	1.35	.03915	140-foot well.
Arthur	I	2.2	491	165.2	--------	--------	116.4	--------	160.5	--------	--------	--------	331.9	19.2	2.76	--------	86-foot well.
Ashton	III	0.3	512	--------	22.8	46.9	87.6	--------	194.4	66.6	3.8	.55	260.6	15.1	3.00	.02600	545-foot well.
Assumption	I	0.3	196	24.9	--------	--------	50.6	--------	88.9	--------	--------	--------	130.3	7.5	.10	.00050	17-foot well.
Astoria	II	0.2	3620	--------	--------	296.6	--------	139.3	252.4	369.8	21.5	3.07	279.5	16.2	2.32	.07300	1658-foot well.
Atlanta	I	8.4	464	68.6	--------	--------	146.8	--------	210.4	--------	--------	--------	349.3	20.2	2.90	.01450	151-foot well.
Aurora	III	0.4	418	--------	13.9	34.1	50.2	--------	161.0	45.4	2.6	.37	181.0	10.5	1.50	.01490	2250-foot well.
Barrington	II	0.3	375	--------	--------	29.6	121.1	--------	135.8	26.0	1.5	.21	250.8	14.5	2.08	.01460	305-foot well.
Barry	II	0.7	5047	--------	--------	488.4	--------	500.9	242.9	820.6	47.8	6.83	363.2	21.1	3.02	.15170	Former supply, 2510-foot well.
Batavia	I	0.2	315	45.3	--------	--------	96.8	--------	100.1	--------	--------	--------	208.7	12.1	1.73	.00865	2000-foot well.
Beardstown	II	1.8	366	--------	--------	65.0	56.4	--------	189.2	57.2	3.3	.47	211.2	12.3	1.75	.01815	30 and 90-foot wells.
Beecher	II	0.5	995	--------	--------	273.8	--------	210.8	237.1	405.4	23.6	3.37	260.3	15.1	2.16	.08820	165-foot well.
Belleville	I	5.9	410	75.7	--------	--------	83.1	--------	146.0	--------	--------	--------	231.1	13.4	1.92	.00960	Former supply. Edgemont wells.
Bellwood	II	1.0	546	--------	--------	115.7	92.5	--------	154.5	101.9	5.8	.84	263.4	15.3	2.19	.02775	1538-foot well.
Belvidere	III	0.1	511	--------	22.1	106.9	63.3	--------	276.5	118.7	6.8	.97	301.8	17.5	2.51	.02195	1800-foot well.
Bement	I	1.5	503	92.7	--------	--------	134.0	--------	144.5	--------	--------	--------	306.9	17.8	2.55	.01275	140-foot wells.

TABLE SHOWING THE HARDNESS, AND THE AMOUNT OF LIME AND SODA ASH REQUIRED TO SOFTEN THE WATER FURNISHED TO THREE HUNDRED AND THIRTY-EIGHT ILLINOIS MUNICIPALITIES—Continued.

City, town and village.	Class.	Mineral content—parts per million.								Soda ash.			Lime.			Chemicals.	Remarks.
		Iron.	Res.	Na_2CO_3.	$MgCl_2$.	$MgSO_4$.	$MgCO_3$.	$CaSO_4$.	$CaCO_3$.	Parts per million.	Grains per gallon.	Pounds per 1000 gallons.	Parts per million.	Grains per gallon.	Pounds per 1000 gallons.	Approximate cost per 1000 gallons.	
Benson	III	tr.	490	....	25.5	110.2	....	18.6	186.7	139.9	8.1	1.15	170.8	9.9	1.41	.03005	80-foot well.
Benton	II	3.5	155	....	....	20.8	....	8.9	23.7	25.2	1.4	.21	22.9	1.3	.19	.00515	Reservoir.
Berwyn	II	0.4	727	....	....	156.0	11.8	....	238.0	137.2	7.9	1.14	221.6	12.8	1.84	.03200	1650-foot well.
Bloomington	II	1.6	1070	....	....	346.0	....	12.9	436.0	314.9	18.3	2.61	405.3	23.6	3.37	.06905	Well No. 1, 60 feet deep.
Blue Island	II	.0	1164	....	....	148.8	....	70.7	222.0	176.1	10.2	1.46	193.6	11.2	1.60	.03720	1659-foot well.
Blue Mound	II	0.4	414	....	....	100.4	50.6	....	182.1	88.4	5.1	.73	216.1	12.5	1.80	.02360	55-foot well.
Bourbonnais	II	.0	570	....	....	97.1	103.5	....	267.1	85.5	4.9	.71	332.4	19.3	2.76	.02800	181-foot well.
Braceville	II	0.1	965	....	....	168.1	....	206.8	152.0	308.7	17.9	2.56	163.4	9.5	1.35	.05795	30-foot well.
Bradford	II	0.4	1390	....	....	152.5	8.7	....	212.4	134.3	7.8	1.11	201.5	11.7	1.67	.03055	2079-foot well.
Bradley	II	0.1	611	....	....	98.3	34.8	....	241.8	86.6	5.0	.72	227.4	13.2	1.89	.02385	332-foot well.
Braidwood	II	0.3	492	....	....	132.0	....	81.9	172.5	180.1	10.4	1.50	158.0	9.2	1.31	.03655	12 to 20-foot wells.
Brookport	III	0.4	279	....	3.2	26.6	21.8	....	172.5	26.9	1.5	.22	139.8	8.1	1.15	.01015	217-foot well.
Buckley	II	1.4	1105	....	....	432.6	19.0	....	367.2	381.1	22.2	3.17	432.4	25.1	3.60	.08140	152-foot well.
Bureau	I	1.2	2012	402.5	....	....	29.1	....	39.2	....	....	....	273.4	15.9	2.27	.01135	305-foot well.
Bushnell	II	0.8	1880	....	....	182.9	37.7	....	243.6	161.1	9.3	1.34	271.7	15.7	2.26	.03810	1350-foot well.
Byron	II	.0	288	....	....	10.5	113.9	....	110.5	9.2	.5	.07	218.2	12.7	1.81	.02345	2000-foot well.
Cambridge	I	1.0	1044	58.7	....	....	72.7	....	101.4	....	....	....	184.5	10.7	1.53	.00765	1380-foot well.
Campus	I	0.4	728	10.8	....	....	67.9	....	137.1	....	....	....	173.5	10.0	1.44	.00720	130-foot well.
Canton	II	......	1892	....	....	156.0	25.2	....	234.0	137.4	79.8	1.14	237.2	13.8	1.97	.03265	1646 and 2042-foot wells.
Capron	I	1.3	362	18.2	....	....	119.1	....	192.9	....	....	....	276.0	16.0	2.30	.01150	680-foot well.
Carbon Hill	II	0.8	1295	....	....	233.3	....	10.6	265.4	213.8	12.4	1.77	257.3	14.9	2.14	.04610	1900-foot well. Water from mine?
Carbondale	I	0.7	2198	268.8	....	....	27.4	....	53.4	....	....	....	208.4	12.1	1.73	.00865	410-foot well.
Carpentersville	II	2.9	500	....	....	58.0	131.2	....	249.6	51.1	2.9	.42	341.2	19.8	2.84	.02260	17-foot well.
Carrollton	II	0.2	357	....	....	5.0	76.9	....	186.7	4.4	0.2	.03	209.1	12.1	1.74	.00930	Spring.
Carthage	II	4.6	2755	....	....	357.9	....	222.7	189.7	488.8	28.4	4.06	272.9	15.8	2.26	.09250	847-foot well.
Cary	I	0.8	341	21.6	....	....	90.4	....	137.4	....	....	....	208.5	12.1	1.73	.00865	300-foot well.
Casey	I	2.3	535	152.3	....	....	106.5	....	164.0	....	....	....	313.9	18.2	2.61	.01305	80 and 131-foot wells.
Cedar Point	I	0.3	1023	63.9	....	....	2.4	....	178.9	....	....	....	137.1	7.9	1.14	.00570	1750-foot well.
Cerro Gordo	I	2.2	591	155.2	....	....	136.1	....	186.9	....	....	....	367.7	21.3	3.06	.01530	150-foot well.
Chadwick	I	0.3	399	20.0	....	....	141.6	....	232.3	....	....	....	328.9	19.1	2.73	.01365	600-foot well.
Chatsworth	I	0.5	617	168.9	....	....	69.6	....	195.4	....	....	....	291.2	16.9	2.42	.01210	1285-foot well.

Chenoa	I	1.1	1289	57.6			84.5		139.5				220.9	12.8	1.83	.00915	2035-foot well.
Cherry	I	2.0	706	286.5			183.3		178.2				495.0	28.8	4.12	.02060	98-foot well.
Chicago Heights	II	0.2	694			207.5	5.2		354.6	182.8	10.6	1.51	302.1	17.6	2.51	.04275	200-foot well
Chillicothe	II	0.3	504			65.6	27.7		242.4	57.7	3.3	.48	203.1	11.8	1.69	.01805	35-foot well.
Chrisman	III		648		126.0	27.7	0.8		182.5	157.9	9.1	1.30	187.1	10.9	1.55	.03375	132-foot well.
Christopher	II	0.3	255			76.6		42.8	37.1	100.8	5.5	.83	56.4	3.2	.47	.01895	Reservoir.
Cissna Park	I	0.5	461	21.4			126.7		214.4				299.9	17.4	2.49	.01245	150 and 237-foot wells.
Clinton	I	0.7	520	106.6			118.9		172.0				310.8	18.0	2.58	.01290	340-foot well.
Coal City	II	0.3	1190			163.0	20.0		228.0	143.6	8.3	1.19	230.2	13.4	1.91	.03325	350-foot well.
Colfax	I	2.7	739	238.3			124.5		176.6				390.4	22.7	3.25	.01625	105-foot well.
Collinsville	II	1.0	462			55.5	98.1		219.5	48.9	2.8	.40	279.2	16.2	2.32	.01960	70 to 90-foot wells.
Compton	I	1.7	325				72.4		121.5				164.3	9.5	1.36	.00680	335-foot well.
Crescent City	II	1.5	479			44.3	89.0		225.6	39.0	2.27	.32	265.3	15.4	2.21	.01745	120-foot well.
Creston	I	1.6	292	62.0			94.4		105.0				217.1	12.6	1.80	.00900	582-foot well.
Crete	I	0.9	432	1.6			121.6		256.1				305.9	17.7	2.54	.01270	192-foot well.
Crystal Lake	II	0.1	443			33.0	100.4		225.0	29.0	1.69	.24	274.9	15.9	2.29	.01720	32-foot well.
Cuba	II	8.0	2380			343.6		502.2	180.0	694.0	40.4	5.78	260.8	15.1	2.16	.12640	1768-foot well.
Cullom	I	0.5	1072	209.4			4.8		70.6				6.6	9.0	1.30	.00650	1700-foot wells.
Danvers	I	1.6	548	168.0			136.4		201.2				382.8	22.2	3.18	.01590	218-foot well.
Danville	II	0.1	485			44.5	108.9		210.8	39.2	2.2	.32	283.5	16.4	2.36	.01820	
Deer Creek	I	0.3	327	8.7			149.0		174.0				300.2	17.4	2.50	.01250	260-foot well.
DeKalb	I	0.1	293	36.6			11.4		187.9				139.7	8.1	1.15	.00575	Approx. 1300-foot well.
Delavan	I	1.6	374	32.5			107.3		184.0				262.9	15.2	2.18	.01090	160-foot well.
Depue	I	2.0	545	62.6			82.4		138.5				220.2	12.8	1.83	.00915	1278-foot well.
DesPlaines	III		884		29.6	195.7		129.2	172.7	306.0	17.8	2.55	205.3	11.9	1.70	.05950	Well approx. 130 feet deep.
Dixon	I	tr.	325	7.8			117.7		185.4				264.4	15.3	2.20	.01100	1765-foot well.
Downers Grove	II	0.1	560			142.3	71.7		283.8	125.3	7.2	1.04	320.5	18.6	2.66	.03410	2250 and 240-foot wells.
Dwight	II	0.7	1106			192.0	20.2		276.0	167.4	9.7	1.39	270.8	15.7	2.25	.03905	136-foot well.
Earlville	I	1.2	315	48.1			82.4		143.0				215.0	12.5	1.79	.00895	625-foot well.
East Dubuque	II	0.2	278			16.3	96.3		151.8	14.3	.8	.11	220.6	12.8	1.83	.01135	1343-foot well.
East Moline	II	0.0	1133			102.8	73.1		177.0	90.5	5.2	.75	244.2	14.2	2.03	.02515	1300 and 2000-foot wells.
East Peoria	II	0.2	425			53.7	37.6		216.8	47.3	2.7	.39	196.4	11.4	1.63	.01595	25-foot well.
Edwardsville	II	1.8	256			28.7	24.9		125.8	25.2	1.4	.21	116.9	6.7	.96	.00900	55 and 80-foot wells.
Elburn	I	0.2	361	69.7			88.6		165.9				247.5	14.4	2.05	.01025	1450-foot well.
Elgin	I	0.5	342				91.0		196.0				230.7	13.4	1.91	.00955	1300-foot well.
Elmhurst	II	1.5	501			77.8	61.7		282.9	68.5	3.9	.57	240.4	13.9	2.00	.02140	Spring.
Elmwood	II	0.7	1488			122.4	44.5		208.4	107.8	6.2	.89	232.8	13.5	1.93	.02745	1487-foot well filled to 600 feet?
Eureka	II	3.2	509			101.2	102.8		244.3	89.1	5.1	.74	320.6	18.6	2.66	.02810	84-foot well.
Fairbury	I	0.1	1295	173.8			69.0		74.8				225.5	13.1	1.87	.00935	2000-foot well.
Fairfield	II	2.0	137			11.3	2.4		18.5	9.9	.5	.08	18.8	1.0	.15	.00235	Reservoir.
Farmer City	I	1.0	730	225.7			89.0		168.4				331.8	19.2	2.76	.01380	176-foot well.
Farmington	II	0.8	1620			101.2	39.5		164.5	89.1	5.1	.74	191.7	11.1	1.59	.02275	1700-foot well.
Flanagan	I	0.1	2720	320.6			44.0		50.4				256.2	14.9	2.13	.01065	170-foot well.

TABLE SHOWING THE HARDNESS, AND THE AMOUNT OF LIME AND SODA ASH REQUIRED TO SOFTEN THE WATER FURNISHED TO THREE HUNDRED AND THIRTY-EIGHT ILLINOIS MUNICIPALITIES—Continued.

City, town and village.	Class.	Mineral content—parts per million.								Soda ash.			Lime.			Chemicals.	Remarks.
		Iron	Res.	Na_2CO_3.	$MgCl_2$.	$MgSO_4$.	$MgCO_3$.	$CaSO_4$.	$CaCO_3$.	Parts per million.	Grains per gallon.	Pounds per 1000 gallons.	Parts per million.	Grains per gallon.	Pounds per 1000 gallons.	Approximate cost per 1000 gallons.	
Flora	I	1.0	620	70.9	--------	--------	221.3	--------	155.8	--------	--------	--------	419.0	24.4	3.49	.01745	157-foot well.
Forest Park	II	.0	472	--------	--------	62.8	36.7	--------	135.5	55.3	3.2	.46	153.9	8.9	1.27	.01555	1668 and 2015-foot wells.
Freeburg	II	0.8	313	--------	--------	1.0	73.0	--------	74.8	.8	.0	.00	139.4	8.1	1.15	.00575	Reservoir.
Freeport	III	0.7	432	--------	3.1	37.1	126.0	--------	192.0	36.1	2.1	.30	294.0	17.1	2.45	.01825	Before filtration.
Fulton	I	tr.	409	23.4	--------	--------	91.0	--------	153.3	--------	--------	--------	219.2	12.7	1.82	.00910	1500-foot wells.
Galena	I	0.2	254	2.2	--------	--------	115.7	--------	128.7	--------	--------	--------	227.1	13.2	1.89	.00945	1530-foot well.
Galesburg	II	0.3	1689	--------	--------	203.1	23.1	--------	259.2	178.9	10.3	1.48	270.4	15.7	2.25	.04085	1252-foot well.
Galva	I	1.0	929	125.1	--------	--------	57.9	--------	88.6	--------	--------	--------	192.7	11.1	1.60	.00800	1525-foot well.
Geneseo	II	.0	394	--------	--------	75.5	98.9	--------	161.1	66.5	3.8	.55	256.9	14.9	2.13	.02165	Springs.
Geneva	I	.0	415	53.5	--------	--------	104.4	--------	113.4	--------	--------	--------	230.6	13.4	1.91	.09550	890-foot well.
Genoa	I	.0	315	12.9	--------	--------	124.0	--------	163.8	--------	--------	--------	263.4	15.3	2.19	.01095	1500-foot well.
Gibson City	I	1.0	260	57.6	--------	--------	40.2	--------	123.4	--------	--------	--------	153.0	8.9	1.27	.00635	55-foot well.
Gilman	II	0.1	1040	--------	--------	299.4	--------	111.4	302.1	350.5	20.4	2.91	308.6	17.9	2.56	.07100	120-foot well.
Glasford	II	2.2	1630	--------	--------	66.8	57.3	--------	172.5	58.8	3.4	.49	203.8	11.8	1.69	.01825	1669-foot well.
Glen Ellyn	I	0.4	450	30.6	--------	--------	106.0	--------	154.8	--------	--------	--------	243.8	14.1	2.02	.01010	310-foot well.
Glenview	II	1.1	585	--------	--------	78.2	72.1	--------	163.8	68.8	4.0	.57	224.0	13.0	1.86	.02070	1251-foot well.
Grand Ridge	I	0.9	286	138.3	--------	--------	47.4	--------	61.7	--------	--------	--------	170.7	9.9	1.41	.00705	160-foot well.
Grant Park	II	0.9	480	--------	--------	25.9	109.4	--------	242.1	22.8	1.3	.19	292.7	17.0	2.43	.01595	147-foot well.
Granville	I	1.2	975	26.4	--------	--------	96.1	--------	144.4	--------	--------	--------	222.6	12.9	1.85	.00925	1742-foot well.
Grayslake	II	0.2	450	--------	--------	162.3	45.9	--------	104.4	142.9	8.2	1.18	195.1	11.3	1.62	.03170	1039-foot well.
Greenup	III	0.0	681	--------	25.1	60.8	42.9	--------	135.5	81.4	4.7	.67	176.0	10.2	1.46	.02070	Embarrass River.
Greenview	III	1.0	530	--------	22.2	213.1	22.2	--------	222.6	212.4	12.3	1.76	266.5	15.5	2.31	.04675	40-foot well.
Greenville	III	0.0	665	--------	16.1	109.5	57.5	--------	296.3	114.3	6.6	.95	302.8	17.6	2.51	.03155	47-foot well.
Harmon	I	0.6	366	44.8	--------	--------	111.8	--------	166.2	--------	--------	--------	265.4	15.4	2.21	.01105	532-foot well.
Harvard	III	1.0	500	--------	6.8	66.2	101.8	--------	256.6	65.8	3.8	.54	313.9	18.2	2.61	.02385	1475-foot well.
Harvey	II	tr.	1448	--------	--------	251.1	--------	352.6	171.7	495.9	28.8	4.12	213.1	12.4	1.77	.09125	1680-foot well.
Havana	III	0.0	202	--------	1.2	27.3	28.0	--------	100.9	25.3	1.4	.21	107.1	6.2	.89	.00865	72-foot well.
Hebron	I	3.0	267	--------	--------	--------	88.6	--------	107.1	--------	--------	--------	177.8	10.3	1.47	.00735	272-foot well.
Hennepin	I	1.0	2904	500.2	--------	--------	2.4	--------	32.7	--------	--------	--------	285.9	16.6	2.37	.01185	800-foot well.
Henry	III	0.0	520	--------	26.9	55.7	64.8	--------	208.4	79.0	4.6	.65	244.6	14.2	2.03	.02315	40-foot well.
Hinckley	I	0.7	340	38.7	--------	--------	133.3	--------	129.8	--------	--------	--------	270.4	15.7	2.25	.01125	708-foot well.
Hinsdale	II	1.3	664	--------	--------	120.0	20.0	--------	338.0	105.7	6.1	.87	271.7	15.7	2.26	.02870	Before softening.
Homewood	II	1.8	620	--------	--------	105.0	132.8	--------	202.1	92.5	5.3	.77	338.7	19.7	2.81	.02945	250-foot well.
Hoopeston	I	1.6	326	67.9	--------	--------	102.1	--------	130.0	--------	--------	--------	244.2	14.2	2.03	.01015	360-foot well.
Huntley	II	0.8	430	--------	--------	0.5	124.7	--------	225.7	.4	.0	.00	292.5	17.0	2.43	.01215	69 to 74-foot wells.

Ipava	II	.0	2977			297.6		229.6	167.0	441.1	25.7	3.67	232.1	13.5	1.93	.08305	1570-foot well.
Jacksonville	II	3.2	432			10.0	124.0		208.0	8.8	5.1	.73	286.0	16.6	2.38	.02050	68-foot well, No.5.
Jerseyville	II	0.1	3297			292.1		13.6	292.6	267.9	15.5	2.22	299.9	17.4	2.49	.05685	1542-foot well.
Johnston City	II		260			72.0			46.0	63.4	3.6	.52	59.3	3.4	.49	.01285	Stream.
Joliet	I	.0	515	54.7			78.7		144.7				214.6	12.4	1.78	.00890	1547-foot well. Van Buren St.
Kansas	I	3.0	450	25.3			115.1		204.6				281.0	16.3	2.34	.01170	80-foot well.
Keithsburg	III	0.3	1262		26.6	236.8		171.1	341.0	371.5	21.6	3.09	316.9	18.4	2.63	.07495	50-foot well.
Kempton	I	0.3	878	671.3			5.2		14.2				369.7	21.5	3.07	.01535	404-foot well.
Kewanee	II	0.2	1274			42.8	55.1		174.8	37.7	2.1	.31	191.0	11.1	1.59	.01415	1460-foot well.
Kincaid	II	0.2	167			39.7	16.6		64.9	34.9	2.0	.29	76.9	4.4	.64	.00900	Pond.
Kirkwood	I	2.0	530	70.9			155.2		237.2				376.7	21.9	3.13	.01565	127-foot well.
Knoxville	II	0.5	1376			36.1	61.3		169.2	31.7	1.8	.26	182.0	10.6	1.51	.01275	1350-foot well.
LaGrange	II	1.4	737			209.6	59.0		324.6	184.6	10.7	1.53	357.8	20.8	2.97	.04545	2000-foot well.
LaHarpe	I	10.0	515				126.8		272.6				313.3	18.2	2.61	.01305	55-foot well.
LaMoille	I	6.0	500	121.5			131.5		192.2				346.7	20.1	2.88	.01440	268-foot well.
Lacon	II	.0	427			12.0	111.1		202.8	10.5	.06	.08	266.9	15.5	2.21	.01265	60-foot well.
Ladd	I	1.3	475	46.2			136.0		178.0				304.9	17.7	2.53	.01265	187-foot well.
Lake Bluff	I	0.2	318	339.0			20.2		64.0				241.9	14.0	2.00	.01000	Well.
	II	0.1	580			67.6		89.8	251.0	129.5	7.5	1.07	172.0	10.0	1.43	.02851	Well.
Lake Zurich	II	0.2	1376			560.1		583.9	61.4	948.4	55.2	7.90	295.3	11.3	2.46	.17030	218-foot well.
Lanark	I	2.1	338	7.5			105.2		203.8				257.9	14.9	2.14	.01070	600-foot well.
LaSalle	II	0.2	464			99.0	45.6		224.9	87.2	5.0	.72	230.4	13.4	1.91	.02395	40-foot well.
Lee	I	0.4	274	106.0			62.4		73.0				179.8	10.4	1.49	.00745	335-foot well.
Leland	I	4.8	337	20.9			118.7		145.2				250.2	14.5	2.08	.01040	230-foot well.
Lemont	I	0.5	1337	52.7		3.1	64.4		206.6	2.7	.15	.02	230.6	13.4	1.91	.00995	2000-foot well.
Lena	III	0.1	497		1.7	72.0	119.1		254.1	65.3	3.8	.54	335.2	19.5	2.79	.02475	600-foot well.
Lenore	I	0.2	435	98.4			131.2		170.5				321.9	18.7	2.67	.01335	34-foot well.
Leroy	I	0.8	484	36.8			148.9		249.6				346.6	20.1	2.88	.01440	90-foot well.
Lewistown	II	0.2	360			76.7	52.3		179.5	67.5	3.9	.56	205.7	11.9	1.70	.01970	25-foot well.
Lexington	I	1.0	400	70.7			100.1		180.2				271.4	15.7	2.26	.01130	115-foot well.
Libertyville	II	0.8	730			192.2		61.6	131.0	217.3	12.6	1.80	161.9	9.3	1.34	.04270	170 and 180-foot wells.
Lincoln	II	0.1	281			21.7	74.2		145.8	19.1	1.1	.15	190.4	11.0	1.58	.01290	10 to 20-foot wells
Little York	I	0.4	1535	391.1			41.8		45.1				287.6	16.7	2.39	.01195	400-foot well.
Lockport	III	0.1	1376		139.6	62.8		196.0	217.2	363.4	21.1	3.02	233.0	13.5	1.94	.07010	1650-foot well.
Lombard	I	1.6	445	14.5			34.7		297.3				220.2	12.8	1.83	.00915	93-foot well.
Lostant	I	0.1	555	156.2			29.1		120.3				188.5	10.9	1.56	.00780	70-foot well.
Lovington	I	1.3	548	77.4			155.0		264.1				394.9	22.9	3.28	.01640	147-foot well.
Low Point	III	0.2	555		40.3	109.3	58.1		231.7	141.1	8.2	2.00	281.6	16.3	2.34	.05170	51-foot well.
Lyons	II	0.0	583			171.2	41.7		225.2	150.8	8.7	1.25	261.3	15.2	2.17	.03585	1650-foot well.
McHenry	I	0.5	355	33.6			107.4		142.2				240.2	13.9	2.00	.01000	71-foot well.
Mackinaw	I	1.7	540	26.7			172.8		250.9				384.4	22.3	3.20	.01600	172-foot well.
Malta	I	0.1	265	69.3			81.4		91.6				228.8	13.2	1.90	.00950	Well.
Manhattan	II	0.2	464			21.6	133.3		220.6	18.7	1.0	.15	310.8	18.0	2.58	.01590	105-foot well.
Manteno	III	0.4	646		2.6	229.9		2.1	300.8	207.0	12.0	1.72	277.0	16.1	2.31	.04595	426-foot well.
Maple Park	I	0.1	307	38.7			93.2		130.8				217.6	12.6	1.80	.00900	250-foot well.
Marengo	III	0.1	392		20.1	66.8	60.2		210.3	81.1	4.7	.67	240.7	13.9	2.00	.02340	14-foot well.
Marion	I	0.7	865	508.2			9.3		5.0				283.8	16.4	2.36	.01180	Wells.
Maroa	I	4.0	413	161.6			45.0		155.2				232.1	13.5	1.93	.00965	85-foot well.

TABLE SHOWING THE HARDNESS, AND THE AMOUNT OF LIME AND SODA ASH REQUIRED TO SOFTEN THE WATER FURNISHED TO THREE HUNDRED AND THIRTY-EIGHT ILLINOIS MUNICIPALITIES—Continued.

City, town and village.	Class.	Mineral content—parts per million.								Soda ash.			Lime.			Chemicals.	Remarks.
		Iron.	Res.	Na_2CO_3.	$MgCl_2$.	$MgSO_4$.	$MgCO_3$.	$CaSO_4$.	$CaCO_3$.	Parts per million.	Grains per gallon.	Pounds per 1000 gallons.	Parts per million.	Grains per gallon.	Pounds per 1000 gallons.	Approximate cost per 1000 gallons.	
Marseilles	II	0.2	568	------	------	29.0	94.0	------	178.0	25.5	1.4	.21	238.2	13.8	1.98	.01410	800-foot well.
Marshall	II	0.0	286	------	------	20.9	41.6	------	172.2	18.4	1.0	.15	161.4	9.3	1.34	.00970	27-foot well.
Mascoutah	II	4.0	741	------	------	227.9	1.8	25.9	254.4	220.9	12.8	1.83	251.0	14.6	2.09	.04705	35 to 40-foot wells.
Mason City	I	0.8	285	8.9	------	------	96.4	------	158.4	------	------	------	221.6	12.8	1.84	.00920	198-foot well.
Matteson	II	1.2	699	------	------	218.6	46.7	------	296.7	192.6	11.1	1.60	330.0	19.2	2.75	.04575	282-foot well.
Mattoon	I	3.8	515	73.9	------	------	136.5	------	218.8	------	------	------	343.1	19.9	2.86	.01430	70-ft. well, No. 27.
	I	2.0	520	164.7	------	------	97.6	------	156.3	------	------	------	304.3	17.7	2.53	.01265	96-ft. well, No. 26.
Maywood	I	.2	620	3.6	------	------	86.6	------	150.5	------	------	------	201.3	11.7	1.67	.00835	2048-foot well.
Melrose Park	II	0.1	547	------	------	136.8	21.8	------	245.0	120.5	6.9	1.00	229.9	13.3	1.90	.02600	1571-foot well.
Melvin	I	2.4	426	59.1	------	------	132.3	------	178.0	------	------	------	306.8	17.8	2.55	.01275	231-foot well.
Mendota	I	3.2	382	65.6	------	------	86.9	------	176.5	------	------	------	249.0	14.5	2.07	.01035	Well.
Metropolis	III	0.4	236	------	2.7	19.9	17.7	------	162.5	20.5	1.1	.17	125.9	7.2	1.04	.00860	270-foot well.
Milan	I	1.9	1149	120.3	------	------	73.4	------	103.2	------	------	------	226.2	13.1	1.88	.00940	1157-foot well.
Milford	II	1.4	710	------	------	137.2	93.5	------	267.8	120.8	6.9	1.00	338.2	19.7	2.81	.03405	65-foot well.
Milledgeville	I	0.0	332	7.8	------	------	121.5	------	178.1	------	------	------	265.4	15.4	2.21	.01105	East well.
Minier	I	1.5	384	60.5	------	------	117.7	------	151.9	------	------	------	273.5	15.9	2.27	.01135	143-foot well.
Minonk	I	0.2	2337	363.5	------	------	24.6	------	22.2	------	------	------	237.3	13.8	1.97	.00985	1850-foot well.
Minooka	I	0.3	1182	51.0	------	------	71.0	------	138.0	------	------	------	125.8	7.2	1.04	.00520	620-foot well.
Mokena	II	0.6	612	------	------	149.7	41.9	------	360.5	131.8	7.6	1.09	327.3	19.0	2.72	.03540	139-foot well.
Momence	III	0.0	501	------	3.9	202.8	2.1	------	244.9	183.0	10.6	1.52	236.7	13.7	1.96	.04020	85 to 135-foot wells.
Monee	II	8.0	1035	------	------	244.2	------	192.9	367.4	365.4	21.2	3.04	319.5	18.5	2.65	.07405	166-foot well.
	II	1.2	768	------	------	186.3	145.8	------	274.8	164.1	9.5	1.36	434.5	25.3	3.61	.04525	169-foot well.
Monmouth	II	0.1	1715	------	------	235.2	------	21.5	248.8	223.9	13.0	1.85	248.8	14.5	2.06	.04730	1222-foot well.
Monticello	I	2.4	328	84.2	------	------	88.5	------	123.6	------	------	------	231.4	13.5	1.92	.00960	209 to 309-foot wells.
Morris	I	0.0	402	18.8	------	------	111.2	------	170.9	------	------	------	253.5	14.7	2.11	.01055	800-foot well.
Morrison	II	0.5	293	------	------	10.4	104.8	------	138.0	9.1	0.5	.07	221.4	12.8	1.84	.01060	2048-foot well.
Morrisonville	II	0.5	918	------	------	152.2	------	173.6	319.0	269.3	15.6	2.24	249.5	14.5	2.07	.05515	35-foot well.
Morton	I	1.0	515	44.4	------	------	139.0	------	205.0	------	------	------	323.1	18.8	2.69	.01345	230-foot well.
Morton Grove	II	1.5	616	------	------	125.8	15.6	------	253.8	110.8	6.4	.91	221.4	12.8	1.84	.02740	1468-foot well.
Mound City	III	0.3	282	------	24.9	16.3	9.7	------	112.8	42.0	2.4	.35	98.3	5.7	.81	.01105	630-foot well.
Mounds	I	0.4	252	117.2	------	------	24.9	------	111.5	------	------	------	157.5	9.1	1.30	.00650	650-foot well.
Mount Carroll	II	0.1	350	------	------	6.0	132.2	------	137.2	5.2	.3	.04	255.4	14.8	2.12	.01140	2500-foot well.
Mount Morris	III	0.1	500	------	60.5	44.6	68.9	------	207.4	106.6	6.1	.88	264.1	15.3	2.20	.02860	500-foot well.
Mount Olive	II	0.4	81	------	------	4.1	12.1	------	34.4	3.6	.2	.03	37.2	2.1	.31	.00215	Reservoir.

Mount Pulaski	III	0.1	982	-------	120.9	181.4	-------	63.6	390.9	343.9	19.9	2.86	374.6	21.8	3.11	.07275	32-foot well.
Mount Sterling	I	0.1	4635	-------	-------	-------	461.6	199.6	272.0	155.5	9.0	1.29	766.2	44.6	6.38	.06770	2235-foot well.
Moweaqua	I	0.8	316	0.7	-------	-------	88.0	-------	162.7	-------	-------	-------	208.5	12.1	1.73	.00865	56-foot well.
Naperville	II	0.1	495	-------	-------	123.8	66.4	-------	211.2	109.0	6.3	.90	264.2	15.3	2.20	.01280	1375-foot well.
Neoga	I	2.0	335	45.8	-------	-------	72.7	-------	145.9	-------	-------	-------	202.6	11.7	1.68	.00840	16-foot well.
Niles Center	II	0.4	400	-------	-------	33.3	27.7	-------	115.1	29.3	1.7	.24	116.7	6.7	.96	.00960	1440-foot well.
Nokomis	II	5.3	721	-------	-------	110.4	32.5	-------	304.5	97.2	5.6	.81	265.1	15.4	2.21	.02725	42-foot well.
Normal	I	3.8	414	140.2	-------	-------	122.2	-------	77.6	-------	-------	-------	280.0	16.3	2.33	.01165	180-foot well.
North Crystal Lake	I	0.8	328	46.6	-------	-------	94.1	-------	138.0	-------	-------	-------	227.0	13.2	1.89	.00945	279-foot well.
Oakland	I	0.8	545	143.0	-------	-------	89.0	-------	162.9	-------	-------	-------	285.1	16.6	2.37	.01185	95 and 115-foot wells.
Odell	I	0.1	2343	170.2	-------	-------	67.9	-------	103.5	-------	-------	-------	239.0	13.9	1.99	.00995	1360-foot well.
O'Fallen	I	1.3	392	-------	-------	-------	122.3	-------	190.3	-------	-------	-------	269.2	15.6	2.24	.01120	50-foot well.
Oglesby	I	0.5	970	79.6	-------	-------	81.0	-------	122.3	-------	-------	-------	218.2	12.7	1.81	.00905	1645-foot well.
Ohio	I	5.0	345	147.4	-------	-------	67.2	-------	100.3	-------	-------	-------	224.2	13.0	1.86	.00930	385-foot well.
Onarga	II	1.7	935	-------	-------	280.7	-------	50.4	331.6	286.5	16.6	2.38	316.4	18.4	2.63	.06075	110 to 115-foot wells.
Oregon	I	0.8	285	2.0	-------	-------	63.7	-------	157.5	-------	-------	-------	173.9	10.0	1.44	.00720	1610-foot well.
Oswego	II	0.1	600	-------	-------	80.3	54.0	-------	144.5	70.7	4.1	.58	190.1	11.0	1.58	.01950	18-foot well.
Ottawa	I	0.4	402	89.0	-------	-------	77.0	-------	144.0	-------	-------	-------	230.1	13.4	1.91	.00955	1200-foot well.
Palatine	II	0.7	740	-------	-------	283.6	-------	26.4	174.9	270.4	15.7	1.72	230.0	13.4	1.91	.04395	168-foot well.
Paris	II	0.1	245	-------	-------	27.6	45.0	-------	131.5	24.3	1.4	.20	146.2	8.5	1.21	.01005	Reservoir.
Paw Paw	I	1.5	220	68.9	-------	-------	89.2	-------	113.6	-------	-------	-------	218.6	12.7	1.81	.00905	1018-foot well.
Paxton	I	0.4	500	104.9	-------	-------	116.3	-------	199.1	-------	-------	-------	321.6	18.7	2.67	.01335	142 to 148-foot wells.
Pearl	II	0.1	243	-------	-------	13.1	37.3	-------	137.6	11.5	.6	.09	143.9	8.3	1.19	.00775	Spring.
Pearl City	III	0.6	707	-------	59.2	154.0	67.6	-------	299.5	201.5	11.7	1.67	365.0	21.2	3.04	.04860	40-foot well.
Pecatonica	II	0.1	336	-------	-------	44.2	105.0	-------	169.0	38.9	2.2	.32	254.8	14.8	2.11	.01695	20-foot well.
Pekin	III	0.0	500	-------	22.9	67.4	59.7	-------	211.3	84.8	4.9	.70	242.5	14.1	2.01	.02405	75 to 85-foot wells.
Peoria	II	0.1	404	-------	-------	57.1	12.1	-------	188.4	50.3	2.9	.41	146.8	8.5	1.21	.02125	Well No. 1.
	II	0.1	440	-------	-------	-------	141.6	-------	225.2	-------	-------	-------	314.4	18.3	2.61	.00605	Well No. 7.
Peotone	II	0.6	599	-------	-------	120.4	53.3	-------	264.1	106.0	6.1	.88	274.8	15.9	2.28	.02900	135-foot well.
Peru	II	0.6	1027	-------	-------	102.4	13.2	-------	225.4	90.2	5.2	.75	191.4	11.1	1.59	.02295	1200 to 1500-foot wells.
Petersburg	III	7.0	749	-------	28.3	239.3	7.2	-------	345.7	242.3	14.1	2.01	331.2	19.2	2.76	.05400	44-foot well.
Piper City	I	0.6	440	64.8	-------	-------	124.1	-------	233.1	-------	-------	-------	329.8	19.1	2.74	.01370	70-foot well.
Pittsfield	II	0.4	3518	-------	-------	413.4	-------	183.5	313.1	507.2	29.5	4.22	367.9	21.3	3.06	.09970	200-foot well, filled to 600 feet?
Plainfield	II	0.4	650	-------	-------	53.6	105.6	-------	216.7	47.2	2.7	.39	286.7	16.6	2.38	.01970	1380-foot well.
Polo	II	0.2	339	-------	-------	5.3	122.6	-------	174.4	4.6	.2	.03	263.1	15.3	2.19	.01155	1200 and 2100-foot wells.
Poplar Grove	III	0.3	387	-------	4.8	75.4	80.0	-------	195.4	71.7	4.1	.59	253.7	14.7	2.11	.02235	130-foot well.
Princeton	I	tr.	416	58.9	-------	-------	86.9	-------	149.8	-------	-------	-------	230.5	13.4	1.91	.00955	2550-foot well.
	I	0.2	483	93.2	-------	-------	70.3	-------	120.6	-------	-------	-------	210.2	12.2	1.75	.00875	2092-foot well.
	I	0.6	348	97.6	-------	-------	81.0	-------	142.5	-------	-------	-------	239.1	13.9	1.99	.00995	245-foot well.
Princeville	II	1.4	1645	-------	-------	188.8	-------	4.5	234.5	162.7	9.4	1.35	219.2	12.7	1.82	.03610	1600-foot well.
Rankin	I	1.6	359	49.0	-------	-------	107.7	-------	199.7	-------	-------	-------	280.9	16.3	2.33	.01165	270-foot well.
Rantoul	I	1.8	350	55.7	-------	-------	63.5	-------	202.1	-------	-------	-------	227.0	13.2	1.89	.00945	120-foot well.
Red Bud	I	0.3	457	50.6	-------	-------	56.3	-------	156.7	-------	-------	-------	189.3	11.0	1.57	.00785	294-foot well.

TABLE SHOWING THE HARDNESS, AND THE AMOUNT OF LIME AND SODA ASH REQUIRED TO SOFTEN THE WATER FURNISHED TO THREE HUNDRED AND THIRTY-EIGHT ILLINOIS MUNICIPALITIES-Continued.

City, town and village.	Class.	Mineral content—parts per million.								Soda ash.			Lime.			Chemicals.	Remarks.
		Iron.	Res.	Na_2CO_3.	$MgCl_2$.	$MgSO_4$.	$MgCO_3$.	$CaSO_4$.	$CaCO_3$.	Parts per million.	Grains per gallon.	Pounds per 1000 gallons.	Parts per million.	Grains per gallon.	Pounds per 1000 gallons.	Approximate cost per 1000 gallons.	
Riverdale	I	0.3	418	156.5			31.2		50.4				144.4	8.3	1.20	.00600	430-foot well.
	II	0.1	148			12.7	30.5		87.1								
River Forest	II	0.2	526			50.4	55.4		179.0	44.4	2.5	.37	197.3	11.4	1.64	.01560	1000-foot well.
Riverside	I	0.2	891	121.3			72.0		159.1				248.9	14.4	2.06	.01030	2000-foot well, east well.
	II	3.6	643			268.8	39.8		197.3	236.8	13.7	1.96	288.6	16.7	2.40	.04940	2000-foot well, west well.
Roanoke	II	0.6	634			195.5	39.1		272.1	172.2	10.0	1.43	295.4	17.1	2.46	.04090	30-foot well.
Roberts	II	2.4	644			133.0	35.7		272.1	117.1	6.8	.97	261.8	15.2	2.17	.03025	216-foot well.
Robinson	III	tr.			2.6	23.6	27.7		129.1	23.6	1.3	.19	121.6	7.0	1.00	.00880	30-foot well.
Rochelle	II	0.0	364			560.0	114.6		160.0	493.4	28.7	4.11	502.9	29.2	4.18	.10310	1980-foot well.
	II	1.0	362			29.2	87.9		145.6	25.7	1.4	.21	212.0	12.3	1.76	.01300	1026-foot well.
Rockdale	I	0.6	526	34.3			75.5		144.8				190.6	11.6	1.65	.00825	662-foot well.
Rockford	II	0.7	325			7.6	117.7		169.9	6.6	.3	.05	255.2	14.8	2.12	.01160	Wells.
Roodhouse	I	6.4	206				50.2		76.3				109.5	6.3	.90	.00450	Reservoir.
Roseville	II	1.4	2527			429.6		441.1	223.2	722.2	42.0	6.02	325.1	18.9	2.71	.13395	1350-foot well.
Rossville	I	2.0	400	64.0			130.0		160.0				296.3	17.2	2.46	.01230	120 to 130-foot well.
Rushville	I	0.3	401	1.2			130.7		206.0				289.8	16.8	2.41	.01205	24-foot well.
St. Anne	II	2.6	832			217.5		148.7	234.6	307.4	17.8	2.56	232.6	13.5	1.93	.06085	210-foot well.
St. Charles	II	0.8	565			28.7	138.2		212.4	25.2	1.4	.21	316.1	18.4	2.63	.01735	350-foot well.
	I	0.4	389	55.4			106.3		161.3				260.9	15.1	2.16	.01080	850-foot well.
San Jose	III	1.0	526		52.4	75.4	37.0		255.1	124.7	7.2	1.03	258.0	15.0	2.15	.03135	105-foot well.
Sandwich	II	0.1	380			11.7	116.4		185.2	10.3	.5	.08	263.9	15.3	2.19	.01255	600-foot well.
Savanna	II	0.5	301			1.6	131.6		123.8	1.4	.0	.01	245.0	14.2	2.04	.01040	1430-foor well.
Secor	I	4.0	664	40.7			205.4		306.7				486.1	28.3	4.05	.02025	185-foot well.
Sheffield	II	0.1	505			44.5	128.8		241.8	39.2	2.2	.32	326.8	19.0	2.71	.01995	50-foot well.
Shelbyville	II	0.6	413			60.0	50.5		194.1	52.8	3.0	.44	203.8	11.8	1.69	.01725	25-foot well.
Sheldon	I	0.4	370	147.9			64.1		74.0				204.8	11.8	1.70	.00850	130-foot well.
	I	0.1	600	321.4			9.4		12.8				189.5	11.0	1.57	.00785	1850-foot well.
Shermerville	II	0.9	1260			410.3		238.4	97.9	547.2	31.8	4.56	245.9	14.2	2.04	.10140	1345-foot well.
Somonauk	I	1.4	352	87.5			75.8		139.0				224.8	13.0	1.86	.00930	500-foot well.
South Chicago Heights	I	0.2	465	3.9			147.5		233.0				328.7	19.1	2.73	.01365	2700-foot well.
Spring Valley	I	0.1	770	46.0			106.3		155.3				252.6	14.6	2.10	.01050	1480-foot well.
Springfield	II	1.1	370			53.4	66.1		182.4	47.0	2.7	.39	214.9	12.4	1.78	.01670	

Standard	I	1.4	1084	44.4			61.3		121.3				172.9	10.0	1.43	.00715	1767-foot well.
Stanford	I	1.4	402	55.0			124.6		208.7				311.6	18.1	2.59	.01295	131-foot well.
Staunton	II	0.1	249			82.1		72.4	41.4	128.7	7.4	1.06	61.4	3.5	.51	.02375	Reservoir.
Steger	I	0.4	471	8.1			138.1		218.7				310.4	18.0	2.58	.01290	318-foot well.
Sterling	III	0.0	348		9.8	28.0	99.7		164.8	35.5	2.0	.29	243.6	14.1	2.02	.01590	1334 to 1829-foot wells.
Steward	I	0.6	295	40.7			69.3		160.0				203.2	11.8	1.69	.00845	100-foot well.
Stockton	II	0.2	339			2.5	126.5		170.9	2.2	.1	.01	265.1	15.4	2.21	.01025	1500-foot well.
Stonington	II	2.5	495			3.4	94.2		253.3	2.9	.1	.02	268.7	15.6	2.23	.01155	40-foot well.
Strawn	II	2.5	532			125.4	56.4		233.3	110.4	6.4	.91	264.0	15.3	2.20	.02920	45-foot well.
Stronghurst	II	4.0	2971			545.7		546.5	239.1	906.6	52.8	7.55	388.1	22.6	3.23	.16715	1009-foot well.
Sublette	I	0.4	270	73.6			82.8		97.6				203.6	11.8	1.69	.00845	752-foot well.
Sullivan	I	1.2	505	154.9			133.7		157.0				347.6	20.2	2.89	.01445	79-foot well.
Summit	I	0.5	699	3.2			102.5		181.9				239.8	13.9	1.99	.00995	1864-foot well.
Sycamore	II	1.3	354			0.9	121.5		222.4	.7	.0	.00	286.5	16.6	2.38	.01190	905-foot well.
Tampico	II	0.2	358			60.0	3.4		200.0	52.8	3.0	.44	144.4	8.3	1.20	.01480	25-foot well.
Taylorville	II	1.2	805			297.2		59.0	277.3	307.8	17.8	2.56	293.7	17.0	2.44	.06340	92-foot well.
Thomson	III	tr.	239		8.1	32.4	7.5		77.7	37.5	2.1	.31	73.3	4.2	.61	.00925	37 and 40-foot wells.
Tinley Park	I	0.9	488	3.2			178.4		216.3				360.0	20.9	3.00	.01500	915-foot well.
Tiskilwa	II	0.2	330			12.8	135.6		105.9	11.2	.6	.09	245.6	14.2	2.04	.01200	Spring.
Tolono	I	2.7	678	264.4			117.6		221.2				420.0	24.4	3.50	.01750	157-foot well.
Toluca	I	2.0	2233	69.0			15.9		92.5				109.4	6.3	.90	.00450	2000-foot well.
Toulon	I	0.1	1147	48.8			68.9		116.0				182.3	10.6	1.51	.00755	1445-foot well.
Tremont	I	2.6	396	79.4			133.0		132.5				293.0	17.0	2.44	.01220	132-foot well.
Trenton	I	0.3	980	480.1			24.6		31.4				304.1	17.7	2.53	.01265	235-foot well.
Tuscola	I	0.5	405	94.1			87.1		128.0				237.2	13.8	1.97	.00985	300-foot well.
Union	III		532		68.6	137.2		14.7	259.5	208.6	12.1	1.73	249.6	14.5	2.07	.04495	16-foot well.
Urbana	I	1.8	392	46.2			118.4		180.7				283.0	16.4	2.36	.01180	160-foot well.
Utica	I	0.7	388	4.3			100.4		212.2				254.6	14.8	2.11	.01055	Mill St. well.
	III	0.5	444		5.1	8.5	103.9		215.1	13.1	.7	.10	265.5	15.4	2.21	.01305	Well near city hall.
Viola	I	1.1	1128	16.5			88.9		121.7				195.0	11.3	1.62	.00810	1281-foot well.
Walnut	I	5.0	345	26.7			102.8		167.5				244.6	14.2	2.03	.01015	230-foot well.
Warren	III	0.1	379		1.7	38.0	122.3		184.5	35.3	2.0	.29	284.6	16.5	2.36	.01760	875-foot well.
Washington	I	2.4	361	45.1			48.5		193.5				196.7	11.4	1.63	.00815	90-foot well.
Waterman	II	1.0	572			33.9	177.4		121.5	29.8	1.7	.34	319.7	18.5	2.66	.02010	72-foot well.
Watseka	I	1.6	345	151.2			51.3		95.2				201.4	11.7	1.67	.00835	150-foot well.
Waynesville	I	1.8	537	101.5			169.1		249.8				418.4	24.3	3.48	.01740	116-foot well.
Weldon	I	1.5	596	99.7			204.2		240.6				464.0	27.0	3.86	.01930	86-foot well.
Wenona	II	0.3	1522			31.2	108.4		86.4	27.4	1.5	.22	207.0	12.0	1.72	.01300	1857-foot well.
West Brooklyn	I	2.2	385	73.8			91.8		186.5				265.5	15.4	2.21	.01105	358-foot well.
West Chicago	II	0.8	405			27.3	110.4		166.2	24.0	1.3	.20	252.6	14.6	2.10	.01450	322-foot well.
West Dundee	II	tr.	360			45.1	93.5		170.2	39.7	2.3	.33	240.6	13.9	2.00	.01660	Springs.
West Frankfort	III	6.8	1105		22.3	85.0	136.8		394.5	99.7	5.8	.83	455.5	26.5	3.79	.03655	62-foot well.
Western Springs	II	5.6	1175			393.5		176.6	415.6	484.3	28.2	4.03	416.0	24.2	3.46	.09790	2046-foot well.
Wheaton	II	0.1	375			4.5	109.4		141.6	3.9	.2	.03	226.8	13.1	1.88	.01900	175-foot well.
Whitehall	I	0.1	140	3.5			111.6		65.9				187.1	10.9	1.55	.00775	Reservoir.
Wilmington	II	0.4	1145			139.3	30.5		220.0	122.7	7.1	1.01	228.6	13.2	1.90	.02970	720-foot well.
Winchester	I	2.0	304	12.2			101.3		163.8				232.8	13.5	1.93	.00965	42-foot well.

TABLE SHOWING THE HARDNESS, AND THE AMOUNT OF LIME AND SODA ASH REQUIRED TO SOFTEN THE WATER FURNISHED TO THREE HUNDRED AND THIRTY-EIGHT ILLINOIS MUNICIPALITIES—Concluded.

City, town and village.	Class.	Mineral content—parts per million.								Soda ash.			Lime.			Chemicals.	Remarks.
		Iron.	Res.	Na_2CO_3.	$MgCl_2$.	$MgSO_4$.	$MgCO_3$.	$CaSO_4$.	$CaCO_3$.	Parts per million.	Grains per gallon.	Pounds per 1000 gallons.	Parts per million.	Grains per gallon.	Pounds per 1000 gallons.	Approximate cost per 1000 gallons.	
Winslow	II	0.0	315	--------	--------	13.1	64.5	--------	208.2	11.5	.6	.09	208.4	12.1	1.73	.01045	200-foot well.
Woodhull	I	0.6	946	69.2	--------	--------	52.6	--------	105.8	--------	--------	--------	165.7	9.6	1.37	.00685	1394-foot well.
Wood River	II	0.4	323	--------	--------	51.1	34.9	--------	168.9	45.0	2.6	.37	164.7	9.5	1.36	.01420	100-foot well.
Woodstock	I	2.6	403	20.3	--------	--------	145.1	--------	190.7	--------	--------	--------	309.2	18.0	2.57	.01285	85-foot well.
Wyoming	I	tr.	1047	58.2	--------	--------	69.6	--------	98.8	--------	--------	--------	178.6	10.3	1.48	.00740	1557-foot well.
Yorkville	II	tr.	380	--------	--------	97.7	28.1	--------	195.5	86.0	5.0	.71	192.3	11.1	1.60	.02220	Springs.

THE FERTILIZER VALUE OF ACTIVATED SLUDGE.*

By William Durrell Hatfield.

INTRODUCTION.

In the early part of the nineteenth century sewage was disposed of by discharging it into the nearest body of water. This practice soon polluted the small rivers of England until they became "boiling stinking masses." Interest in sanitary legislation in England began in 1842 when the Poor Law Commission reported that all sewage should be run on farm land. Six years later in 1848 the Public Health Act was enacted to prevent rivers and other receivers of sewage from becoming offensive to the eye and nose. These two acts were equally unsuccessful since they were not enforced. After a severe cholera epidemic, the Nuisance Removal Act, passed in 1855, marked the first really serious legislation. It was followed by the appointment of the Royal Sewage Commission in 1857, the Royal Commission on River Pollution in 1865, and the Second Royal Commission on River Pollution in 1868, to study methods of avoiding nuisance caused by dumping putrescible matter in rivers.

The history of the sanitary awakening of the authorities in Europe and America would take up too much space to be discussed here, the it would make most interesting reading. The great amount of experimental work going on in our larger cities at the present time is evidence of the importance attached to safeguarding our streams from gross pollution.

Pollution of a stream by sewage is caused by the introduction of more suspended and colloidal organic matter than it is able to handle by its natural tendencies toward self-purification. Therefore, the best method of sewage disposal, in a particular case, is the one which so reduces the quantities of the suspended and colloidal matter that the treated sewage can be handled by the receiving body of water without overtaxing its natural purification power. The presence of this material gives ries to a large accumulation of sludge, which in the case of domestic sewage is made up of the insoluble fecal matter, paper, insoluble

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material from sinks, laundries, and baths, and the grit and debris from the street washings, if allowed to enter the sanitary sewers. In case the sewage is contaminated with industrial waste many other types of solids will be present, depending on the kind of wastes. The dried sludge obtained by plain sedimentation will usually be from one-half a ton to a ton per million gallons, according to the amount of dilution water used. In Europe, the amount will usually be from *2* to 3 tons per million gallons, because less water is used for dilution. Sludge as it is removed from the sewage purification tanks is in a semi-liquid state containing from 70 to 90 per cent water, part of which must be removed before it can be handled for disposal. In some cities it may be collected in boats and dumped into the sea without removing any water, but usually it must be dried on sand beds or filter-pressed to lower the moisture content to 60 or 80 per cent, thus reducing the volume 50 to 80 per cent. This dried sludge may be disposed of by dumping, trenching, lagooning, or destructive distillation; in a few cases, after further drying, the fats are extracted, and the residue is used as a fertilizer.[10] Chemical analysis of sludges suggests their value as fertilizers, but in few instances have they been sold for this purpose.

The supply and demand of nitrogen in the United States in 1914 and 1916[17] indicated that in 1918 the demand would be 309,000 tons of nitrogen, while the prospective supply, in case of war, would be 77,000 tons. Thus the demand in 1918 is four times as great as the supply. Even before the war the importance of nitrogen fixation was recognized by the United States Government and an appropriation of $20,000,000 was made for a government nitrate plant. This appropriation was to make us independent of imports for our nitrogen supply in case of war. An increase in the production of organic nitrogenous fertilizers would relieve the situation to a considerable degree. On the other hand, the high grades of organic nitrogenous fertilizers, cotton seed meal, gluten meal and dried blood, are finding more profitable use as cattle feed and are disappearing from the fertilizer market.

The nitrogen loss by the wasteful disposal of sludge from sewage purification processes is one of the greatest economic wastes in the civilized world today. The Metropolitan Sewerage Commission[25] of New York City, in 1910, estimated the dry suspended matter in the New York City sewage at 45 tons annually per 1,000 inhabitants. When it is considered that sewage sludge contains from 1.5 to 3 per cent nitrogen, 0.5 to 1.8 per cent phosphorus as P_2O_5 and 6 to 10 per cent fats, it is easy to see the economic waste in not recovering the vast supply of nitrogen and phosphorus which might be made available for use as fertilizer, and of fat which is so valuable at the present time. The chief difficulty in the disposal of sludge from septic and Imhoff tanks as a fertilizer, is its high grease and water content.

A new method of sewage disposal[2] popularly known as "the activated sludge method" yields a sludge relatively high in nitrogen and phosphorus, and low in grease, but the moisture is very high and is held with great tenacity and methods of drying are still a serious problem in the preparation of the sludge for the fertilizer market. It has been shown[6] that the nitrogen is in a form available for plant food, and further studies, to be reported in this thesis, confirm and attempt to explain our first results.

Vast amounts of nitrogen are thrown away in the disposal of the sewage sludge from septic and sedimentation tanks, but a still larger amount is lost through anaerobic decomposition in these processes.[15] Nitrogen, ammonia and volatile amines are liberated by reduction and hydrolysis of the more complex solid organic nitrogenous substances. Furthermore, the colloidal material remaining in suspension after sedimentation is highly nitrogenous, and is wasted unless subsequently caught in sprinkling filters, where the oxidizing reactions prevent putrefaction. Sprinkling filter sludge contains about two or three times as much nitrogen as ordinary septic sludge (3 to 4 per cent), and recently engineers[34] have recommended supplementing sprinkling filters with humus tanks to recover this sludge.

The Miles acid method of sewage treatment[41] has recently been discussed in technical magazines because large quantities of grease may be extracted from the sludge, leaving a residue high in nitrogen which should be available as a fertilizer base. The nitrogen content of this sludge obtained by Dorr[41] working with a strong Boston sewage is 3.3 to 3.6 per cent, figured on a dry basis. In this process the sewage is nearly sterilized, and no loss of nitrogen by putrefaction and reduction should take place. This is borne out by the high nitrogen content of the sludge. On the other hand, much nitrogen in the colloidal form is not thrown down by this method of treatment.

In the aeration of sewage in the presence of activated sludge, a sludge is formed which is still higher in nitrogen content than those mentioned above. This is probably due to the more complete precipitation of colloidal matter in the sewage, and the limited action of aerobic bacteria upon the nitrogenous matter. Some have attributed the high nitrogen content to the destruction of carbonaceous matter by aerobic decomposition.[32]

In Table 1 is found a summary of chemical analyses of various types of sludges showing the variation in their nitrogen content.

TABLE 1—NITROGEN CONTENT OF VARIOUS SLUDGES.

	Per cent organic matter.	Per cent total N.	Per cent P_2O_5.
Septic tanks	29–54	1.1–2.9	
Emscher tank	38	1.2	
Filters—intermittent		1.45	0.78
Chemical precipitation		1.28	0.98
Grossmann's process	35	1.5	5.5
Globe fertilizer	43	1.65	1.71
Miles acid		2.7 to 3*	
Milwaukee activated sludge		4.5†	1.75
Urbana activated sludge	75	6.3	1.44
Urbana activated sludge		4.59	
Chicago Packing House waste		4.59	2.

* Calculated from NH_3 to N_2.
† Calculated as N_2.

HISTORICAL DEVELOPMENT OF SEWAGE SLUDGE AS A FERTILIZER.

The conservation of fecal material for fertilizing purposes was practiced years ago in China,[12] where the need was most pressing for nitrogen and phosphorus to fertilize the vast expanse of land. This most primitive and effective method of disposal has long been followed on the continent of Europe, and until quite recently has been employed on a large scale in Baltimore, Md. In 1909[1] Dr. J. M. Bosley, Commissioner of Health, reports that 61,748 loads (200 barrels each) of night soil were removed from cesspools and towed by barges down the Patapsco River for about eight miles, where the contents were pumped into lagoons prepared by farmers. These lagoons were used merely for storage until the material was required; then it was bailed with long-handled dippers into tank carts and sprinkled over the fields. Farmers reported that the liquid portion appeared to be more immediately effective but the heavier portion produced a more lasting effect. With the introduction of sewers this method of disposal, of course, is rapidly being abandoned.

The utilization of the fertilizing constituents of a city's sewage was first officially recognized in England by the Royal Sewerage Commission appointed in 1857, whose report in 1865 recommended land treatment of sewage but expressed doubt as to the profits of sewage farming. However, irrigation of land with sewage was a very old practice when this report was made. A famous example had existed for two centuries in Edinburgh.[2]* Since the middle of the sixteenth century the sewage of Bunzlau, a German town, had been used for irrigating cultivated ground, and. the same method had been practiced in Ashburton and other Devonshire towns from the beginning of the eighteenth century. A committee appointed by the local governing board in 1875 reported "that **town sewage can be best and most cheaply disposed of and purified by the pro-**

cess of land irrigation for agricultural purposes, where local conditions are favorable to its application." It was pointed out however that the fertilizing value to the farmer was greatly reduced because the sewage must be disposed of daily throughout the year. Sewage farms in England have not been successful from a financial point of view, and have gradually been replaced by chemical and biological treatment.

The largest and best managed sewage farms are those of Berlin and Paris. Data on the cost and return from the Berlin farms are given in the 1914 report of the Metropolitan Sewage Commission of New York. The expense for the year ending March 31, 1910, was:

Maintenance	$1,300,385.24
Interest and loans	741,817.62
Total	$2,042,202.86
Receipts for year	$1,240,772.58
Estimated increase of live stock and other property	122,593.50
Total	$1,363,366.08

This shows a total loss for the year of $678,836.78.

Calmette according to Clark[8] after studying the Paris farms concluded that they will be abandoned, and Dunbar believes that at Berlin artificial filters will some day take the place of the vast sewage farms now in use. In the United States sewage farming has not been considered favorably by our large cities but there are a number of smaller places where it is practiced with varying success.

Literature' is full of reports on the availability of the nitrogen and phosphorus in sludge. The conclusion in the 5th Report (1908) of the British Royal Commission on Sewage Disposal was that, while sludge undoubtedly has a fertilizing value, the value is small compared with the gross mass of the sludge, and consequently depends on the cost of carriage. In Appendix 4 of this report Dr. J. A. Voelcker concluded that sludge on grass land had doubtful fertilizing value and that lime was needed to increase the availability of the nitrogen. T. H. Middleton, in the same appendix also reports that the sludge has no manurial value on grass land. More promising results were reported later by Dr. Voelcker after two years work with grain fields. Sludge applied at the rate of 40 pounds of nitrogen per acre increased the wheat crop 10 to 12 per cent in both straw and grain. Later experiments reported in the appendix of the Commission's Monthly Report showed that neither plain nor degreased sludge had any effect on the crops. But it is interesting to note that in pot cultures untreated and degreased sludge increased the yield of wheat 25 and 14 per cent respectively, the degreased sludge proving inferior. In most of the reports of the Commission it is seen that sludge is of little value, and the unavailability of its fertilizing constituents is attributed to the large per cent of grease present, which forms an impervious layer or covering and hinders biological decomposition.

Naylor[26] attributed unavailability to grease and believes that it must be removed before sewage sludge will be accepted as a manure; worthy of consideration by agriculturists. H. M. Wilson[42] of the West Biding Rivers Board states that these experiments and conclusions are opposed to practical experience, in view of the fact that farmers and market gardeners near the large cities continue to use sludge and can show that it has a marked effect on their crops, whether of hay, grain, roots, rhubarb or vegetables. He also claims that the agriculturists of France, Argentine and the United States make large purchases regardless of the cost of shipping. To quote Wilson, "If sludge is so valuable in these countries it should be well worth trying at home where transportation costs are much lower." This report mentions several municipalities in England with unusually rich sewage, which are able to sell part, if not all, of their sludge, and a few which add lime or other constituents to the sludge to make it marketable. At the Dalmarnock works in Glasgow, a chemical precipitation plant, the sludge is dried, ground, and sold under the name of Globe Fertilizer at $2.40 a ton. The Royal Commission on Sewage Disposal in its Fifth Report, page 162, comments thus on the success of the plant: "It will be seen, therefore, that at Dalmarnock by careful organization and advertising, practically the whole of the sludge is disposed of by sale, either as pressed cake or as Globe Fertilizer, the cost of the sewage' treatment being in this way materially reduced. The saving effected is about 4 shillings per million gallons (Imperial). During the 3 years ending March 31, 1907, the whole of the pressed cake was sold to the farmers. The demand is still increasing and the connection is now good enough to obviate the necessity for advertising. Mr. Melvin states that it is much easier to sell sludge as pressed cake than as Globe Fertilizer, partly because less work in entailed in the former case. . . . . For this reason Globe Fertilizer is now made during spring and autumn only and the quantity is diminished year by year."

At Oldham, England, the Grosmann[10], process is used. This consists in drying, powdering, distilling with acidulated super-heated steam, and again drying. This plant began operation in 1912 and proved so satisfactory that in 1914 the Local Government Board sanctioned an additional loan to complete parts of the plant which were not provided in the initial works.

At Bedford, England, the sewage contains a large quantity of grease from woolen mills. This grease is precipitated in the sludge by means of sulphuric acid and the sludge is heated to 100° with more acid and pressed to extract the grease. Part of the pressed sludge is used as fuel, part is sold to farmers for 84 cents a ton at the works, and part is dried and powdered, selling at $1.32 to $1.60 a ton (pre-war prices).

Sludge from the Travis tanks at Norwich[24] is treated by the Eckenburg wet carbonization process in which some of the grease is carried away by the hot gases and steam generated from the wet sludge. The sludge after this treatment drains easily and is filter-pressed and dried in rotary driers to 10 per cent moisture. The cake is extracted with benzine and dried. It finds a market at about $12 per ton of 2,240 pounds. The grease recovered is sold at $35 to $50 per long ton (pre-war prices).

Watson[40] mentions with approval the process at Dublin, Ireland. Here the sludge is incubated with 5 per cent brewer's yeast for 24 hours at 90° F. and drained, reducing the moisture to 82 per cent. Phosphates and potash are then added and the mixture dried and powdered.

H. W. Clark[8] from his study of the literature and his own work concludes: (.1) sewage farming is rapidly being abandoned in favor of modern methods of purification; (2) in order to reclaim the valuable material from sludge it must be dried, degreased, and powdered. Any known method of grease extraction is costly. The sludge has a value, however, and as the processes of treatment are improved, sewage sludge will become of greater agricultural value than at present.

An important point is emphasized by H. Bach and L. C. Frank,[3] which may explain the reports of the poor fertilizing value of sludge. They show that in fresh sludge the grease and fibrous material cause-the earth to become impervious to rain so that the sludge probably does more harm than good, while decomposed sludge contains less fat and is not so fibrous. Moreover, in the latter the fat, finely dvided and uniformly distributed through the mass of porous sludge, is not an appreciable hindrance to percolation; hence when such sludge is used as a fertilizer the prorosity of the ground is not affected. That the physical condition of a sludge is an essential factor in its usefulness as a fertilizer has been commonly overlooked.

Lipman and Burgess,[20] after extensive work on organic nitrogenous fertilizers, have introduced a biological method for the determination of availability of organic nitrogen. This method depends on the power of a soil to decompose and nitrify the organic material, the availability being expressed in the percentage of total nitrogen that is converted into nitrate. Table 2 shows a comparison of availability of nitrogen in sludges and other standard organic nitrogenous fertilizers as determined by Lipman and Burgess in three typical California soils.

They have shown from the standpoint of nitrifiiability that (1) the nitrogen in mine sewage sludges and low grade tankage is superior to that of dried blood, high grade tankage, fish guano, cotton seed meal and goat manure; (2) soils differ greatly in their power to nitrify dried blood, high grade tankage, fish guano, cotton seed meal and goat manure; (3) nitrification of sludge and low grade tankage was more uniform. They conclude that if nitrifiability is a guide, sludge nitrogen is of equal value with low grade tankage, and of greater value than any other material named.

Bartow and Hatfield, in "The Value of Activated Sludge as a Fertilizer"[5] studied the physical, chemical and fertilizing properties of activated sludge. Their conclusions were that: (1) activated sludge has a chemical composition which indicates that it is far superior to ordinary sewage sludges as fertilizers; (2) the nitrogen is readily available, in fact more so than in other organic nitrogen fertilizers; (3) the physical character of the sludge makes it easy to handle: (4) the grease content of eleven per cent does not inhibit the fertilizing value, probably because it is finely divided and in no way clogs the soil; (5) the dried sludge contains only spore-forming bacteria; and (6) the nitrogen and phosphorus content calculated at prices in 1916 should give it a value of $34 per ton, while the cost of drying and preparing for market would be much less.

The most recent development in obtaining fertilizer and grease from sewage appeared in a proposal to the United States Government by experts from the Massachusett Institute of Technology, January 26, 1918.[29] The data presented showed that by the Miles acid process, there could be recovered annually from the sewage of 97 American cities, each with a population above 50,000, the following ingredients:

Fertilizer	97,393,680 tons
Ammonia	4,869,684 tons
Grease	25,780,680 tons
Glycerine	1,289,034 tons

The judgment was that an experimental plant should be tested at one of the army cantonments. On the other hand, the Massachusetts Joint Investigation Board,[23] appointed by the Massachusetts Legislature, 1917, reported January 1, 1918, against applying the Miles acid process to Boston sewage.

L. Pearse[30] shows that the activated sludge process is the best method for treating packinghouse waste in Chicago, that the sludge shows a high nitrogen content and that it should have considerable fertilizer value. The estimated value of recoveries from a plant treating 50,000,000 gallons per day amounts to $150,000 to $300,000 per annum calculated at normal prices.

THEORETICAL DISCUSSION OF ORGANIC NITROGENOUS MATERIAL AND ITS DECOMPOSITION PRODUCTS AS A FERTILIZER.

A brief history of the development of ideas on soil fertility serves best to show the inadequacy of some modern methods of soil and fertilizer analysis.

In the seventeenth century Van Helmont,[12] a Flemish alchemist, proposed the theory that water was the plant food, but later Bradley proved that water could be evaporated and plants could not. In the eighteenth century Jethro Tull taught that the soil particles were the food of plants, and that, if the soil were made sufficiently fine by cultivation, the plants could then absorb these fine particles. During the following century the humus theory advanced by Thaer gained some recognition. The humus of the soil was held to be the source of carbon and carbonaceous matter for the plant. In 1804 Dr. Saussure proved the fixation of carbon, hydrogen, and oxygen by photosynthesis, and the absolute necessity of mineral plant food. About this time Lawes and Gilbert proved that the soil must furnish the nitrogen for most plants and Hellriegel (1868) discovered the fixation of nitrogen by the root-tubercle bacteria of legumes.

At present it is generally considered that the ten essential elements of plant food may be grouped as follows: carbon, hydrogen and oxygen obtained chiefly from air and water; phosphorus, potassium and nitrogen, sometimes deficient in soils; and sulfur, calcium, iron and magnesium required in small amounts and not likely to be deficient in soils.

Of these we are intedested in the nitrogen, phosphorus, and organic matter, since they are constituents which would make activated sludge valuable as a fertilizer. These elements are bound in organic combination, and their availability to the plant will depend on the rate of decomposition of this matter in the soil. Agronomists classify organic matter in the soil in two classes, the active organic material which is easily decomposed and incorporated in the soil, and the inactive which resists decomposition, remaining for a number of years in the soil. No distinct line, however, can be drawn between these classes, the fertilizer practice has given us numerous availability determinations for elements, which arbitrarily set the line. These determinations are made on the theory that a definite chemical reaction takes place in the soil which makes the easily hydrolyzable forms available for the plant. The available nitrogen is determined by distilling the ammonia from the fertilizer after digesting with a certain concentration of permanganate, in alkaline or neutral solution depending on the preference of the analyst and the statutes of the state in which he is working. The availability of phosphorus is determined by extraction of the phosphate with various concentrations of acids. Of course these procedures do not even approximate the conditions in the soil and are used because we have had no better methods at our disposal.

Plant food is made available by chemical and biological processes, of which ammonification and nitrification are among the best known. For the exact information we now have regarding these processes, we are indebted to Pasteur, Schlösing, and Müntz of France, Winogradsky of Russia and Warington of England. They have shown that complex organic nitrogen is first ammonified by certain classes of bacteria; then another class converts this ammonia into nitrite, and a third class transforms the nitrite into nitrate. It has recently been shown by Hopkins and Whiting[14] that these reactions increase the availability of insoluble phosphate. The nitrous and nitric acids as well as the organic acids formed in the hydrolytic and ammonification processes convert insoluble phosphates into soluble acid phosphates.

Because the availability of the nitrogen in soils is dependent on biochemical action and the well-known arbitrary chemical methods have no relation to the actual condition of availability of nitrogenous material in soils, bio-chemical methods of analysis have been introduced. In 1910 J. C. Lipman[21] proposed incubating soils with organic nitrogenous fertilizers and determining the ammonia and nitrate formed after a certain period of incubation. C. B. Lipman[19] points out that in some soils there is no connection between their ammonifying and nitrifying powers. He recommends incubation of one gram of fertilizer with 100 grams of soil at optimum moisture content for 30 days at 28° to 30° C, then nitrates are determined and the availability of the nitrogen expressed in the percentage of total nitrogen that is converted into nitrate. He has proved his point by comparison with pot culture experiments and recommends this method as the best one so far proposed, the he says that the only absolute method is that of actual crop production.

A compilation of the data given by Lipman and Burgess[20] in their article on "The Utilization of the Nitrogen and Organic Matter in Septic and Imhoff Tank Sludges" and the analyses made for us by Professor Lipman using activated sludge are given in Table 2:

TABLE 2—PARTIAL COMPOSITION OF AIR-DRIED SLUDGES AND THEIR AVAILABLE NITROGEN COMPARED WITH THAT OP COMMERCIAL ORGANIC FERTILIZERS.

	Volatile matter, per cent.	Ash, per cent.	Total N., per cent.	Nitrate N., per cent.	Phosphoric acid, per cent.	Percentage of N. in sludges and fertilizers available when inoculated with—		
						Davis soil.	Oakley soil.	Anaheim soil.
Sludge—								
Orange Imhoff tank (city)	49.68	50.32	2.66	0.012	1.11	32.50	32.30	27.20
Fullerton Imhoff tank	25.31	74.69	1.23	0.045	0.86	43.90	43.50	40.60
Anaheim Imhoff tank	33.09	76.91	1.54	0.115	0.99	32.40	36.00	40.20
Lindsay septic tank	42.92	57.08	1.83	0.090	0.89	25.70	18.00	18.80
Pasadena Imhoff tank	29.34	70.76	1.68	0.135	1.46	38.00	28.20	35.70
Orange Imhoff tank (country)	38.41	61.59	2.38	0.060	0.77	25.70	21.40	15.70
Worcester exp. Imhoff tank	43.86	56.14	2.10	0.010	1.82	26.90	12.40	34.50
Cleveland exp. Imhoff tank	36.37	63.63	1.44	0.000	1.28	32.90	8.30	44.10
Chicago Stock Yards exp. Imhoff tank	50.46	49.54	1.73	0.400	1.46	24.50	9.80	10.10
Activated sludge	75.00	25.00	6.2	0.000	2.9	15.8	2.9	6.5
Fertilizers—								
Dried blood	------	------	------	------	------	12.79	0.00	4.05
High-grade tankage	------	------	------	------	------	16.21	0.00	3.95
Low-grade tankage	------	------	------	------	------	27.39	22.70	43.89
Fish guano	------	------	------	------	------	15.11	trace	4.65
Cottonseed meal	------	------	------	------	------	14.18	2.00	21.45
Goat manure	------	------	------	------	------	4.89	3.50	10.39

These results show that the nitrogen in activated sludge is more easily nitrified, under the conditions of these experiments, than that in dried blood, high-grade tankage, fish guano, cotton-seed meal and goat manure; but that it is not so available as that of septic and Imhoff tank sludges. The experiments with wheat in pot cultures using activated sludge, dried blood and other ammoniates, reported by us in 1916[5] and later in this thesis, confirm the above comparison between dried blood and activated sludge. On the other hand we have obtained much better results with activated sludge than with Imhoff and septic tank sludges (See Table 7.) Here this method seems to fail, as all arbitrary methods have done. A possible explanation for this lies in the fact that equal amounts of fertilizer are applied regardless of the nitrogen content; in the ease of Imhoff and septic tank sludges 14 to 26 milligrams of nitrogen were applied while in the case of activated sludge 62 milligrams were added. A glance at the data[20] shows that in the three soils used, the nitrification capacity was from 1 to 9 milligrams of nitrate nitrogen. If it is true that a soil has a maximum capacity to produce nitrates, the percentage of the total nitrogen changed to nitrates will be an inverse function of the amount applied. On this basis the results on dried blood are unfair, since approximately 140 milligrams of nitrogen or 5 to 10 times as much nitrogen as that applied in sewage sludge was added in the form of dried blood. In comparison with activated sludge, only twice as much nitrogen was applied in the form of dried blood nitrogen.

The terms ammonifieation and nitrification sound quite simple and might lead one astray. On second thought we realize that the organic matter in soils and organic nitrogenous fertilizers is in very complex form, and that its ammonifieation and subsequent nitrification must ba preceded by reduction, oxidation, hydrolysis, and many other cleavages, each brought about by a specific group of organisms. The organic material containing nitrogen must be largely albuminoids and complex proteins (nucleoproteins, phospho-proteins and glyco-protein, and their various hydrolytic products.)

Schreiner and his associates[35] have isolated from soils the following nitrogenous hydrolysis products of proteins and other organic matter: (1) histidine; (2) arginine; (3) nucleic acid; (4) hypoxanthine; (5) xanthine; (6) guanine; (7) adenine; (8) asparagine; (9) creatinine; (10) creatin; (11) choline; (12) leucine; (13) allantoin, and (14) picoline carboxylic acid. Many other compounds in the soil have been isolated and studied but as they are non-nitrogenous we will not consider them. Schreiner and Skinner[36] have shown that, in water culture, wheat plants will directly absorb these compounds (except picoline carboxylic acid) and use them as food for growth without their first being changed into ammonia or nitrates. In the presence of nitrates the plants used not only the nitrate in preference but also some of the more complex compounds directly, and the plants grown in solutions containing both organic nitrogen and nitrate were better developed than those grown with nitrate alone. Some of Schreiner and Skinner's[80] data is compiled in Table 3 to show these results:

TABLE 3—PERCENTAGE INCREASE IN WHEAT CHOP IN SOLUTION OULTURE WITH ADDED ORGANIC COMPOUNDS FOUND IN SOILS WITH AND WITHOUT NITRATE.

Organic nitrogen.	p. p. m. application.	No nitrate present.	With 8 p. p. m. NH_3 as nitrate.	With 16 p. p. m. NH_3 as NO_3.
Histidine	50	30	14	5
Arginine	50	33	0	0
Nucleic acid	100	74	23	12
Hypoxanthine	100	41	14	3
Xanthine	25	21		
Guanine	40	5		
Adenine				
Asparagin	50	47	14	7
Creatinine	50	36	17	8
Creatine	50	44	11	3
Choline	Less	100 no effect	greater tha	n 100 toxic
Leucine	50	11	3	0
Allantoin	?	23	0	0

Results published in the bulletin show that even where nitrate is present, the above, organic nitrogen compounds were absorbed directly by the plant and a decrease in the nitrate consumption took place, even though an increase in growth was shown. "The knowledge that beneficial organic compounds exist in the soil and play so prominent a part in the life processes of growing plants is of fundamental significance in soil fertility and gives a breadth of view to the subject, which, in its horizon, can not be compared with the restricted vision imposed by the purely mineral consideration."

Of course conclusions drawn from solution cultures can not necessarily be applied to soil conditions because the soil is very complex and the bacterial flora is equally so. The chance of absorption by colloidal substances, and of bacterial decomposition in the soil is so great that we must guard against false deductions. Nevertheless it is significant that the plant will use these products if they are available.

E. C. Lathrop[18] discusses in his paper, "The Organic Nitrogen Compounds of Soils and Fertilizers," the nature of organic compounds in the soil. It is shown that the compounds isolated by Schreiner and also by himself are obtained by the hydrolysis of the complex protein-like compounds occurring in soils and organic fertilizers. He shows that the rates of ammonification and nitrification are important, and that they are dependent on the rate and type of hydrolysis and hydrolic products. To quote Lathrop, "It is obvious that a knowledge of the normal decay of protein material in soils will materially aid in solving the availability problem." In his study of the hydrolysis of organic matter, in the soil and of dried blood in the same soil, Lathrop used the Van Slyke method of nitrogen partition. He has shown that dried blood is rapidly hydrolyzed in the soil, as indicated by the decrease in hydrolyzable nitrogen found after, 18, 24, 86, 148 and 240 days. It is emphasized that the intermediate products are beneficial to plant growth and that so far we have no chemical method of determining availability.

The decomposition of such a complex protein as nucleo-protein may be taken as an example to show the intermediate and final products, so far as we know the reactions in biochemistry. The complete enzymatic decomposition of nucleoprotein into its intermediate and final products in so far as animal metabolism is concerned, may be found in Jones Monograph.[16] The final products are amino acids, uric acid or allatoin, purine and pyrimidine bases, carbohydrate, and phosphoric acid. These may all undergo bacterial decomposition in the soil to form ammonia and carbon dioxide.

The ammonia thus formed may be converted into nitrite and thence into nitrate by nitrifying bacteria. The opportunity which a plant would have to absorb any intermediate product would depend partly on the solubility of the substance and partly on the speed with which it is converted into a still simpler compound.

The above considerations may explain the results obtained in pot culture. The results obtained showed the superiority of activated sludge to dried blood, glutonmeal, sodium nitrate and ammonium sulfate, when used on wheat in pot culture. In all the experiments dried blood has been used for comparison because it is generally considered the best organic ammoniate. Several factors probably affect these results. (1) The large amount and the type of organic matter applied in activated sludge may favor the growth of a better flora of microorganisms to ammonify and nitrify the nitrogenous matter; (2) the organic matter itself may be more easily hydrolyzed; (3) it has been suggested that in dried blood the organic matter is too easily ammonified and that the high concentration of ammonia inhibits the growth of the nitrifying bacteria; (4) if this be true the superiority of activated sludge may be due to slow hydrolysis, which gives the nitrifying bacteria time to convert the ammonia into nitrates as rapidly as it is formed; (5) possibly too high concentrations of dried blood were used; and (6) the nature of the organic matter and its intermediate hydrolytic products may play a prominent part in inhibiting or stimulating the growth of the plant. These explanations have all been considered and an attempt made through laboratory analysis and pot culture studies to verify them.

These experiments with one exception have all been made with dried sludge. The sludge as obtained from the process contains 98 to 99 per cent moisture. The reduction of the moisture content is now one of the most pertinent problems in the practical operation of the activated sludge process of treatment. The colloidal, gelatinous nature of the wet sludge makes the problem of dewatering more complex, and if not dewatered while fresh the sludge soon putrefies and becomes still more difficult to handle. Also if the sludge is to be marketed it must be converted into an attractive, saleable form and must contain less than 10 per cent moisture. The various precipitants and methods of filtering and drying tried in this laboratory are reported below.

EXPERIMENTAL PART.

The Application of Fertilizers to Plants in Pot Culture and Garden.

The results on the first series of pot cultures were reported in 1915.[5] Thirty wheat seeds were planted, two in each of fifteen holes in white sand to which the necessary plant foods were added as shown in Table 4. After germination the young wheat plants were weeded out, leaving the best fifteen plants in each pot.

TABLE 4—POT CULTURES, USING WHEAT, SERIES 1, 1915.

Plant food in grams.							Yield.				
Pot No.	Dolomite.	Bone meal.	Potassium sulfate.	Activated sludge.	Extracted activated sludge.	Dried blood.	Grams seeds.	Bu. per acre (calculated).	Av. stalk length (in.).	Straw grams.	Tons per acre (calculated).
1	60	6	3	0	0	0.0	2.38	6.2	19.4	2.25	0.18
2	60	6	3	0	0	8.61	5.29	13.6	23.0	8.25	0.68
3	60	6	3	20	0	0.0	13.748	35.9	35.4	26.75	2.23
4	60	6	3	0	20	0.0	14.504	37.7	36.1	26.21	2.18

19,820 grams of white sand were used in each pot.

TABLE 5—KETTJRNS FROM POT CULTURES, SERIES 2, 1915.

GROUP I.

No.	Fertilizer used.*	Application.		Nitrogen equivalent.		Grain.		Straw.	
		Grams.	Tons per acre.	Grams.	Lbs. per acre.	Weight grams.	Bu. per acre.	Weight grams.	Tons per acre.
1		0	0	0	0	2.7	7.0	1.9	.2
2	Activated sludge	20	1.7	1.26	210	13.5	35.1	22.2	1.8
3	Fat-free activated sludge	19.14	1.6	1.26	210	13.3	34.6	22.4	1.8
4	$NaNO_2$	2½	.2	.41	68	.5	1.3	2.3	.19 Toxic**
5	$(NH_4)_2SO_4$	5.94	.5	1.26	210	1.8	4.7	5.0	.4
6	Gluten meal	16.93	1.4	1.26	210	3.7	9.6	6.7	.6
7	Dried blood	8.61	.7	1.26	210	3.6	9.4	5.4	.4

GROUP II.

No.	Fertilizer used.*	Application.		Nitrogen equivalent.		Grain.		Straw.	
		Grams.	Tons per acre.	Grams.	Lbs. per acre.	Weight grams.	Bu. per acre.	Weight grams.	Tons per acre.
1		0	0	0	0	2.9	7.5	2.5	.2
2	Activated sludge	30	2.5	1.89	315	13.0	33.8	19.6	1.6
3	Fat-free activated sludge	28.72	2.4	1.89	315	14.2	36.9	25.1	2.0
4	$NaNO_2$	2½	.2	.41	68	1.5	3.9	5.0	.4 Toxic**
5	$(NH_4)_2SO_4$	8.91	.7	1.89	315	2.85	7.4	7.9	.7
6	Gluten meal	25.39	2.1	1.89	315	8.6	22.1	13.7	1.1
7	Dried blood	12.91	1.1	1.89	315	3.9	10.1	7.7	.6

* To each pot of white sand, plant food was added as follows: 60 grams of dolomite (5 tons per acre), 6 grams of bone meal (½ ton per acre) and 3 grams of potassium sulfate (¼ ton per acre).

** The sodium nitrate seemed to produce a toxic effect in this concentration, so no more was added as had been anticipated.

Activated sludge applied on an equivalent nitrogen basis produced over twice the grain and straw produced by dried blood. Before the final results on this series of pot cultures were obtained, a second series[5] was started in order to check the first results. The second series was made more extensive, consisting of fourteen pots divided into two groups of seven each, and compared the availability of the nitrogen in activated sludge, dried blood, gluten meal, sodium nitrate and ammonium sulfate. The same amounts of sand and plant foods, except nitrogen, were used as in the first series. Each group contained a check pot to which no nitrogen was added. To the other six pots of the first group nitrogen equivalent to twenty grams of activated sludge was added as sludge and as the other fertilizing materials indicated above. In the second group nitrogen equivalent to thirty grams of activated sludge was used to determine if a large application would produce better results. Wheat was planted in this series in the same maner as in Series 1. A picture of this series, when 5 weeks old, was published in 1915, but final results on crop recoveries were not ready at the time of publication. Table 5 contains complete data on plant food application and crop production.

The data show again that activated sludge gave better results than dried blood in production of both grain and straw. In the low application it gave much better results than gluten meal, while in the higher application this difference was not so marked. The results obtained with sodium nitrate and ammonium sulfate were unimportant. The concentrations used should not have been toxic; in fact only part of the nitrate was added at first in order to avoid toxicity. Again the results indicated beyond any reasonable doubt that the nitrogen in activated sludge is very readily available to the plant. The difference in high and low application was minimal. With gluten meal the higher application produced a substantial increase in yield over that from the lower application. In the case of dried blood the increased application showed no material improvement. The slight results obtained with the mineral nitrogen fertilizer may have been partially due to the lack of organic matter present to furnish food for the proper microscopical flora. It seems significant at least that the organic nitrogen cultures all surpassed those fertilizers with inorganic nitrogen alone. As these results with sodium nitrate are not in accord with general agricultural practice the subject should be investigated. Further results on nitrate cultures are reported in Series 6 (1918), Table 17.

In both Series 1 and *2* the degreased sludge showed no material increase in yield of crops over that of the original sludge. The results obtained in a garden experiment with lettuce and radishes, using both plain and degreased activated sludge, are given in Table 6 and show a slight increase in favor of the degreased sludge.[5]

TABLE 6—COMPARISON OF THE LETTUCE AND RADISHES FROM UNFERTILIZED AND FERTILIZED PLOTS.

Plot.	Treatment.	Weight.	Per cent increase.	Weight.	Per cent. increase.
1	None	4.5g.		23.4g.	
2	Sludge	6.3g.	40	63.0g.	169
3	Extracted sludge	6.8g.	51	68.0g.	190

The extraction of grease in preparing activated sludge for a fertilizer appears to be unnecessary. The fat present in activated sludge is so finely divided and evenly distributed thru the mass that it causes no greasiness and would not hinder the decomposition of sludge in the soil. On the other hand the present demand for fats may make it expedient and profitable to recover them. Further results on acidified sludge from which the fat has been extracted are reported in Series 6 (1918), Table 17.

It is difficult to reconcile the discordant estimates of the value of sewage sludge as a fertilizer. The fact that a few places, taking the trouble to properly dry and powder sludge have successfully sold it makes it appear that possibly some results in pot cultures with different sludges on different soils would be of value. In the spring of 1916 . Series 3 was started. Four sludges were used in this experiment.

1. Imhoff tank sludge from the city of Baltimore, which had been dried on sand beds, and contained considerable sand which lowered its nitrogen value as a fertilizer was further dried on a steam bath in this laboratory and ground in an ordinary coffee mill. It was light gray in color and had little or no odor.

2. Septic tank sludge was collected from the Urbana septic tank, January 29, 1916. As most of the sludge in the tank had risen to the surface it was necessary to collect both the surface sludge and that from the bottom. An average sample was obtained and dried on a steam bath. The color of this sludge was a very light gray and the odor was quite foul.

3. Activated sludge was collected after 30 minutes' settling, from the "fill and draw" activated sludge tanks described by Bartow and Mohlman.[6] As much water as possible was separated by sedimentation and the resulting sludge was dried as described above. When dried, the sludge was brownish-black and had a characteristic fertilizer odor.

4. A sample of activated sludge from Milwaukee did not arrive until after the experiments were started. This sludge was filter-pressed in Milwaukee, and dried on a steam bath after its arrival. It had the characteristic fertilizer odor and brownish-black color.

The dried blood used in this series was from the same sample as that used in Series 1 and 2. The analyses for nitrogen in these fertilizers are:

Inhoff sludge	0.9 per cent
Septic tank sludge	1.49 per cent
Activated sludge (Urbana)	4.47 per cent
Milwaukee activated sludge	4.63 per cent

The three types of soil used in' this series were obtained from the Agronomy Department of the College of Agriculture of the University of Illinois and represent three characteristic types of Illinois soil. They are known as yellow silt loam on tight clay, white silt loam on tight clay, and brown silt loam on tight clay. The analyses of these soils (Table 7) give an idea of the elements which they lack.

Average pounds per acre in 2,000,000 pounds of surface soil.

TABLE 7—ANALYSIS OF THREE TYPES OF ILLINOIS SOILS.[13]

Soil type.	Total organic carbon.	Total nitrogen.	Total phosphorus.	Total potassium.	Soil acidity.
Yellow silt loam	22,110	2,068	696	36,024	940
White silt loam	14,860	1,360	660	30,120	1,400
Brown silt loam	-------------	7,000	1,200	35,000	0

On February 7, 1916, three groups of six 4-galion pots were tilled, one group with each soil, and to the yellow and white silt loam 60 grains of dolomitic limestone, equivalent to 5 tons per acre, were added to neutralize the acidity of the soil. The fertilizers to be tested were added on an equivalent nitrogen basis and were plowed into the top six inches of soil. Thirty wheat seeds were planted in fifteen holes in each pot. The Milwaukee activated sludge was not plowed in and planted until March 20 and hence did not give results comparable with the rest of the series. The sludges were added in amounts equivalent to the nitrogen in 15 grams of dried blood, reserving one pot in each soil as a check pot. The actual quantities of sludges used are shown in Table 8. After complete germination some plants were removed, leaving the fifteen best plants in each pot. Activated sludge and dried blood slightly hindered germination in the brown silt loam, tho the plants which germinated were not hindered in growth. In those pots fertilized with septic tank sludge both germination and growth were retarded.

After four weeks the pots of yellow and white soils fertilized with activated sludge were by far the best, those fertilized with Imhoff sludge next, then those fertilized with dried blood and the check pot. Those fertilized with septic tank sludge were not so far along as the check pots. The pots containing the brown silt loam, a rich soil to begin with, were all good. Some trouble was experienced with a white mold which attacked the leaves 'of all the plants, but this was eventually overcome and did not seem to cause any permanent injury.

On April 10, when the plants were about two months old, pictures were taken of the white and yellow silt loam cultures. Figures 1 and 2 are pictures of yellow and white silt loam groups respectively. The leaves of the rapidly growing plants are tender and do not hold themselves up as good, strong plants should. This is characteristic of plants that are overtreated with organic nitrogen fertilizer.

During May the plants fertilized with septic tank sludge began to surpass those fertilized with Imhoff sludge. The final results on the crop are given in Table 8.

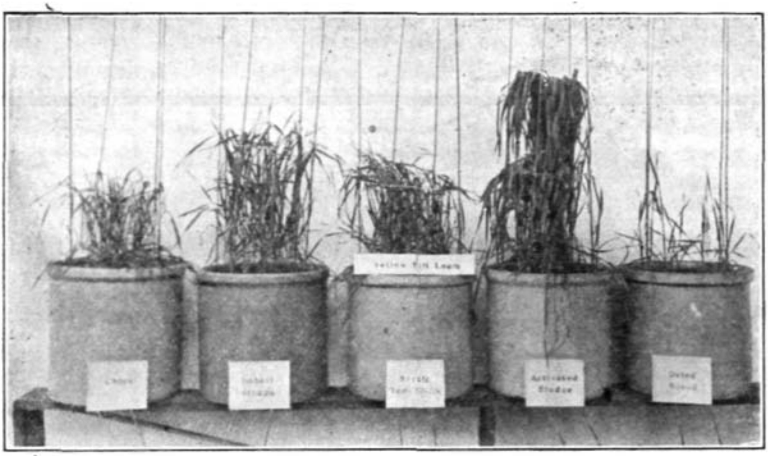

Figure 1. -Yellow Silt Loam Group: Plants About Two Months Old.

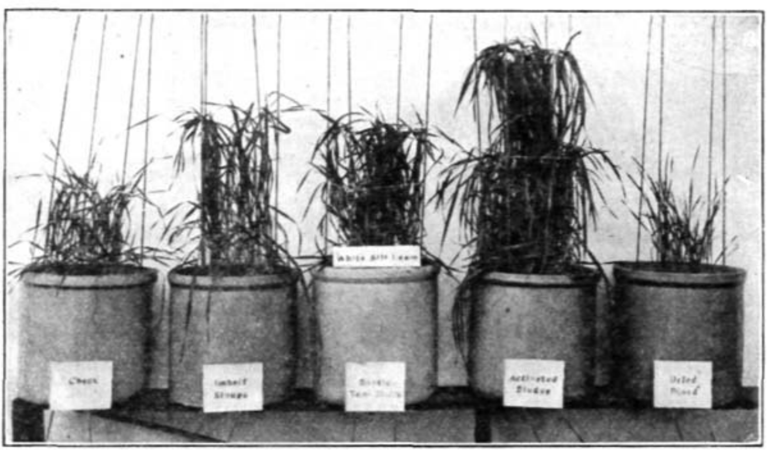

Figure 2.—White Silt Loam Group: Plants About Two Months Old.

The data shows that, altho the plants fertilized by Imhoff sludge grew rapidly at first and gave an increase in straw, a decrease in grain production on the white and brown silt loam resulted. In the yellow silt loam a substantial increase in grain was obtained. Septic tank sludge caused a material increase in grain on the yellow and white silt loams and a slight decrease on the brown soil. The production of straw was increased about 50 per cent on all three soils. The Urbana activated sludge increased the yield of grain far above that of the other fertilizers added, the same being true in production of straw. On the brown soil, which is a rich type and produced a good crop without fertilizer, both activated sludge and dried blood gave an increase in yield of wheat and straw. On the other soils dried blood fell far below the activated sludge in fertilizing value both in grain and straw production. With wheat planted a month and a half late the results with Milwaukee activated sludge, show an increase in straw, but only a slight increase in grain on the yellow soil and a decrease in grain on the other two soil types.

TABLE 8—DATA OK SERIES 3, 1916.

Fertilizer,	Fertilizer.		Bushels of wheat per acre.			Tons of straw per acre.		
	Grams.	Tons per acre.	Yellow soil.	White soil.	Brown soil.	Yellow soil.	White soil.	Brown soil.
Check	0	0	10.7	17.0	30.6	1.1	1.5	3.0
Imhoff	244	19.5	18.8	13.5	21.3	1.9	1.6	4.0
Septic tank sludge	147	11.8	23.8	22.3	27.3	2.7	2.5	4.6
Activated sludge	49	3.9	33.8	27.4	41.3	3.2	3.3	5.1
Dried blood	15	1.2	15.6	17.0	41.4	1.1	1.6	5.0
*Milwaukee activated sludge	47.25	3.8	14.5	16.8	27.3	1.9	1.6	3.0

* Results not comparable with others because of late planting.

Residual nitrogen in the soils was determined according to the regular method for total soil nitrogen and is expressed in Table 9 in pounds of nitrogen per acre.

TABLE 9—POUNDS PER ACRE OF RESIDUAL NITROGEN IN SOILS.

Fertilizer applied.	Soils.		
	Yellow.	White.	Brown.
Check	1,100	840	6,800
Imhoff	1,400	1,000	7,400
Septic tank	1,500	1,340	7,600
Urbana activated sludge	1,340	lost	7,400
Dried blood	1,160	890	7,600
Milwaukee activated sludge	1,260	1,400	7,400

These results compared with Table 7 show approximately the nitrogen recovered by the crops and lost to the air.

On May 22, 1916, a fourth series of eight pots was started, using a light gray silt loam from Lawrence County, Illinois. The pots were treated with an equivalent of 5 tons per acre of dolomitic limestone, and were fertilized with various amounts of activated sludge equivalent to an application of from zero to 3 tons. On two pots, dried blood equivalent to 1.0 ton was used. One of the samples of dried blood was the same as that used in our earlier experiments, and the other was a new sample obtained from Swift and Company which contained 13.9 per cent nitrogen. Ten seeds of bantam sweet corn were planted, two each in five holes in each pot. After the plants were up the number in each pot was reduced to the five best plants. In this series the corn was not harvested, but the mature plants were cut at the surface of the ground and the dry weights taken. Data on the fertilizer application and crop yield are given in Table 10.

TABLE 10—DATA ON BANTAM SWEET CORN GROWN IN LIGHT GRAY SILT LOAM.

No.	Activated sludge.		New Swift dried blood.	Old dried blood.	Weight of crops.		Per cent increase over check.	Residual N. in pounds per acre in soil.
	Grams.	Tons per acre.			Grams.	Tons per acre.		
1	0	0	0	0	29	2.3	0	440
2	7.5	0.5	0	0	34	2.7	17.4	720
3	15.	1.0	0	0	39	3.1	34.8	800
4	22.5	1.5	0	0	57	4.5	95.6	880
5	30.0	2.0	0	0	41	3.3	41.3	lost
6	45.0	3.0	0	0	56	4.4	91.5	900
7	0	0	15 gr. (1 ton)	0	39	3.1	34.8	lost
8	0	0	0	15 gr. (1 ton)	33	2.6	13.0	1,200

This series shows that on this light gray silt loam 1.5 tons of activated sludge gave the best results, tho higher application did not prove toxic. The new dried blood showed better results than the old. One ton of the new dried blood gave the same results as one ton of activated sludge.

On July 9, 1916, a garden experiment was started near the Illinois State Water Survey sewage experiment station east of Urbana. The soil was a poor yellow clay which for many years had been unproductive. Four plots twenty-eight feet square were plowed and two of them fertilized with an equivalent of 1.22 tons of activated sludge per acre (102.5 pounds of nitrogen per acre), equivalent to about 0.4 ton of dried blood. The other two were not fertilized. Cucumbers and evergreen sweet corn were planted in the plots. On September 18, all cucumbers were harvested, and an increase of 71 per cent over the unfertilized plot was ascribed to activated sludge. The corn at this time was not ready to be harvested and was allowed to remain; later it was accidentally destroyed and results cannot be given. From all appearance the corn would have shown an increase due to sludge equal at least to the cucumber increase just mentioned.

In the Series 5 in 1917, the plan was: first, by a study of the apparent toxic effect of dried blood to explain, if possible, the small results obtained with it in the earlier work; second, to study the effect, if any, of applying the different sludges as fertilizer to the same ground on the second year; third, in order to eliminate the question of the possible advantage of activated sludge over dried blood because of its phosphorus content, to add sufficient acid phosphate to one series so that phosphorus would not be the limiting element; and fourth, to see if toxic effects on wheat could be obtained by adding excessive amounts of activated sludge.

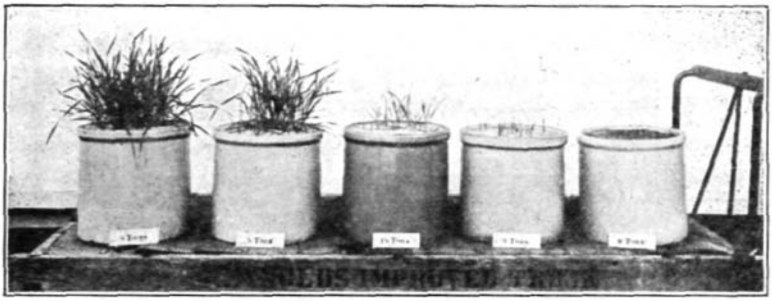

Figure 3.—This picture taken five weeks after germination shows the toxic effect of dried blood in sand as the amount applied increases. Pots 5 and 6 were not photographed since the plants were killed soon after germination.

First—The effect of increasing applications of dried blood was studied in sand culture containing all elements for plant food as in Series 1 and *2*. The new sample of Swift's dried blood was then added in increasing amounts and wheat sown, with the results shown in Figure 3 and Table 11.

TABLE 11—WHEAT WITH INCREASING AMOUNTS OF DRIED BLOOD IN SAND.

No.	Dried blood.		Lbs. N_2. per acre.	Total crop.	Weight of grain.	Bushels per acre grain.	Total straw grams.	Tons straw per acre.
	Grams.	TONS.						
1	3.1	0.25	69.5	34.1	11.4	29.6	22.7	1.8
?	9.3	0.75	305.8	36.8	10.0	26.0	26.8	2.1
3	18.75	1.5	417.0	21.0	0.0*	0	21.0	1.6
4	37.5	3.0	838.0	16.4	0.0*	0	16.4	1.3
5	75.	6.0	1,670.0	0	0.0	0	0.0	0.0
6	125.	10.0	2,780.0	0	0.0	0	0.0	0.0

• Heads empty.

In sand, dried blood is toxic in applications above 0.75 of a ton, and that one-half a ton gave the largest yield of grain. In the pots containing the 1.5 and 3.0 tons treatment, plants grew but the heads contained no grain; in the still higher applications the blood was so toxic that the plants were killed before they completed germination. In soils this toxicity might not be shown at such low concentrations because the colloidal nature of the soil might adsorb and destroy more toxic substances than the sand. Nevertheless these results indicate that we may have used too much in some of our earlier work.

Second—The yellow silt loam pots of Series 3 were again fertilized with the same sludges and dried blood at about the same concentrations that were used the year before in order to determine if there would be any detrimental effect due to the accumulation of toxic substances. Wheat was planted as described above. Table 12 gives the data showing the amount of fertilizer applied, and the final crop harvested.

TABLE 12—DATA ON SECOND TEAR CROPS OF YELLOW SILT LOAM FERTILIZED WITH SLUDGE AND DRIED BLOOD.

No.	Fertilizers.	Application.		Total weight.		Bushels per acre of grain.	Weight of straw.	Tons per acre, straw.
		Grams.	Gr. N_2 applied.	Crop.	Grain.			
1	Check	0	0	10.6	4.0	10.4	6.6	0.5
2	Imhoff	120	2.12	12.8	4.6	12.0	8.2	0.6
3	Septic tank	70.6	2.12	31.8*	9.4*	22.4*	22.4	*1.8
4	Urbana activated sludge	42.4	2.12	31.7	6.4	16.5	25.3	2.0
5	Dried blood	15.0	2.12	9.1	2.5	6.5	6.6	0.5
6	Milwaukee activated sludge	52.3	2.12	16.8	5.5	14.3	11.3	0.9

* By mistake this pot was planted with bearded wheat and consequently is not comparable.

The sludges caused an increase in grain and straw, whereas dried blood was detrimental to grain production and had no effect on the straw. If these results are compared with those on the same soil in Series 3 (1916), it is seen that the increase due to fertilizing is considerably less in the second year. This is particularly noticeable with dried blood. We may expect crops to vary from year to year according to seasonal conditions, but in this case it seems probable that too much fertilizer had been added. The results, however, do not show that the extra application caused accumulation of substances toxic to the plants except in the case of dried blood.

Third—The white silt loam pots of Series 3 (1916) were fertilized on February 12, 1917, with the equivalent of one ton of acid phosphate per acre and nitrogen in the same forms and quantities as used the year before. Wheat was planted as in previous experiments. The object of adding the acid phosphate, as stated above, was to eliminate the possible advantage activated sludge might possess by virtue of its phosphorus content. The data on this series are given in Table 13.

TABLE 13—DATA ON SECOND-TEAK CROP GROWN IN WHITE SILT LOAM TO WHICH ACID PHOSPHATE AND FERTILIZER HAVE BEEN ADDED.

Fertilizer.*	Application.		Total weight.		Bushels per acre.	Weight straw grams.	Straw tons per acre.
	Grams.	Gr. N_2.	Crop.	Grain.			
Check	0	0	30.4	9.8	25.5	20.6	1.6
Imhoff	12.0	2.12	19.8	4.0	10.4	15.8	1.3
Septic tank	70.6	2.12	34.6	7.7	20.0	26.9	2.1
Urbana activated sludge	42.4	2.12	30.2	12.6	32.8	17.6	1.4
Dried blood	15.	2.12	27.2	5.6	14.6	21.6	1.7
Milwaukee activated sludge	52.3	2.12	36.8	7.6	19.8	29.2	2.3

* To each potan equivalent to one ton of acid phosphate was added.

Activated sludge was the only fertilizer that increased the yield of wheat over that on the check pot. It appears that phosphorus was the lacking element in this series, and that in the first experiments in this soil phosphorus, not nitrogen, was the limiting element. Also the toxic effect of a second application of Imhoff sludge, septic tank sludge, dried blood, and to a certain extent Milwaukee activated sludge, is plainly seen. Here again there appears to be an accumulation of toxic compounds from dried blood as well as from the anaerobic sludges, and no toxic effect from Urbana activated sludge.

TABLE 14—WHEAT GROWN ON ACID GRAY SILT LOAM FERTILIZED WITH ACTIVATED SLUDGE AND DRIED BLOOD (1917).

Application.					Total weight.			Bushels grain per acre.	Tons straw per acre.
Activated sludge.		Dried blood.		Lbs. N_2	Crop.	Seeds.	Straw.		
Grams.	Tons per acre.	Grams.	Tons per acre.						
6.3	0.5			50	34.4	13.1	21.3	34.1	1.7
12.5	1.			100	31.0	10.2	20.8	26.4	1.6
25.0	2.0			150	35.1	9.4	25.7	22.4	2.0
50.	4.0			200	40.8	8.9	31.9	23.1	2.5
100.	8.0			400	50.5	10.3	40.2	26.9	3.3
200.	20.			2,000	45.5	10.3	35.2	26.8	2.8
0	0	15	1.2	334	16.6	6.1	10.5	15.9	8
0	0	15	1.2	334	14.1	4.4	9.7	11.5	77

Fourth—The same soil used in Series 3 to study the effect of in- inereasigg amounts of activated sludge on corn was used in this group.

(See Table 10, p. 45). The purpose of this test was to determine again the effect on plants of increasing the amounts of activated sludge, and incidentally the cumulative effect of the repeated use of high amounts of activated sludge. The soils were plowed up and the second application mixed with the top 6 inches of the soil. Wheat was planted and the final results tabulated in Table 14.

The production of straw is increased by an application of activated sludge up to eight tons per acre, and the yield from 20 tons falls only a little below that from the 8-ton application. It is safe to say that even very high applications of activated sludge are not toxic so far as the production of straw is concerned. The yield of grain, however, is materially affected, for each successive increased application of activated sludge decreased the yield of grain. The best results were obtained with the application of one-half a ton; but it must be remembered that in the

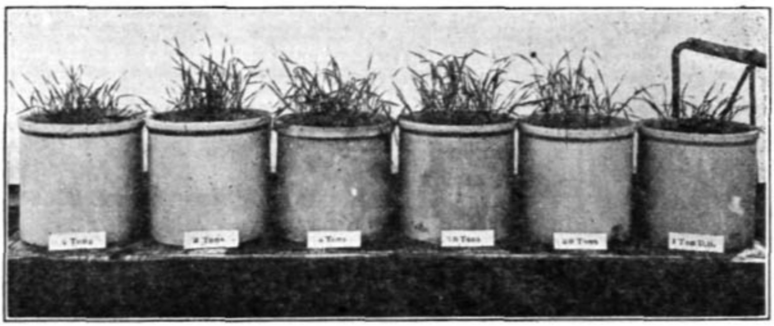

Figure 4.—Effect on plants of increasing amounts of activated sludge.

previous year this pot had received no sludge and the high yield may have been due to this fact, since it has been shown that on the second application the yield of wheat grains is reduced. The other pots had received a somewhat similar application of sludge the year before, the rate of application being in the same order tho not the same quantities. It appears that 1.2 tons of dried blood was not equivalent in fertilizer value to one-half a ton of activated sludge; and that 1.2 tons of dried blood produced a greater toxic effected on wheat than did 20 tons of activated sludge. Figure 4 shows this series at the end of five weeks.

On May 16, 1917, two large garden experiments were started west of the activated sludge experimental plant which was east of Urbana. One of the garden plots was just west of the experimental plant. The soil of the plot was worn-out brown silt loam which had been used as a potato patch for some years. It had received no fertilizer in five or six years and had produced poor potatoes all of this time. Half of this plot was fertilized by pumping wet activated sludge from the plant directly on the ground and plowing it in two or three days later. With this method of application the quantity of fertilizer applied cannot be given. The object was to try the application of wet sludge for fertilizing purposes, since in many small installations the expense would be materially reduced if the sludge could be disposed of without drying. This plot will hereafter be designated as the "wet sludge plot."

One-half of the second plot, to be known as the "dry sludge plot," was fertilized with a mixture of dried activated sludge from Urbana and Milwaukee. The other half of the plot was left unfertilized as a control. The soil of this plot was a poor yellow clay, the same type of soil used in the garden experiments reported above for the summer of 1916.

Radishes, lettuce, beets, onions and sweet corn were planted in both plots on May 20, 1917. Tomato plants were set out in the dry sludge plot on May 23 and 24 but due to the scarcity of these plants we were unable to set them out in the wet sludge plot until the last of June. Results on the tomato crop from this plot were not obtained before the early autumn frost. Data on these experiments are given in Table 15.

TABLE 15'—EFFECTS OF DRY AND WET SLUDGES ON GARDEN PRODUCTS.

Crop.	Wet sludge plot per cent increase over check.	Dry sludge plot per cent increase over check.
Radishes	28	14
Lettuce	100	36.3
Beets	135	lost
Onions	10.0	6.4
Corn (green)	51.8	46.0
Corn (ripe)	23.0	6.7
Tomatoes	283.0	frost

While the comparison between the two plots is not entirely justified because sludges from different sources were applied and soils of different types were used, wet sludge was favorable to plant growth and gave much better results than the sludge used on the dry sludge plot, which was made up mostly of Milwaukee activated sludge. The results on the beet crop from the dried sludge plot were not obtained. Figures 5 and 6 show the quality of sweet corn produced on the fertilized and unfertilized plots. The ears from the fertilized plot were all good while most of those from the unfertilized plot were small and wormy.

A discussion of Series 6 and 7 planted in February, 1918, will follow the presentation of studies in the chemical constitution of the nitrogenous organic matter in activated sludge.

Figure 5.—Corn from fertilized plot.

Figure 6.—Corn from unfertilized plot.

THE CHEMICAL CONSTITUTION OF THE ORGANIC NITROGENOUS COMPOUNDS IN ACTIVATED SLUDGE.

The question of the nitrogen chemistry of sludges involves the study of a mixture of very complex chemical compounds which have been subjected to a multitude of physical, chemical and bio-chemical influences which change both their physical and chemical nature. The first question is that of the original source of the materials in sludge, and then so far as possible, prediction of results of the many biological changes occurring under conditions which govern the formation of various sludges.

Sewage sludge is made up of substances which separate from sewage under certain conditions and therefore our first knowledge must be gained from a study of the chemical nature of sewage. It is estimated[24] from data on several sewages that the total solids in residential sewage are derived from the constituents as follows:

	Grams per capita per day.
Total solids in city water supply (soft)	12.7
Faeces	20.5
Urine	43.3
Toilet and newspapers (suspended)	20.0
Sinks, laundries, wash water	77.5
Total for residential sewage	174.0

The total solids of the city waters will vary considerably but do not enter into this discussion since they are soluble and do not form sludge. The feces, however, are largely insoluble and form a large part of the sludge. Solids classed as urine are soluble and may be eliminated from the discussion. Paper, tho it becomes very finely divided, must be classed as insoluble, sludge-forming material. Only a small part of the solids from sinks and laundries need be considered since they are largely soluble. The solids from street washing are of a gritty nature and could be removed in grit chambers. Therefore, it is plain that sewage sludge consists of fecal matter and paper in some stage of decomposition.

Fecal matter[11] is composed of the following substances: (1) food residues; (a) those portions of the food which have escaped absorption, (b) that part of the diet either not digested or incapable of absorption; (2) the remains of the intestinal and digestive secretions not destroyed or reabsorbed; (3) substances excreted into the intestinal tract, notably salts of calcium, iron, and other metals; (4) the bacterial flora of the intestinal tract; (5) cellular elements, to which may be added under pathological conditions, blood, pus, mucus, serum, and parasites; (6) abnormally; enteroliths, gallstones and pancreatic calculi.

Of these we are interested only in the nitrogen compounds, so a study of the various forms of protein and pigments present will throw considerable light on the question. These may be divided into the following groups: (1) simple proteins; albumin, globulin, casein and their decomposition products; (2) conjugated proteins; nucleo-proteins, nucleic acid, etc., glycoproteins (muscoids); (3) albuminoids; keratin, elastin, collagin; (4) pigments, etc.

Group 1 may be eliminated from the discussion since these proteins are found in the feces only under pathological conditions. The compounds in Group *2* are present in the bacterial bodies and cellular material in the feces. These form a large portion of the total fecal nitrogen. The albuminoids of Group 3 are the unabsorbed food residues mentioned above. The pigments of Group 4 are derived chiefly from the intestional secretions.

The data given below on the composition of feces was compiled from "Die Faeces des Menchen" by Schmidt and Strasburger,[39] "Faeces of Children and Adults" by Cammidge,[7] and "Die Analyse des Harns" by Neubauer.[28]

Per cent of dried feces.

Total nitrogen, 8 to 9, normal ammonia in feces, 0.151, ether soluble extract, 16 to 17, ash 13 to 14.

Per cent of total nitrogen.

Soluble nitrogen, 32.0, bacterial nitrogen, 30 to 50, purine nitrogen, 10.

MacNeal, Latzer, and Kerr[22] have shown that the total nitrogen in dried feces of men averaged 11.69 per cent, the per cent of dried bacteria in feces was 29.86 per cent and the per cent bacterial nitrogen of the total nitrogen was 46 to 48 per cent.

Now if 32 per cent of the nitrogen in feces is soluble, 47 per cent is bacterial nitrogen, and 10 per cent is purine nitrogen, there remains 11 per cent of nitrogen from insoluble food residues. The. insoluble nitrogen, therefore, which separates from sewage in the form of sludge would consist of 47 parts of bacterial or nucleo-protein nitrogen, 11 parts of other organic nitrogenous matter, and that portion of the 10 parts of purine nitrogen which is insoluble or 69, 16 and 14 per cent respectively. Of this 16 per cent of organic nitrogenous matter, part is the resistant albuminoid proteins and part nucleoprotein and nuclein from the intestinal secretions. Thus, a very large per cent (80 to 90) of the nitrogen present in sewage sludge, if not acted on by biological agents, would be present in the form of nucleoproteins and their insoluble intermediate decomposition products.

Sewage sludge, however, has in almost all cases undergone considerable decomposition, particularly in the case of septic tank and Imhoff sludges. Jesse,[15] in studying the gases given off from septic tanks, showed that large quantities of carbon dioxide, carbon monoxide, methane, nitrogen and hydrogen sulfide were evolved. That large quantities of nitrogen compounds are lost is evidenced by the fact that septic sludge contains only 1 to 2 per cent nitrogen.

Schittenhelm[37] has shown that B. coli splits up nucleic acid into its purine bases and then deammonifies adenine and guanine to give xanthine and hypoxanthine. He also showed[38] that nuclein bases are rapidly lost in putrefying feces, and that if adenine is added to fresh feces after three weeks of putrefaction it has almost entirely disappeared.

Activated sludge is formed under aerobic conditions and the nitrogenous substances are not decomposed by putrefactive processes. The high nitrogen content of the sludge indicates that no great amount of insoluble nitrogen is lost. If we take Hawk's data of 9 per cent total nitrogen in feces and subtract the 32 per cent water soluble nitrogen we get 6.12 per cent nitrogen left. The average analyses of activated sludge in this country and England have shown a total nitrogen content of 5.0 to 6.3 per cent. At first these high results were thought to be due to a large carbonaceous decomposition of the sludge, which left the nitrogen compounds more concentrated. In view of the above considerations this explanation is unnecessary. Besides, the amount of carbonaceous fermentation which goes on must be counterbalanced by an equivalent loss of nitrogen.

In view of the above data it follows that the nitrogen in activated sludge is for the most part in the form of nucleo-proteins and their intermediate decomposition products.

The percentage composition of activated sludge according to present analytical methods for fertilizers is: moisture 10, total nitrogen 5.7, total phosphorus (P_2O_3) 3.9, ether soluble matter (4 hours extraction) 5.0.

	Alkaline permanganate method.	Neutral permanganate method.
Inactive water insoluble nitrogen	3.39	0.67
Active water soluble nitrogen	2.37	5.45
Availability of water insoluble organic nitrogen	44.7	89.0

Such an analysis is arbitrary and gives no indication of the forms of nitrogen present other than their ease of hydrolysis under specified conditions. That these methods are unsatisfactory is universally accepted by scientific men, since they do not compare with vegetation experiments. The above analysis is self-contradictory; according to the alkaline permanganate method activated sludge would be classified as an inferior fertilizer, while the results of the neutral permanganate method show that it is a good fertilizer. The vegetation experiments demand better understanding of the forms of nitrogen originally present and of their decomposition in explaining the availability of organic nitrogen to the plant.

The forms of nitrogen in activated sludge were studied by extracting known quantities of sludge with nitrogen free water. A summary of results is given below. Extracts 1, 2, 3 and 4 were prepared from Milwaukee activated sludge (4.0 per cent N.) 100 grams were shaken in a shaking machine for 24 hours, settled and filtered until clear and tested as follows:

Buret reaction (+?)■ Coagulation with heat and acetic acid (—). $CuSO_4$ — $NaHS_2O_2$ test for purines (+) Amrnonical $AgNO_3$ test for purines (+). Test for purimidines (—). Test for PO_4 (—). Test for Fe^{++} (—). The biuret reaction was hard to read because the color of the extract was so deep. The percentages of soluble material obtained from the four extracts were so similar that they were averaged:

	Per cent of total.	Per cent of soluble material.	Per cent of total nitrogen.
Sludge dissolved	12.33		
Ammonia nitrogen	.37	2.96	9.15
Organic nitrogen	.97	7.90	24.28
Total nitrogen	1.34	10.86	33.44

It was surprising to find such a large per cent of sludge soluble. Analysis of the sludge moisture before drying showed that an error of only 0.3 of one per cent could be introduced from soluble material in this moisture which the wet sludge contained. Hot water was found to increase solubility to a slight degree as shown below:

	Cold water extract.	Hot water extract.
Soluble matter	10.18 per cent	15.27 per cent
Total nitrogen	1.16 per cent	1.59 per cent
Ammonia nitrogen	.32 per cent	.26 per cent
Organic nitrogen	.84 per cent	1.33 per cent
Per cent of total nitrogen sol.	.29 per cent	37.8 per cent

Sludge as it exists in the purification plant must be made up of insoluble material, for it is constantly stirred with a large excess of water which would dissolve all soluble matter.

The increased solubility of the sludge must be due to a breakdown of the insoluble complexes into soluble compounds in the process of drying. In work described later it was found that acidification of the sludge changes its physical nature and facilitates filtering and drying. A series of extractions similar to those above, using sludges dried in different ways, acidified and unacidified, are reported in Table 16. The effect of different methods of drying on the solubility of nitrogen is very noticeable.

TABLE 16—BESULTS OF DIFFERENT METHODS OF DRYING.

Number—treatment.	Dried on steam bath.	Centrifuged and dried on cheese cloth in 1 week.	Dried on sand bed 2 months.
Per cent in sludge nitrogen, N	4.4	4.1	4.0
Sludge soluble	6.27	5.42	5.99
Total N_2	1.42	.53	1.54
Ammonia nitrogen	.39	.09	.58
Organic nitrogen	1.03	.44	.96
Per cent total nitrogen in soluble sludge—			
Total nitrogen	32.3	12.9	38.5
Ammonia—nitrogen	8.9	2.2	14.5
Organic—nitrogen	23.4	10.7	24.0

Number—treatment.	Acidified, and extracted.	Acidified, dried and extracted.	Acidified, dried and extracted.
Per cent in sludge nitrogen, N	5.0	5.8	4.6
Sludge soluble	12.51	10.14	16.12
Total N_2	1.20	1.02	1.08
Ammonia nitrogen	.08	.13	.29
Organic nitrogen	1.12	.89	.79
Per cent total nitrogen in soluble sludge—			
Total nitrogen	24.0	17.6	35.0
Ammonia—nitrogen	1.6	2.2	6.3
Organic—nitrogen	22.4	15.4	17.2

The great fluctuation in the ammonia nitrogen is due to the varying amounts of decomposition taking place in the extracts before the extractions were made. The soluble nitrogen is very easily decomposed into ammonia even when preservatives are used. The loss of nitrogen in drying sludges is dependent on the amount of decomposition which takes place. The longer the period, the more bacterial decomposition will take place. The higher solubility of acidified sludge must be due to a hydrolysis of the nitrogenous matter on drying in the presence of acid. As will be shown later the acid-treated sludge is more beneficial to plants than the unacidified sludge.

A study of a hot dilute hyrochlorie acid (1 to 3) extract of activated sludge showed on qualitative analysis: Biruet test (+), coagulable proteins (—), reduction of Fehlings soln. (+) phosphate ion (PO_4), (+), ammonia nitrogen (+), Purines (+) and Fe (+)

The reactions of this extract were much stronger than those of the water extract, indicating that more of the nucleo-protein was hydrolyzed.

According to the method for the quantitative determination of Neuclein nitrogen given on page 253 of Cammidge's "Feces of Children and

Adults," activated sludge was found to contain about one per cent of Neuclein nitrogen, (average of four determinations). These results have little significance since the method is purely arbitrary. In the process of the analysis it was found that a 2.5 per cent alcoholic hydrochloric acid solution would extract 22 per cent of the total nitrogen in the sludge. According to the method this is supposed to be pigment nitrogen. The residue after removing the pigmented and nuclein material was found to contain 20.2 per cent nitrogen.

A sample of activated sludge was treated according to Plimmer "Practical organic and bio-chemistry"[31] for the isolation and identification of purine bases. Small amounts of guanine and xanthine, a considerable amount of adenine, and smaller amounts of hypoxanthine were found and identified. No attempt was made to determine these quantitatively on account of lack of accurate methods.

Since activated sludge nitrogen is principally in the form of nucleoproteins and their decomposition products, we are ready to consider what effeet these compounds have on the growth of plants. It has been shown above that in water solution culture[35] the decomposition products are readily assimilated by growing plants and are very beneficial to growth. In pot culture, of course, these may be ammonified and nitrified before the plant takes them up. Proof that nucleic acid is readily nitrified in the soil is given by M. J. Funchess.[9] It has also been shown that nucleic acid is in most cases more easily nitrified than dried blood. That activated sludge has given better results than dried blood is partly because above a certain concentration dried blood is toxic to the plant. But why should it be toxic when much more sludge is beneficial? A more complete explanation rests on the forms of nitrogen which are present before and after hyrolysis of the fertilizers in the soil.

The nitrogen of dried blood is mostly in the form of serum albumin and globulin. These proteins are very easily broken down into their amino acids. A few of these amino acids, leucine, histidine, creatinine and asparagin have been shown to be beneficial[36] to plants in pot culture, but a larger number have been found to have no beneficial effect, and aspartic acid, cistein, guanidine and tyrosine were decidedly harmful. In the soil, amino acids are readily ammonified and nitrified if not applied in too high concetration.[9] That too high concentration of these amino acids prevents ammonification and nitrification and is toxic to the plant, may explain our results. On the one hand, activated sludge gives decomposition products that are themselves beneficial to the plant or may be nitrified; on the other dried blood is more easily hydrolized to give amino acids some of which may be toxic to both nitrification and plant growth.

In view of this there may be a fallacy in comparing such different materials, but from a practical point of view dried blood was chosen as the standard because it is generally accepted as the best form of organic nitrogenous fertilizer. It has been shown that activated sludge when applied on an equivalent nitrogen basis is superior to dried blood as a fertilizer; from a theoretical point of view the above comparison of their chemical constitution explains this fact. But theoretical considerations do not always work when we are dealing with such a multitude of conditions as are found in the soil. Series 6 was started on February 2, 1918 with different types of organic nitrogen as fertilizers, and with these various considerations in mind.

This series was planted in sand culture which was fertilized with the equivalents of 5 tons per acre of dolomitic limestone, 1 ton of acid phosphate, 1/4 ton of potassium sulfate, and nitrogenous fertilizer. Data will be found in Table 17.

TABLE 17—RESULTS FROM APPLICATION OF DIFFERENT TYPES OF ORGANIC NITROGEN AS FERTILIZERS, SERIES 6, 1918.

Pot	Fertilizer.	Per cent nitrogen in fertilizer.	Grams application of fertilizer.	Tons per acre fertilizer.	Nitrogen equivalent pounds per acre.	Bushels wheat per acre.	Tons straw per acre.
1	Check	0	0	0	0	3.0	.6
2	Unextracted activated sludge	5.	17.37	1.39	139.0	7.0	1.5
3	Extracted activated sludge	4.6	18.80	1.50	139.0	8.2	2.0
4	Acidified activated sludge	5.8	14.90	1.19	139.0	5.5	2.0
5	Uric acid	33.3	2.60	0.21	139.0	.5	1.6
6	Sodium nucleinate	14.5	5.97	0.48	139.0	10.0	2.7
7	Dried blood	13.9	6.25	0.50	139.0	10.2	2.7
8	Dried egg white	12.4	7.00	0.56	139.0	1.3	1.0
9	*Sodium nitrate	16.45	5.28*	0.46	139.0	4.8	3.7
10	Gluten meal	7.0	10.98	0.88	139.0	5.1	2.0

* One half of $NaNO_3$ applied February 2, 1918; the rest March 29, 1918.

In this series the application of 0.5 ton of dried blood was taken as the standard. This quantity was decided upon from the results obtained with dried blood on sand in Series 4. The three types of activated sludges used represent a sample of sludge obtained by mixing a number of sludges taken from the Water Survey Experimental Continuous-Plow Plant[4] during July, 1917, and dried on the steam bath, and two samples which were acidified, dried and extracted with gasoline. Because of the prohibitive cost and impossibility of getting adenine, guanine, xanthine or hypoxanthine in quantities for pot culture work, uric acid, which is the nearest to these in chemical structure, was used. The sodium nucleinate was prepared by Kahlbaum. The dried blood was the same used in the series of 1917. The protein of blood is albumin and globulin; since dried egg albumin (Mercks) is a good example of an easily hydrolysized albumin it was used to see if toxic effects would be produced. The sodium nitrate was "C.P." The gluten meal represents a vegetable protein and its decomposition products.

The sodium nucleinate and gluten meals at first appeared to retard germination, but in a few weeks the plants regained strength and soon

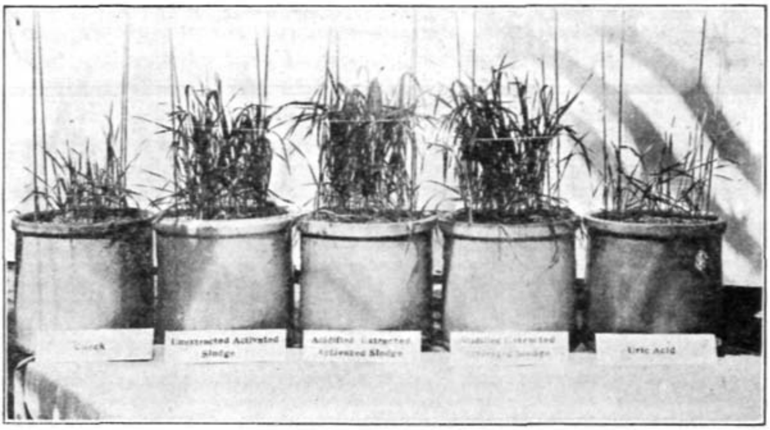

Figure 7.—First five in Series 6, end of eight weeks.

Figure 8.—Second five in Series 6, end of eight weeks.

the sodium nucleinate showed itself to be very beneficial. Uric acid and egg albumin were very toxic to the young plants and retarded growth for 6 weeks. Then the plants looked better and began to grow as if the toxic effect were disappearing. The sodium nitrate and dried blood cultures were the best from the first, with the activated sludge pots almost equally good. Figures 7 and 8 show pictures of this series after 8 weeks, when the uric acid and egg albumin cultures were recovering from the toxic effect. At the end of three months these cultures were growing fast and showed prospects of as good results as the others.

The plant growth, in this series, shows that dried blood and sodium nitrate give the best results when they are used at this low concentration. No toxic effect was produced by dried blood. Gluten meal is not equal to dried blood as a fertilizer. The very toxic effect produced at first during the breakdown of egg albumin indicates that these intermediate products are toxic to the plant, but after these products had been further decomposed and nitrified the plants grew with renewed vigor, tho seed production was poor. Uric acid gave similar results. It was not used directly by the plant, as Schreiner[35] has shown purines to be. The results with sodium nucleinate show that its nitrogen is readily available and gives results equal to those of dried blood. Not all the nitrogen in activated sludge is available for immediate use; at first rapid growth of the plant is produced, then there is a slight relapse which is followed by a second healthy growth apparently due to the hydrolysis of more nitrogen to an available form. Activated sludge which had been acidified, dried and extracted gave much better results than the untreated sludge. It has been shown that the amount of grease in activated sludge does not decrease its availability, therefore the acid treatment must have caused a beneficial change in the nature of the sludge.

DEWATERING ACTIVATED SLUDGE.

Activated sludge as it comes from the settling chamber of the purification plant is very liquid, containing 98 to 99 per cent moisture. On further settling, this moisture may be reduced to 95 per cent, which is about the limit to which the water will separate on settling. In some plants the sludge may be sold as a fertilizer in this wet condition; but in most cases the moisture must be removed, for this large bulk of water would make the transportation charges prohibitive. Lowering the moisture of activated sludge to 75 per cent will reduce the volume of sludge 80 per cent. In order to market the sludge as a fertilizer the moisture must be reduced to 10 per cent. This reduction from 75 to 10 per cent moisture is easily and economically accomplished in rotary hot air dryer's. The real difficulty comes in removing the 20 per cent moisture between 95 and 75 per cent.

Sand beds were first tried by us in the summer of 1916. The results did not prove satisfactory. In 1917, five sand beds were built which were carefully underdrained and protected from rain by a canvas covering. Even with this protection the sludge clogged the sand and the excess water was removed by evaporation; two months elapsed before the sludge was in condition to be raked off the beds. This slow drying allowed the sludge to undergo putrefaction which not only lowered its fertilizing value but caused nuisance around the plant from odor and flies. In cold climates beds of this type would be of no value during winter, so this method of drying was abandoned.

For experimental purposes much sludge was dried by using coarse cheese cloth to cover the bottom of a box 2½ feet by 3½ feet having a wire net in the bottom. The water filtered through this much better, but even with coarse cheese cloth the pores of the cloth clogged with the gelatinous sludge and a large proportion of the moisture had to be removed by evaporation. For practical purposes cheese cloth could not be used, but for experimental purposes it was very convenient. Under the very best weather conditions sludge would dry in this way in one week. Cheese cloth bags were also used with some success.

The results of Hatton at Milwaukee, and of the packers in Chicago in filterpressing activated sludge have not been duplicated in this laboratory. A Kelly press was used with canvas, cheese cloth, burlap and wire gauzes of various meshes for filtering materials. In every case the sludge clogged the filtering medium and water could not be forced through the press with 250 pounds pressure. The addition of lime and also sulfuric acid were tried, the lime doing no good and the acid being only slightly beneficial. These results show that the colloids of the sludge stop up any type of filtering material tried, and that pressure induces clogging more rapidly than gravity filtration. Therefore, the experiments that follow, attempt to change the physical properties of sludge to facilitate filtration.

In order to study the effect of excess aeration on the physical properties of activated sludge, a 50-gallon barrel was provided with a 12-inch filtros plate near the bottom and a 4-inch air chamber beneath this plate. The air used was measured with a gas meter and all errors due to sampling and evaporation were accounted for. The sludge used in this experiment was taken from the settling chamber of the continous-flow plant and settled in barrels for 20 minutes, the clear liquid was siphoned off and concentrated sludge placed in the aeration barrel. Samples were taken every 24 hours. (Table 18).

Experiments on the rate of settling were made by placing 500 cc. of the sample in a 500 cc. graduated cylinder and noting the time required for settling to marks indicated on the cylinder. For comparison only the time required for settling to 75 per cent of the volume is recorded in Table 18.

In studying the rate of filtration as aeration proceeded two liters of aerated activated sludge in a 2-liter flask were inverted over a 10-inch corrugated funnel so that a constant level was obtained in the funnel. The filter paper used was carefully selected. The rate of filtration per 100 cc. was timed with a stop watch, but the accuracy of the data was not sufficient to permit the formulation of an equation expressing the decrease in rate of filtration per 100 cc. Table 18 gives the total time required to filter 1,000 cc. under constant level and complete data on the experiments.

The suspended solids gradually went into solution and the dissolved solids increased. Analysis of the sludge showed that this aerobic decomposition does not cause a loss of nitrogen in the sludge, at least in the first seven days.

TABLE 18—DATA ON AERATION OF ACTIVATED SLUDGE.

	Liters.	Gallons.
Capacity of barrel	168	44.4
Total sludge removed for samples	22½	5.94
Loss by evaporation	19	5.02
Loss by evaporation per 24 hours	2.5	.72
Total loss (sample plus evaporation) per 24 hours	5.0	1.37
Sludge remaining after experiment	126½	33.4

Sample.	Total hours areated.	Hours between samples.	Cu. ft. air per 24 hours.	Cu. ft. air per hours per gal.
1	0	0	0	0
2	12	12	210	.487
3	36	24	540	.515
4	60	24	850	.863
5	84	24	675	.710
6	132	48	2(662½)	.718
7	156	24	785	.892
8	180	24	765	.899

Sample.	Time of setting to 75% vol. minutes.	Time of filtration of 1,000 cc. in minutes.	Loss of suspended matter.	Gain in dissolved residue.	Per cent nitrogen in dried sludge.
1	90	----------	0	0	5.95
2	134	34.0	----------	150	6.22
3	136	14.8	----------	162	6.05
4	66	12.2	1,422	146	6.25
5	----------	----------	1,818	168	6.10
6	53	3.1	2,000	256	5.97
7	45	4.2	1.896	344	5.99
8	188	4.3	2,322	496	5.30*

* Some loss of nitrogen through stopper.

After 4 to 5 days of aeration, activated sludge filters with much greater rapidity. The loss of suspended solids during 180-hour aeration was 29.15 per cent. This lowering of the suspended solids may explain the increase in rate of filtration shown in the table.

A second experiment similar to the above was carried out using less air. Altho the results were not of the same magnitude they were of the same order and indicated that seven days' aeration would be the practical limit and that the resistance to filtration is materially lowered. The cost of aeration makes this method expensive, while the benefits derived are not great.

Coagulation.[1]— Coagulants to precipitate the sludge and aid in its filtration were tried.

Those used grouped according to their concentration are as follows:

A.	B.	C.
HC1 N/1	NaCl saturated	Solids
NaOH N/1	$Ca(OH)_2$ saturated	Kaolin
Na_2SO_4 N/1	$Al_2(SO_4)_3$ 10 per cent.	$CaCO_3$
Na_3PO_4 N/1	Colloidal Fe (prepared according to Taylor)	
NaCl N/1	Aluminium cream	
$CaCl_2$ N/1		
$FeSO_4$ N/1		

The first experiments were made by adding one cc. of solution to 50 cc. of sludge in Nessler tubes and comparing the rate of settling with a check tube to which nothing was added but the sludge, and also the final volume occupied by the sludge when maximum settling had taken place. The results of these studies placed the reagents in the following descending order according to the decrease in efficiency in increasing the rate of settling. HC1 N/1, $CaCO_3$ (saturated), $CaCO_3$ solid, $Al_2(SO_4)_3$ 10 per cent, Na_2SO_4 N/1, NaCl (saturated), Ca (OH), (saturated), and Kaolin.

NaCl N/1, $CaCl_2$ (saturated), $FeSO_4$, colloidal iron, aluminum cream, and NaOH N/1 gave no better results than the blank determination. Sodium phosphate (Na_3PO_4) hindered sedimentation.

Best results were obtained with acid and with solid pulverized limestone, the rate of settling being proportional to the amounts added. With acid the sludge first settles, and then if sufficient acid has been added to approach neutrality or acidify to methyl orange, Carbondioxide gas is liberated and the sludge is lifted to the top of the container. Repeated experiments showed that on standing 24 hours the acidified sludge occupied about one-third the volume of that occupied by untreated sludge, although it would be on the surface while the untreated remained on the bottom of the vessel. Large amounts of $CaCO_3$ were found to be as efficient as acid, but these quantities were not practical.

Experiments were next made on the rate of filtration, using HC1 and powdered $CaCO_3$. These experiments showed that if the sludge is made acid to methyl orange its rate of filtration is greatly increased, smaller amounts of acid are without appreciable benefit. Ground limestone gave better results with sludge that had been aerated for six days than with fresh sludge. Experiments on the rate of filtration of the concentrated sludge after treatment with acid showed that the acid sludge filtered 50 per cent faster than sludge treated with $CaCO_3$, while a check filtration experiment using untreated sludge did not filter in 24 ■ hours. At the end of 24 hours the untreated and $CaCO_3$ treated sludge putrefied, while the acid sludge had only a "fishy" odor characteristic of acidified activated sludge. Filtration of acidified, limestone-treated and untreated sludge on Buchner funnels with suction showed that the untreated and the limestone-treated sludge clogged the pores of the paper and did not filter in 24 hours. The acid sludge filtered rapidly and a good cake was formed in less than 12 hours. If activated sludge putrefies it is still more resistant to filtration.

It would be natural to expect acid to solve the problem of filter-pressing this material, but this was not found to be the case with the press used in these experiments. However, a much better cake was formed in the press-with the acid sludge than with untreated sludge. Sludge treated with $CaCO_3$ showed no improvement at all.

Gentrifuging.—Previous to these experiments the only attempts to use centrifugal force for dewatering activated sludge have been based on the principle of filtration, as in a laundry centrifuge. This is only another way of exerting pressure on filtering material; and, as has been shown above, pressure increased the tendency of the sludge to clog the filtering material. The experiments were not very successful. Those carried on in this laboratory were based on the principle used in a cream separator. The bowl of a small basket type of laboratory centrifuge was made imperforate with a strip of rubber packing. Sludge was allowed to flow in near the center of the bowl which was moving at maximum speed. The heavier material packed against the sides of the bowl and the lighter clear water stood on the inside. As more sludge was added the clear water flowed over the top of the bowl and was caught by the outer stationary casing. When sludge was added until the liquid coming over the edge of the bowl was quite turbid a good cake was usually formed. The following tabulated data show the results obtained at different speeds of revolution of the bowl:

Moisture of sludge used . . . . 98.4 per cent
Revolutions per minute of bowl 1100
Cake—Moisture . . . . 92.9 per cent

This cake was "runny" but was far better than any obtained from our filter presses.

Revolutions per minute 1500
Cake much more solid, moisture . . . . 91.5 per cent

These results were so promising that an old cream separator was purchased and used. The results obtained with higher revolutions per minute are as follows:

Sludge used	99.3 per cent moisture
Cake at 7,000 r.p.m. of bowl	88.5 per cent moisture
Cake at 9,000 r.p.m. of bowl	86.5 per cent moisture.
Cake at 10,500 r.p.m. of bowl	85.6 per cent moisture

These cakes were quite solid and retained their shape, standing up to the sides of the centrifuge bowl.

Next a small Tolhurst centrifuge with a 12-inch imperforate bowl was installed at the Experimental Activated Sludge Plant. This machine was designed to run at a speed of 2,200 revolutions per minute, but the pulleys were so modified that the experiments reported below were run at 1,800 revolutions per minute.

For two months this machine was run almost daily in order to determine the best methods of operation and the capacity of the machine. To give an idea of the results, a number of characteristic runs are described below. In all cases the concentration of the sludge used' is expressed in percentage volume to which the sludge settled in 30 minutes. This represents the degree of dilution of the sludge better than it can be given in any other way. The sludge was measured into the receiving reservoir of the centrifuge in buckets having a capacity of 7 liters. The general method of operation was to start the centrifuge and allow it to reach its maximum speed, which required a minute, then the sludge was run into the centrifuge bowl near the center from a valve in the sludge reservoir. For a while the effluent which escaped thru an opening in the outer casing would be clear, but later as the sludge cake built up the effluent would become turbid with suspended sludge, and if allowed to run much longer would be of the same consistency as the inflowing sludge. When the sludge began to run out of the effluent pipe the machine was stopped and the sludge cake removed, carefully sampled and its moisture determined.

Data on the first run made after the general method of operation was determined, are as follows:

Percentage to which sludge settled in 30 minutes	56
Moisture of sludge used	99.19
Liters of sludge used	70.0
Pounds of wet cake	9.7
Percent moisture in wet cake.	88.2
Pounds of dry cake	1.07

Data on a similar run using sludge which settled to 61 per cent by volume:

Liters of sludge used 70
Minutes to run sludge thru machine 12
Minutes to clean sludge from bowl 8
Pounds of wet cake 9.45
Pounds of dry cake 1.04
Per cent moisture in wet cake 87.8

The cake formed in these tests was quite solid and remained in place on the wall of the centrifuge. The cake was about an inch and a half thick.

A test using more concentrated sludge gave the following results:

Per cent to which sludge settled in 30 minutes 95
Liters of sludge used 35
• Minutes to run sludge thru machine 10
Pounds of wet cake 9.15
Pounds of dry cake 1.07
Percent moisture in wet cake 88.9

A test of sludge which settled to 96 per cent was run until the effluent was of the same consistency as the inflowing sludge. The results were better:

Liters of sludge used 56
Minutes to run sludge thru machine 10
Pounds of wet cake 9.35
Pounds of dry cake 1.09
Per cent moisture in wet cake 85.4

These runs show that the efficiency of the removal of water is not dependent on the original concentration of the sludge. The total time of running was also found to be about the same for both dilute and concentrated sludges, because a dilute sludge may be run through the centrifuge much faster than a concentrated one. In order to get a sludge drier than 88 per cent moisture, sludge must be run through the machine until the effluent is about as concentrated as the influent.

An attempt was made to get a drier cake by adding the sludge rapidly at first and then more slowly, with the following results:

Percentage to which sludge settled in 30 minutes 95
Liters of sludge used 42
Total time to run sludge thru (minutes) 8
Minutes for first four buckets to run thru 4
Minutes for last two buckets to run thru 4
Per cent moisture in cake 89.4

This being unsuccessful, runs were so made that between the additions of sludge the bowl was allowed to spin without the addition of more sludge for a definite period, and then more sludge was added.

One more bucket was added in each case after the effluent showed the presence of sludge.

28 liters of "95 per cent sludge" were put thru the machine in	8¾	minutes
Bowl spun without addition of more sludge	1	minute
7 liters of sludge	3¾	minutes
Bowl spun	1	minute
Total time	14	minutes
Cleaned in	5	minutes
Per cent moisture in cake	88.6	
11 liters of sludge added in	4	minutes
Bowl spun	1	minute
14 liters more	5	minutes
Bowl spun	1	minute
14 liters more	5½	minutes
Bowl spun	½	minute
Cleaned in	5	minutes
Per cent moisture in cake	87.7	

These runs show that intermittent addition of sludge is without advantage. In most of the runs made during the two months, a cake containing about 88 per cent moisture was obtained. If considerable quantities of sludge ran through the machine after the effluent became colored, the best result obtained was a cake containing 84.7 per cent moisture. Sludge acidified with H_2SO_4 was put through and centrifuged in a similar manner with these results:

	Per cent.
Concentration of sludge used	95
35 liters gave sludge cake with moisture of	88
42 liters gave sludge cake with moisture of	84.6
49 liters gave sludge cake with moisture of	82.5
Total time	35 minutes

Better results were obtained by using a 95 per cent acidified sludge; adding the last few buckets of sludge more slowly. Data:

42 liters in	8	minutes
14 liters in	3	minutes
14 liters in	5	minutes
7 liters in	3	minutes
Total 77 liters in	19	minutes
Cleaned in	7	minutes
Total time of run	26	minutes
Per cent moisture in cake	81.95	

The best result was obtained by adding acidified, 85 per cent, sludge with intermittent spinning of the bowl. Data:

49 liters added in .... 10 minutes
Bowl spun ....10 minutes
14 more liters .... 5 minutes
Bowl spun ..,................................ 5 minutes
14 more liters .... 10 minutes
Bowl spun .... 5 minutes

When the bowl was stopped clear water ran down from the cake. This water was removed and the bowl spun 5 minutes longer when 40 cc. more of water were removed.

Total time of run. ...,.......................... 50 minutes
Per cent moisture in cake 79.15

These results show that with acidified sludge a cake containing 80 to 82 per cent moisture may easily be obtained so that two runs could be made in an hour, whereas with unacidified sludge under the same conditions a cake containing 88 per cent moisture is usually obtained.

Some experiments were made with the speed of revolution of the centrifuge bowl reduced to 1,200 r.p.m.; the centrifugal force at this speed was not sufficient to form a good cake.

The J. P. Devine Company has dried for us 200 pounds of sludge containing 88 per cent moisture and reported that it can be done economically. The cost of acidifying activated sludge as obtained by us in Urbana, with H_2SO_4 at $30 a ton, would be 38 cents per million gallons of sewage treated or 76 cents per ton of dried sludge.

Nasmith and McKay's[27] article, "The fertilizing value of activated sludge," which appeared in print after this thesis was accepted, deserves mention. Carefully conducted garden experiments with radishes, lettuce, beans, beets, tomatoes, carrots, and onions are reported. Activated sludge is compared with manure and with other types of sewage sludge, using an equivalent application on each plot of 14.5 tons per acre. The activated sludge used was air dried and had a very low nitrogen content (2.5 per cent nitrogen), evidently due to the loss of nitrogen by bacterial decomposition of the sludge while drying. Application of 14.5 tons of activated sludge with the usual 5 to 6 per cent nitrogen would be a waste of nitrogen, and probably would produce a poorer crop than much less sludge. However, the experiments showed the following percentage increase of production with activated sludge over that with standard barnyard manure.

	Per cent.
Radishes	"40.0
Lettuce	103.3
Beans	77.3
Beets	138.0
Late radishes	316.0
Tomatoes	291.0
Carrots	0.0
Onions, Spanish	191.0
Weatherfield	554.0
Danvers yellow globe	87.1

"From these results it is clearly evident that activated sludge is a most valuable fertilizer."

If these results are compared to those in Table 15, there is a striking resemblance to the results on the "wet sludge plot." Data in. Table 14 on the results of high applications of activated sludge (5 per cent nitrogen) to wheat, show that the production of grain is materially decreased as the application is increased. However, the growth of straw is increased and it is probable that high applications to truck garden vegetables would not be detrimental, but would greatly stimulate the growth as Nasmith and McKay have reported.

P. Rudnick[33] of the Armour and Company chemical laboratory in criticizing this article suggests that the results published by Bartow and Hatfield[5] in 1916, which showed that activated sludge gave better results proportionally than dried blood, were "contrary to experience and known facts regarding dried blood which is considered the most valuable of commercial organic ammoniates," and that the results were due to the use of sterile sand, sterile dried blood and activated sludge which "teems with proteolytic and nitrifying organisms."

The sludge used in the early experiments reported above was dried 3 to 7 days on a steam bath. It does not seem probable that the nitrifying organisms could withstand this temperature, since the thermal death point of the nitrite organisms is 45° C. for 5 minutes, and that of the nitrate organisms is 55° for 5 minutes. Numerous experiments on activated sludge by Bartow and Hatfield have shown that there are no nitrifiers present as indicated by incubation of standard ammonium sulfate broth. Again, these organisms are very sensitive to acid, and acidified sludge should be sterile, yet acidified sludge has given the best results in pot cultures.

Furthermore, agricultural practice has not shown that dried blood always gives good results. The Agricultural Experiment Station of the University of Illinois has given up the use of dried blood on a number of experimental farms in the State because it produces retarding effects. These same results have been found by Lipman of California and Fred of Wisconsin.. The generally accepted explanation of these results is that since dried blood is so easily ammonified, an accumulation of ammonia is caused which is toxic to nitrobacter. Winogradski and Oleliansk[43] have shown that 0.0005 per cent ammonia retards and 0.015 per cent kills nitrobacter. If the growth of nitrobacter is hindered or stopped the accumulation of nitrite is very toxic to the plant.

The toxic effect of dried blood in sand is plainly shown by the experiments reported in Series 5, Figure 3, and Table 11. These results show that dried blood "which is sterile" when planted in "sterile sand" under the conditions of the above experiments will give good results if used in small enough applications, but that larger applications do produce toxic effects.

Series 6 was fertilized with equivalent amounts of nitrogen which would give the best results with dried blood. This series is the only series where the results with dried blood were as good as those from activated sludge. There is no doubt that dried blood in larger quantities causes toxic effect, and the fact still remains that activated sludge under certain conditions gives better results and less toxic effects than dried blood.

If the work is to be continued in this laboratory or elsewhere the following suggestions are offered: allow the fertilizer to decompose for a month or so in the pot or plot before the seeds are planted; treat all pots or plots with an emulsion made from rich gray silt loam in order that all plots will be sure to have the necessary nitrifying organisms present.

SUMMARY.

In the pot culture experiments of 1915, activated sludge was found to be superior to dried blood, gluten meal, and inorganic nitrogenous fertilizer, when applied to sand. In garden experiments of the same " year, activated sludge produced a still larger increase in the growth of lettuce and radishes.

Pot experiments using three types of soil fertilized with septic tank sludge, Imhoff sludge, activated sludge and dried blood proved that sewage sludge has a fertilizer value and that activated sludge nitrogen again gave better results than dried blood nitrogen. Experiments on another type of soil showed that 1.5 tons of activated sludge gave the best result in growing sweet corn. Garden experiments in 1916 produced an increase of 71 per cent in weight of cucumbers due to activated sludge.

Sand cultures in 1917 showed that, in sand, applications of dried blood greater than one-half to three-quarters of a ton were toxic to wheat. Increasing the application of activated sludge on gray silt loam did not prove toxic to the growth of foliage, tho in applications greater than one to two tons, it decreased the yield of grain.

The application of sewage sludges the second year to yellow silt loam did not prove toxic but did not give as large a yield as was obtained the year before. The addition of phosphorus to the white silt loam proved that phosphorus was the limiting element in this series; activated sludge being the only fertilizer which produced a better yield than the check pot.

Garden experiments in 1917 proved that both wet and dried activated sludges were valuable as fertilizers, the wet sludge giving better results.

Nitrogen in activated sludge is present largely in the form of nucleo-protein nitrogen and its hydrolytic products, which have been shown to be beneficial to plant growth. Pot culture experiments show that sodium nucleinate is readily available to the plant and that uric acid, tho it is at first toxic, in time is nitrified or decomposed so that its nitrogen is also available. Egg albumin was highly toxic to young wheat plants, showing that the intermediate hydrolytic products of albumin are toxic. Activated sludge which had been acidified gave much better results than unacidified sludge. This is probably due to some hydrolysis taking place in drying the acidified sludge.

Good results are obtained with dried blood if the application is in small enough amounts that the concentration of toxic substances is low.

Drying activated sludge on sand beds was found to be impracticable in this climate, and filterpressing under conditions available was not successful. Excess aeration of the sludge proved an aid to filtration but was not economical. Experiments with precipitants showed that sulfuric acid could be used to the best advantage in separating the excess water and increasing the rate of filtration.

Centrifuging activated sludge in an imperforate bowl will produce a good cake having a moisture content of 88 per cent. From sludge acidified with sulfuric acid, a cake of 80 per cent moisture may be obtained. A cake of this type may be economically dried to 10 per cent moisture in hot air dryers.

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SILICIC ACID, ITS INFLUENCE AND REMOVAL IN WATER PURIFICATION.*

By Otto Mitchell Smith.

INTRODUCTION.

Little attention has been paid to the presence of silicic acid in natural waters except in cases where its content is quite high. It is universally present but usually in amounts less than 100 parts per million. It is more prevalent in the surface waters of the Mississippi Valley[16] especially on the western watershed. It is found in as large amounts as 1,163 parts per million at Cesenate, Italy,[46] 1,230 parts per million at Deep Rock Springs, Oswego, N. Y.,[13] and 923 parts per million at the Yellowstone National Park.[37]

Silica in solution usually occurs as colloidal silicic acid and[32] in combination with the basic elements. Its presence in water used for steam purposes has always been considered detrimental and conducive to the formation of a hard flinty scale. Besides forming an undesirable scale, A. Goldberg[21] believes silicic acid is responsible for many boiler disturbances. When the acid is distilled with water solutions of nitrates and chlorides, nitric and hydrochloric acid are liberated.

Turbidity in water is generally caused by the suspensions of very finely divided mineral matter, mainly clay. Clay may be defined as a mixture of minerals of which the most representative members are the silicates of aluminium, iron, the alkalies and alkaline earths. The hydrated aluminium silicate, kaolin. ($Al_2O_3,2SiO_2,2H_2O$) is the most abundant compound.

There are many eases in the literature emphasizing the difficulties of clarifying water containing finely dispersed clay particles. Fuller[20] in 1898 found at times a turbidity which was difficult to coagulate with an abnormal consumption of alum. Ellms,[17] Black and Veatch,[7] and Catlett[12] show the difficulties in the treatment of such water.

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THEORETICAL AND HISTORICAL PART.

. As silicic acid and clay suspension are considered as sol and suspensoid respectively a brief discussion of the general properties of colloids is pertinent. Burton[11] defines a colloid solution "as a suspension, in a liquid medium, of fine particles which may be graded down from those of microscopic to those of molecular dimensions; these particles may be either homogeneous matter, solid or liquid, or solutions of a small percentage of the medium in an otherwise homogeneous complex. The one property common to all such solutions is that the suspended matter will remain almost indefinitely in suspension in the liquid, generally in spite of rather wide variations in temperature and pressure; the natural tendency to settle, due to the attraction of gravitation, is overbalanced by some other force tending to keep the small masses in suspension."

With the development of the ultra microscope and the investigations of Zsigmondy and Siedentopf[53] it is possible to show that there is a continuous gradation in the size of particles of the disperse phase from 1.70×10^{-7} cm. in diameter to that of visible organisms and this leads to the belief that there is a gradation in size from the smallest of these particles to the molecules.

Tyndall[47] (1869) found that small particles could be revealed by the lateral diffusion of a beam of light traversing a solution. Applying this method Linder and Picton[29] were able to grade the sizes of particles of colloidal arsenous sulfide.

Wiedemann[51] (1852) and Quincke[39] (1861) confirmed the discovery of Reuss that a liquid would move across a diaphragm or through a capillary tube towards one of the electrodes when a current is passing. The migration of sols in the electric field was first observed by Linder and Picton. As suspended particles carry electrostatic charges, it seems logical to conclude that as result of these charges, suspended particles whose masses are small enough are equally distributed throughout the liquid, and prevented from ever settling because of the mutual repulsion of the charges. Such a solution is called a sol in contradistinction to the jelly-like form called a gel. When the dispersion of relatively insoluble particles is not so great as to become macroscopically invisible—such a system is termed a suspension. The change of an irreversible hydrosol to an amorphous precipitate wherein there is no Brownian movement is known as coagulation.

Schultz,[43] and Linder and Picton[29] showed that the coagulating power depends upon the valency of the metal ion and according to later workers, equivalent solutions containing monovalent, bivalent and trivalent metallic ions would possess, whatever the nature of the anion, coagulating powers in the ratio of 1:35:1023 which is nearly represented by the formulae 1 :x :x^2. In 1899 Hardy[22] found that the concentration of the acid necessary for coagulation of electronegative particles and of alkali for. the coagulation of electropositive particles is determined by the laws of ordinary chemical equilibrium.

Burton[10] adding graduated amounts of aluminium sulfate $Al_2(SO_4)_3$ to a negative sol, found that there was a decrease and even a reversal of the charge. Thus if one is able to pass from a negative sol to a positive sol there must be a point of zero potential—"isoelectric point." Hardy[23] suggests that the coagulation of colloids by electrolytes takes place when the particles have their charges neutralized by the adsorption of oppositely charged ions of an electrolytic solution and at the isoelectric point. His previously published conclusions were[24] that the conditions which determine coagulation are: (1) concentration of colloid, (2) temperature, (3) the nature of the ion, and (4) that the action is additive if the ions are of the same valency and "subtractive" if of different valencies, as the one inhibits the other.

Crum,[15] Linder and Picton,[29] and Whitney and Ober,[50] have established the fact that during the process of coagulation a portion of the electrolyte is always adsorbed by the coagulum and that amount is proportional to the electrochemical equivalents of the anion.

Lottermoser,[28] Blitz,[9] and Billitzer[5] demonstrated that colloids of opposite sign precipitate each other; that there is an optimum of precipitating action shown for certain proportions of colloid and that, if in any case these favorable proportions are exceeded on either side, no precipitation occurs; and that the direction of migration of the whole under the influence of the electric current is the same as that of the colloid in excess. This leads to the subject of protective colloids. Many organic colloids when added in comparatively minute quantities to suspensoids have the power of preventing the coagulation of the system.

PROPERTIES OF SILICIC ACID AND CLAY SUSPENSIONS.

Silicic Acid.

This colloid possesses the properties common to its class. In concentrated solutions it is unstable, but below 1 per cent it is stable for years. It has not been prepared free from electrolytes; its molecular weight is about 49,000. Billitzer[4] and Fleming[19] found it amphoteric, carrying a negative charge in akaline and a positive charge in acid solutions. Fleming's data, converted into terms of hydrogen ion concentration, indicate that the isoelectric point lies between a P_h value of 13.6 and 13.9, which is not in accordance with facts. It exhibits the Tyndal effect and is precipitated by electrolytes and positive colloids. **The** coagulation from dilute solution is irreversible. Hardy[25] determined that the coagulating power of electrolytes, which precipitate a solution of about 1/120 normal silicic acid, varies with the cation, the anion having little effect. Of these aluminium sulfate was the most active and sodium salts least. It is also coagulated within a short time by copper sulfate, cadmium nitrate, calcium, barium and strontium chlorides and carbonates, barium hydroxide, concentrated solutions of ammonium sulfate, dilute solutions of egg albumin, glue, basic dyestuffs, carbon dioxide gas and graphite.

Pappada[35] found that neutral salts only act at great concentrations but accelerate gelation (coagulation) according to the lyotope series.

$$SO_4 > Cl > NO_3\text{; and}$$
$$Ca > Rb > K > Na > Li$$

Silicic acid hydrosols do not act as a protective colloid for colloidal gold, but P. Kuspert[34] found that real protective action occurs at the moment the silicic acid is being precipitated. Silicic acid is precipitated in insoluble compounds by many chemical reagents, but this phase of the subject is not here discussed.

Properties of Clay Suspensions.

Clay suspensions are impure suspensoids. That they carry a negative charge is shown by Ellms[17] and Count Schwerin.[44] Very dilute suspensions exhibit the Tyndal effect. Ultra-microscopic observations have shown that the parties probably have a diameter of 1.7 x 10^{-7} cm. or less. According to Mayer, Schaffer and Terroine,[30] the addition of a trace of alkali decreases the size of negative suspended particles. Ashley[1] reviewing the work of many investigators came to the conclusion that the colloids in clay are non-crystaline, hydrated, gelatinous aluminium silicates; organic colloids; gelatinous silicic acid and hydrated ferric oxide; that aluminium hydrate, $Al(OH)_3$, is rarely present; and that the colloids of clay may carry into suspension solid particles that are wholly non-colloidal, according to the ordinary ideas, which particles may stabilize the clay sol. The work of Van Bemmelen[48] and Parmelee[36] indicates that the longer clay substance is washed the more colloidal it becomes; and that bodies are gradually hydrolyzed from crystaline compounds to soluble colloids.

Ionic Reactions.

A. Lottermoser[28] considers that "the hydrosol condition is only possible if one of the reacting ions (I'' + Ag^+, Fe^{+++} + $30H^-$, SiO_2 + $2H^+$) remains up to a certain minimum amount in excess; than on exceeding this limit the gel formation begins and becomes complete if equivalent amounts of the reacting ions are brought together. The hydrosol condition is bound up with the presence of certain ions in the colloid."

If sodium carbonate or an acid be added to a clay which has just enough calcium, Ca, to keep the colloid matter in the gel form, it may react according to the following equations:

$$Ca\ Gel + Na_2CO_3 = CaC0_3 + Na_2\ Gel \text{ or}$$

$$Ca\ Gel + H_2SO_4 = CaSO_4 + H_2\ Gel.$$

Foerster[18] first perceived the nature of the action of sodium carbonate on the clay gel. The chemical reactions of the colloidal matter in clay are remarkably similar to those of fats and soaps, the conditions of solubility and insolubility are parallel, but the colloidal matter of clay is more readily acted upon. Thus in a general way the salts of the fatty acid and the sodium, and ammonium sols of clay colloids are soluble in water. The free fatty acid and the acid gels are insoluble in water. The bivalent and trivalent bases form insoluble salts with soaps and insoluble gels with clays. Ashley[1] says "The proof of these conceptions is that they are not inconsistent with known facts about clays; that they have proved a most helpful and suggestive guide in planning investigations, and that they have never misled."

Effect of Electrolytes in Clay Suspensions.

Much valuable information is available in the ceramic research on the action of salts on clay suspensions. The effect of the salt varies with (1) the clay; *(2)* its previous mechanical treatment; (3) its age; (4) concentration; (5) degree of dispersion; (6) and the presence of colloids. The same electrolyte will have widely different effects, coagulating at one concentration and dispersing at another.

The work on slips by Rohland,[40] Mellor and Green and Baugh,[31] Weber,[49] Audley,[3] Kerr and Fulton,[33] Back,[6] Ashley,[2] Thomas,[45] and Bleininger,[8] shows that sodium, potassium and lithium hydroxides, carbonates, silicates and sulfides generally have a high dispersive or stabilizing power while the most active coagulating agencies are the salts of bivalent and trivalent metals. In Table 1 substances have been classified according to their action on clay slips:

TABLE 1—ACTION OF VARIOUS SUBSTANCES ON CLAY SLIPS.

Dispersing.	Irregular.	Neutral.	Usually coagulating.	Coagulating.
Univalent ions in the presence of high hydroxyl ion concentration Alkali salts of weak acids Strongly dissociated salts in small concentration (?) K2SO4, KHSO4, KNO3 " Tannin Gallic acid Water glass Increasing addition tends to coagulate the slip	Na_2SO_3 Na_2SO_4 $HgSO_4$ MgS04 Na_3PO_4 $Na(C_2H_3O_2)$ Ammonium gallate NaCl HCl Water glass Effect is to make the slip thinner CuS04 NH4OH $K_2SO_4Al_2(SO_4)_3.24H_2O$ Small amounts thicken and increasing amounts thin the slip	alcohol dilute solutions of NaCl	Grape sugar Humic acid Borax NH_4Cl $CaCl_2$ $CaSO_4$. Ammonium urate Aniline Methyl amine Ethyl amine	Bivalent and trivalent ions in the presence of high concentration of hydroxyl ions. Bivalent ions in the presence of mono and bivalent ions

This arrangement seems to confirm Hardy's conclusions that the dispersion or coagulation of a negative sol varies inversely with the valency of the cation, and that the action of anion obeys the regular ionic laws.

The above data are obtained from concentrated clay suspensions where the ultimate end is the formation of a stable fluid slip of the highest clay content. In water purification on the other hand, the aim is the removal of a very small amount of clay from a large amount of water. It is clearly evident from a study of dilute clay suspensions and colloidal silicic acid, that the physical state of the substances and their chemical properties must be taken into consideration, together with the factors which influence them, i. e. (1) degree of dispersion; (2) the presence of the protective colloids and absorbed substances; (3) magnitude and kind of electric charge; (4) the liquid or dispersing medium; (5) the ionic content of the liquid; (6) the concentration; (7) the temperature, and (8) the speed of reaction of added substances.

METHODS OF EXPERIMENTATION, MATERIAL AND APPARATUS.

Briefly, the experimental work has developed along three lines: (1) the removal of silicic acid from solutions by electrolytes and colloids; (2) the effect of electrolytes on dilute clay suspensions, and (3) the effect of silicic acid on the coagulation of clay suspensions by alum in the presence of electrolytes.

Regeants.

Washed potters' clays were used in making the suspensions. No attempt was made to obtain the clay in a high state of purity. Those clays which remained in longest suspension were Tennessee Ball Nos. 3 and 1, number three being the best. Ashley[1] rates Tennessee No. 3 as having a relative colloid content of 95 to 100 per cent. The clay was freed from large particles and soluble salts by washing with distilled water and running the suspension through a Sharpies super-centrifuge; the desired end was a suspension nearly like that in surface waters but as free as possible from electrolytes.

Characterization of Suspensions.

	By turbidimeter.	By weight	Coefficient of fineness.
Tennessee No. 1 Ball	400*	325*	0.75
Tennessee No. 3 Ball	400	330	0.82

The No. 3 clay stood in contact with water in ordinary glass bottles over one year before being used. Kahlbaum's, Merck's, or analyzed chemicals were used without further purification. Colloidal silicic acid was prepared as directed by Graham and dialyzed with parchment paper until there remained only a trace of chloride. Determination of hydrogen ion concentrations was by the colorimetric method of Clark and Lubs.[14] Standards and indicators were made as directed using ordinary distilled water. The accuracy of the solutions was determined by checking against fresh permanent standards prepared by Clark and Lubs. The accuracy of the readings is within + 0.1 pH value.

Measurements of Turbidity.

Standards for determining turbidities were prepared from the original clay suspensions and checked with a standardized turbidimeter. Turbidities were not read closer than 7 per cent. Pine particles of various sizes in suspension do not settle uniformly leaving a clear supernant liquid but are deposited in layers or zones. According to Wiley's formulae, which is determined for particles between 0.0001 and 0.02 millimeters in diameter, the rate of fall is proportional to the square root of the diameter of the particle that is $D = 0.0255V.^2$

Those particles of approximately the same diameter will settle together leaving a turbid suspension of finer particles above. In a suspension one can observe two or three of these zones of widely different turbidities and rates of sedimentation. Within a zone the turbidity is

* Expressed in parts per million.

fairly uniform, but different zones vary as much as 100 per cent within a vertical distance of ½ inch.

If the turbidity of an undisturbed suspension be taken at regular intervals at a fixed point, it will be noticed that the numerical values will be nearly constant for some time, then within a brief interval of time will change markedly as particles from a higher zone traverse the field of view. This phenomenon is well shown in many of the figures.

As it was necessary to determine the turbidity of a suspension without disturbing the liquid, the following method was devised. A stereopticon equipped with a 500 watt lamp was adjusted to yield a slightly diverging cone of light. Two screens each having four holes 3/16 inches in diameter were inserted in the path of this beam. The holes in each screen were in a vertical row arranged in pairs. The centers of the holes were ½, ¾, and 2¼ inches below the surface of the liquid in the sample bottles. One screen was placed 1½ inches in front of and 1½ inches to the side of the other screen so that the standard and the unknown could be observed together. The observations were made at right angles to the beam of light.

The 100 cc. samples were contained in 4-ounce French square flint bottles, 1% inches square; the depth of the liquid was 2% inches. For turbidities below 100 parts per million the ordinary method of comparing with standards in similar bottles was used. In the coagulation of the suspensions, the reagents were added in sufficient concentrations to give a reaction before the natural occurrence of sedimentation of particles.

All results. are expressed as turbidities in parts per million, and milligram equivalents per liter, except in the case of colloidal silicic acid which is in parts of SiO_2 per million.

EXPERIMENTAL PART.

In dealing with the action of electrolytes on colloids a method of determining the amount of colloids present is greatly to be desired. A search of the literature revealed only one method that seemed applicable. This was devised by Rohland[41] and improved upon by Ashley.[1] It depends upon the amount of dye adsorbed by the colloid and is fairly successful in estimating the adsorptive or colloidal power of concentrated clay suspension, but is not reliable when applied to dilute suspensions of clay. Further work along this line is needed. The refractive index and viscosity were investigated, but variations were too slight to be serviceable. There appeared to be no correlation between the hydrogen ion concentration and the degree of coagulation. Kataphoresis experiments only measure the sign and not the magnitude of the charge.

Later in the work it was found that silicic acid exerted a marked influence and an endeavor was made to find a method of separating it from the clay. Several[38]-[52] have been given but none of sufficient selective action to be of value at these dilutions.

An attempt was made to filter the silicic acid from a suspension by a Berkefeld army filter No. 3 with the following results:

Silicic Acid. added.	Silicic Acid. recovered.
298*	155
129 .	84

This confirms the work of Linder and Picton.[29] The silicic acid is evidently coagulated by contact with the-walls of the filter.

INFLUENCE OF ELECTROLYTES ON THE PRECIPITATION OF SILICIC ACID FROM DILUTE SOLUTIONS.

The amount of colloidal silicic acid in a solution containing no suspensoids is easily obtained by the usual method of analysis. In the determinations of silica, SiO_2, one evaporation was made, as on a second evaporation only a few tenths of a milligram additional was obtained.[27] The errors due to the manner of adding the reagents and their different concentration was reduced to a minimum by making the methods of manipulation as uniform as possible.

TABLE 2—SILICIC ACID IS NOT PRECIPITATED FROM 5 cc. OF A SOLUTION CONTAINING 625 PARTS PEE MILLION SiO_2 BY THE FOLLOWING SALTS:

Reagent.	Temperature ca 23° C. No. cc. used.	Temperature ca 23° C. Highest concentration.	Reagent.	Time 6 hours. No. cc. used.	Time 6 hours. Highest concentration.
0.1 N $NaCl$	12	.07N	0.2 N $BaCl_2$	8	.06N
0.1 N Na_2CO_3	12	.07N	1.0 N $CaCl_2$	4.2	.05N
0.1 N $NaHCO_3$	12	.07N	0.5 N $Al_2(SO_4)_3$	12	.07N
0.1 N Na_2SO_4 and K_2SO_4	12	.07N	0.1 N $FeCl_3$	11	.07N
0.1 N Na_3PO_4	8	.06N	0.1 N $FeSO_4(NH_4)_2SO_4$	12	.07N
0.1 N $Mg(HCO_3)_2$	12	.07N	0.1 N $FeCl_2$	10	.07N
0.1 N $MgSO_4$	12	.07N	0.1 N $AlCl_3$	12	.07N

From a solution containing not less than 184 nor more than 625 parts per million of SiO_2, silicic acid is not precipitated by the reagents given in Table 1, but is precipitated from 5 cc. of a solution containing 625 parts per million of SiO_2, by the following:

* Expressed as parts per million.

	Temperatureca 23°C.		Time: 5 minutes.
5.5 cc.	0.18 N	NaOH	.099 N concentration
6 cc.	0.018 N	$Ca(OH)_2$	.0019 N concentration
4 cc.	0.26 N	$Ba(OH)_2$	.0019 N concentration
2.6 cc.	(.6 mg)	colloidal Fe	.0045 N concentration

This experiment indicates that bivalent ions have a precipitating value fifty times that of monovalent ions. Trivalent ions according to the formulae 1:x; x^2 should have a coagulating value of 2,500 times that of the univalent, or fifty times that of the bivalent ions. Qualitative experiments with more dilute solutions indicate that the ratio between bivalent and trivalent to be about one to four. Colloidal iron is only one-half as efficient as calcium hydroxide. The more dilute a solution the less marked is this precipitating effect of the cations.

Very dilute solutions —30 or 40 parts per million of SiO_2—are not precipitated by sodium hydroxide, and rather high concentration of calcium hydroxide to silicic acid are necessary to obtain a precipitate within six hours. At these concentrations the reactions no doubt are ionic, and precipitates of calcium silicates are thrown down. Since the hydroxides of calcium and barium precipitate silicic acid, it is desirable to know the effect of ad"ded univalent and bivalent ions upon the amount of calcium hydroxide needed.

To 5 cc. of a dialyzed silicic acid solution, containing 625 parts per million of SiO_2 there was added 0.5 cc. of a 0.1 normal solution of the electrolytes and the silicic acid was precipitated by the addition of calcium hydroxide. The results are given in Table 3.

TABLE 3—THE EFFECT OF THE ADDITION OF VARIOUS ELECTROLYTES ON THE PRECIPITATION OF COLLOIDAL SILICIC ACID* BY CALCIUM HYDROXIDE.

	Temperature ca 23°C.		Time 5 minutes.
	Reagent.		$Ca(OH)_2$ required.
0.0 cc.	0.2 N	$Ca(OH)_2$	0.6 cc.
0.5 cc.	0.1 N	$BaCl_2$	0.3 cc.
0.5 cc.	0.1 N	$MgSO_4$	0.3 cc.
0.5 cc.	0.1 N	$CaCl_2$	0.3 cc.
0.5 cc.	0.1 N	$NaHSO_4$	0.3 cc. } in excess required to neutralize
0.5 cc.	0.1 N	H_2SO_4	0.35 } in excess required to neutralize
0.5 cc.	0.1 N	$KHSO_4$	0.3 cc. } in excess required to neutralize
0.5 cc.	0.1 N	NaCl	0.6 cc.
0.5 cc.	0.1 N	Na_2SO_4	0.7 cc.
0.5 cc.	0.1 N	K_2SO_4	0.7 cc.
0.5 cc.	0.1 N	Na_2SO_4	0.6-0.7 cc.

* 5 cc. of silicic acid containing 625 parts per million of SiO_2 were used.

The following compounds complicate the precipitation by reacting with the Ca. ions:

Na_2CO_3	Na_3PO_4	$Ca(HCO_3)_2$
$NaHCO_3$	$Mg(HCO_2)_3$	

This experiment proved, as expected, that the precipitating value of the cation depends upon its valence and that hydroxyl had some influence at these concentrations. Neutral salts of the univalent cations were not present in sufficient amount to influence the results. In cases where the solution was acid or there was formed an insoluble calcium precipitate, the concentration of calcium ion is that necessary to combine with the anion plus an amount sufficient to produce precipitation. This is shown in the reactions of sulfuric acid and calcium hydroxide.

To measure the effect of the hydroxylion on the reaction, the pH value was determined, the results of which are given in Table 4.

TABLE 4—THE CONCENTRATION OF HYDROGEN ION NECESSARY BEFORE SILICIC ACID* IS PRECIPITATED BY CA(OH), IN THE PRESENCE OF SALTS.

Salts.	pH value.
0.18 N NaOH	9.5
0.01 N $Ca(OH)_2$	9.2
0.02 N NaOH	9.2
colloidal Pe	off color

Precipitation of silicic acid by $Ca(OH)_2$ in presence of 0.5 cc. of 0.1 normal salt solutions:

Salts.	pH value.
0.1 N $CaCl_2$	9.2
0.1 N $MgSO_4$	8.6
0.1 N H_2SO_4	9.2
0.1 N NaCl	9.3
0.1 N $NaHSO_4$	9.0
0.1 N $NaHCO_3$	9.2
0.1 N Na_2SO_4	9.4
0.1 N Na_2CO_3	9.4
0.1 N Na_3PO_4	9.3
10 cc. $CaSO_4$ saturated soln	9.2
0.1 N $Mg(HCO_3)_2$	8.8
0.1 N $MgSO_4$	8.6
0.1 N $AlCl_3$	below 7.5 when precipitation occurred
0.1 N $Al_2(SO_4)_3$	below 7.5 when precipitation occurred
Average	9.0

* 5 cc. of a solution containing 626 parts per million of SiO_2 were used.

The different systems of salt, silicic acid and calcium ions have different normalities but approximately a pH value of 9.0. This points to the fact that silicic acid may act as a buffer in the manner of large complex organic molecules. Magnesium salts show a lower value than calcium which is probably due to the precipitation of magnesium hydroxide which obscured the true end point. It was not possible to determine hydrogen ion concentration of iron salts with indicators. The quantitative removal of silicic acid by calcium hydroxide, barium hydroxide and chloride, aluminium sulfate and colloidal iron was tried on a water from Albuquerque, N. M., the analysis of which is given in Table 5.

TABLE 5—ANALYSIS OF SAMPLES OF WATER FROM ALBUQUERQUE, NEW MEXICO.

Residue.*		479.1 p. p. m.	$\frac{N}{1000}$ equivalents
Silica	SiO_2	82.6	
Non volatile		0.3	
Al_2O_3 Fe_2O_3		0.2	
Iron	Fe	.03	
Manganese	Mn	0	
Calcium	Ca	69.6	3.473
Magnesium	Mg	14.0	1.145
Sodium and potassium	Na & K	76.8	3.257 sum 7.875
Ammonia	NH_3	0.06	
Carbonate	CO_3	84	2.800
Sulfate	SO_4	175.3	3.647
Chloride	Cl	46.5	1.311
Nitrate	NO_3	1.6	.026 sum 7.784
Nitrite	NO_2	0.0	Difference .091
Phosphate	P_2O_5	0.0 Error	of analysis -0.58 per cent.

* NOTE.—Owing to reaction between fixed alkalies and silica on evaporation and heating, the residue is too low.

The reagents were added in excess (but the amount of this excess unfortunately was not recorded) and the reaction carried out at a pH value of 8.5 to 10. Five different treatments were tried. The amount of calcium and barium compounds were those necessary for softening and removing sulfates.

.1. Ca(OH), and heating to 90°C. removed 37 per cent leaving 52 ppm. in soln.

$Ba(OH)_2$ and heating to 80°C. removed 36 per cent leaving 53 ppm. in soln.

2. $Ca(OH)_2$, filtration and adding

$Al_2(SO_4)_3$ removed 30 per cent leaving 58 ppm. in soln.

$AlCl_3$ + NaOH removed 84 per cent leaving 13 ppm. in soln.

$FeSO_4(NH_4)_2SO_4$ removed 37 per cent leaving 51 **ppm. in soln.**

3. $Ca(OH)_2$, $Ba(OH)_2$, $BaCl_2$, filtration and adding
   colloidal Fe removed 38 per cent leaving 31.6 ppm. in soln.
   excess $Ba(OH)_2$ removed 44 per cent leaving 36.0 ppm. in soln.
   $AlCl_3$ + NaOH removed 91 per cent leaving 5.0 ppm. in soln.
4. $Al_2(SO_4)_3$ and $Ca(OH)_2$ removed 34 per cent leaving 55 ppm. in soln.
5. Treatment with colloidal Fe removed 26 per cent leaving 61 ppm. in soln.
   $Al(OH)_3$ cream removed 44.6 per cent leaving 38 ppm. in soln.

It is evident that the most efficient precipitants are the trivalent ions in an excess of hydroxyl ions. According to the theory of coagulation, the optimum conditions for precipitation of negatively charged silicic acid should be (1) an amount of trivalent cations or positively charged colloids to exactly neutralize the negative charges, (2) a minimum amount of cations, protective or stabilizing colloids, and (3) a pH value approaching the isoelectric point. Just what conditions must be defined in order to locate the isoelectric point, chemists have not yet discovered. Fleming[19] designated it in terms of normality of the solution, but it seems preferable to express it as hydrogen ion concentration.

The above tests indicate that the optimum Ph value for the precipitation of silicic acid is approximately 9.0. According to theory this should be the location of the isoelectric point. In order to determine this value more accurately and in the absence of bivalent cation, aluminium hydroxide was precipitated in the silicic acid solution by sodium hydroxide and aluminium chloride.

The silicic acid used was prepared by bringing a solution of sodium silicate to a pH value of 6.5 by the addition of hydrochloric acid. This solution contained 4 mols of SiO_2 to one mol of NaCl. Two dilutions were used: 87 and 232 parts per million of SiO_2 To the silicic acid solution were added water to produce the proper dilution, aluminium cloride and N/10 sodium hydroxide, which was added drop by drop with constant shaking. These solutions were shaken at frequent intervals during 48 hours. By that time the reaction was practically complete. The solution was filtered and silicic acid determined in the filtrate. It was noticed in precipitating aluminium from a solution of aluminium chloride, silicic acid and sodium chloride, that the manner of adding the reagents and the relative ratio of aluminium to silicic acid markedly influenced the character and amount of the precipitate. Table 6 shows **this very strikingly.**

TABLE 6—EELATIONSHIP BETWEEN THE AMOUNT OF SILICIC ACID PRECIPITATED AND THE CHARACTER OF THE PRECIPITATE.

SiO_2—Content 87 parts per million—Temp, ca 23° C—Time 48 hrs.

Milliequivalents of Al.	Si02 p. p. m. precipitated.	Si02 p. p. m. in Soln.	pH	Remarks.
1.75	8	79	7.1	Faint turbidity.
1.75	3	84	7.5	Clear.
2.91	2	85	7.5	Faint turbidity.
2.91	4	83	7.5	Faint turbidity.
4.37	51	36	6.8	Fair precipitate.
5.87	65	22	7.0	Well flocked.
5.87	35	52	7.6	Faint turbidity opalescent filtrate.
7.28	75	12	7.0	Well flocked.
7.28	45	42	7.6	Turbid.
8.73	80	7	7.1	Well flocked.
8.73	81	6	7.6	Well flocked.
#				

Poor removal of silicic acid is associated with a turbid colloidal solution and a sticky gelatinous precipitate which is very difficult to filter, while a good removal is usually obtained when the precipitate is well floculated and settles quickly; the resulting clear solution exhibits little Tyndal effect. In the absence of silicic acid a flocculent precipitate of aluminium hydroxide was produced in a dilute solution of $AlCl_3$ by N/10 NaOH, or in a dilute solution of Na(OH) by 0.0003N $AlCl_8$, regardless of the manner of adding reagent, or presence of NaCl. If the above solution contained 87 parts per million of SiO_2, as colloidal silicic acid, on adding N/10 NaOH drop by drop, a precipitate formed at the end of one hour depending upon the amount of $AlCl_3$ in the solution, but if an equivalent amount of N/10 or stronger NaOH was added all at once, no precipitate formed. Such a solution showed a very strong Tyndal effect and gradually deposited a slight fine precipitate. One solution was made from which a very little precipitate settled at the end of a month. Apparently the system was less stable the higher the concentration of NaOH and the more suddenly it was added and mixed. The same effect was produced when sodium carbonate or acid carbonate was used instead of hydroxide.

With calcium hydroxide an excellent precipitate formed regardless of the manner of adding the reagent. There is evidently, some complex substances formed under these conditions, which are intimately connected with a sodium ion and the silicic acid. Perhaps the silicic acid, in the presence of sodium ions, is acting as a protecting colloid preventing in some manner passage of aluminium hydroxide from the colloid into the crystaline condition. In any event, a recognition of this fact is quite valuable in obtaining well flocked precipitates.

A high ratio of silicic acid to aluminium tends to produce colloidal solutions while the reverse ratio produces nicely flocked precipitates.

The magnitude of the Tyndal effect is inversely related to the removal of the silicic acid and the character of the flock or precipitate.

Thus in plotting the curves, Figures 1 and *2,* from Tables 7 and 8 respectively, only the higher concentrations of aluminium were used.

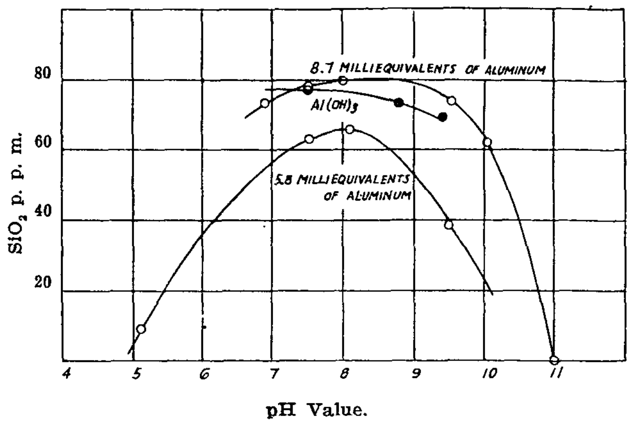


Figure 1.—Comparison between the pH value, the precipitation of silicic acid and **the amount** of $Al(OH)_3$ in the solid phase.

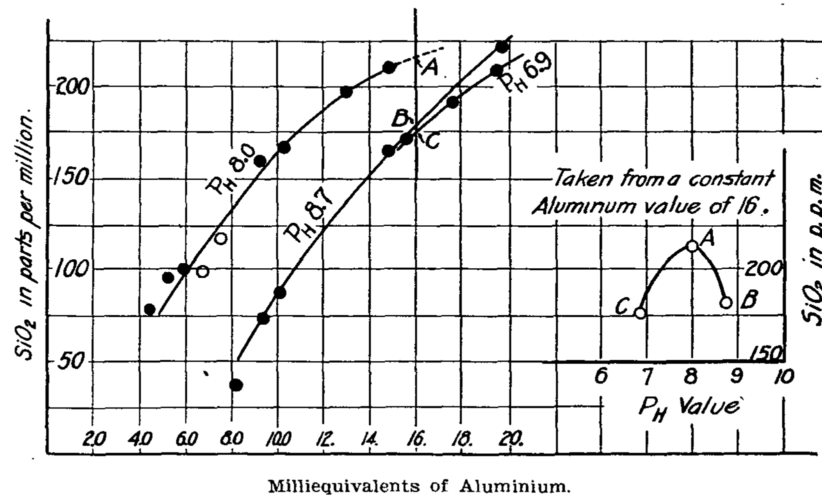


Figure 2.—Comparison between the pH value, the precipitation of silicic acid, and the amount of $Al(OH)_3$ in the solid phase.

The lower values are inaccurate because of the formation of colloidal solutions. There is shown in Figure 1 a third curve plotted from the data in Table 9. Values for this curve were obtained by precipitating the aluminium with ammonia in the absence of silicic acid.

TABLE 7—REMOVAL OF SILICIC ACID* BY ALUMINIUM HYDROXIDE OF VARYING HYDROGEN ION CONCENTRATION.

Milliequivalents of Al.	Temperature ca 23°C.	Time 48 hours.	
	SiO_2 precipitated.	Si02 in solution.	pH
8.73	73	14	6.8
8.73	79	8	7.5
8.73	79	8	8.0
8.73	74	13	9.6
8.73	0	87	11. cno ppt.
5.82	9	78	5.2 colloidal.
5.82	63	24	7.5
5.82	65	22	8.2 colloidal.
5.82	38	49	9.5

* Concentration of SiO2 is 87 parts per million.

TABLE 8—PRECIPITATION OF SILICIC ACID IN SOLUTIONS OF VARYING HYDROGEN ION CONCENTRATION BY AL $(OH)_3$.

Concentration of SiO_2—232 parts per million
Temperature ca 23°C. Time 48 hours.

Milli-equivalents of Al.	Parts per millions.			Remarks.
	SiO_2 precipitated.	SiO_2 in solution.	pH value.	
1.94	50	182	4.7	Slight turbidity.
9.70	----------	----------	4.4	No precipitate.
17.5	----------	----------	4.4	No precipitate.
1.94	----------	----------	6.0	Slight turbidity.
5.82	98	134	5.9	Slight turbidity.
9.70	149	83	6.0	Slight turbidity.
11.70	220	12	6.1	Precipitated.
1.94	4	228	6.7	Slight turbidity.
4.03	26	206	7.0	Turbid.
5.82	96	136	6.7	Difficult to filter.
7.76	120	112	6.4	Well precipitated.
9.70	142	90	6.5	Well precipitated.
11.70	167	65	6.6	Difficult to filter.
13.60	173	59	6.7	Difficult to filter.
15.50	172	60	6.8	Difficult to filter.
17.50	191	41	6.9	Difficult to filter.
19.40	208	24	7.2	Difficult to filter.
3.0	17	215	9.8	Tendency to be colloidal. Filtered through Blue Ribbon No. 589 Filters.
3.7	21	211	8.8	do.
4.4	5	----------	9.2	do.
5.9	57	175	8.7	do.
6.7	101	131	8.7	do.
7.4	101	131	8.6	do.
8.1	37	195	8.8	do.
9.2	73	159	8.5	do.
11.1	87	145	8.6	do.
14.8	167	65	8.8	Well flocked.
20.6	220	12	8.9	Well flocked.
.74	3	229	7.2	Settles well.
1.5	47	185	7.8	Well flocked.
2.2	61	171	7.8	Well flocked.
3.0	59	173	7.0	Well flocked.
3.7	81	151	8.0	Well flocked.
4.4	79	153	8.0	Well flocked.
5.2	95	137	7.4	Well flocked.
5.9	99	133	7.6	Well flocked.
6.7	99	133	7.6	Well flocked.
7.4	129	103	8.4	Well flocked.
9.2	159	73	7.4	Well flocked.
11.1	167	65	8.6	Well flocked.
13.0	197	35	8.6	Well flocked.
14.8	209	23	8.2	Well flocked.
18.5	197	35	7.6	Well flocked.

TABLE 9—EFFECT OF THE HYDROGEN ION CONCENTRATION ON THE PRECIPITATION OF ALUMINIUM HYDROXIDE.

	Temperature ca. 28°C.		Time 48 hours.	
Ph value	6.8	8.0	6.8	9.4
Al in solution	1.5*	0.5	12	17.3
Character of flock	good	good	good	gelationous

• Expressed as parts per million.

A study of data and curves indicates: (1) that silicic acid is best precipitated at a pH value of 8.0 to 8.5, which is probably a closer approximation to the truth than the former value of 9.0 obtained with calcium hydroxide, (2) that the amount of silicic acid precipitated follows closely the amount of aluminium hydroxide in the solid phase, and (3) that below a pH value of 4.0 the concentration of the hydrogen ion shifts the reaction so far to the right in the equation.

$$H^+ + AlO_2^- + H_2O \leftrightarrows Al(OH)_3 \leftrightarrows AlO^+ + HO^- + H_2O$$

and that above a pH value of 11.0 so far to. the left that the solid aluminium hydroxide phase is unstable and disappears.

In the region below these curves the tendency to form colloidal solutions is quite marked, and the gelatinous nature of the precipitate and the magnitude of the Tyndal effect generally varies inversely with the amount of aluminium ions added to the system, and directly as the hydrogen ion concentration departs in either direction from a pH value of 8.25.

The precipitation of silicic acid by aluminium sulfate may be explained: (1) by the neutralization of the charge on the silicic acid complex by the aluminium ion, resulting in a precipitation of silicic acid, (2) by the neutralization of the negatively charged silicic acid by positively charged aluminium hydroxide, (3) by the solid aluminium hydroxide adsorbing silicic acid, and (4) by the formation of an insoluble chemical compound.

THE INFLUENCE OF ELECTROLYTES AND SILICIC ACID ON THE COAGULATION OF CLAY SUSPENSIONS.

The next step was to determine the effect of silicic acid and the commonly occurring electrolytes on the coagulation of a clay suspension with aluminium sulfate.

Reagents were added to one hundred cubic centimeter portions of a clay suspension and thoroughly mixed by shaking for one minute. The sample was then allowed to remain perfectly quiet and the turbidity of the liquid determined at appropriate intervals at a **point ½-inch below its surface.**

The electrolytes used were sodium hydroxide, acid carbonate, carbonate and chloride; magnesium bicarbonate, and sulfate; calcium hydroxide, chloride and bicarbonate; barium hydroxide, Merck's dialyzed iron and sulfuric acid.

The effect of electrolytes on the stability of a dilute clay suspension is similar to that observed with clay slips. The results of adding increasing amounts of sodium hydroxide is first dispersion followed by coagulation.[2] In Tables 10 and 11 and Figures 3 and 4 it is shown that the coagulative powers of calcium and barium hydroxide are practically the same, and that the ratio of aluminium to calcium and barium ions is about five to one. Data from many of the tables have been collected and shown in graphic form in Figures 6 and 7. The salts arranged according to their efficiencies as coagulants are: aluminium sulfate, calcium and barium hydroxides, calcium chloride, magnesium sulfate and magnesium bicarbonate. Sodium chloride has little effect until its concentration becomes so great as to salt out the clay. Sulfuric acid has no apparent effect up to concentration of 0.35 milliequivalents but higher concentrations coagulate. (See Table 16 and Figure 5) Sodium hydroxide, carbonate, acid carbonate and sulfate have at first a stabilizing influence followed by a coagulating effect. The coagulating effect of anions seems to be an inverse function of their valencies.

The effect of added salts on the coagulation of clay suspensions by aluminium sulfate is shown in Tables 12 to 20, Figures 8 to 15.

TABLE 10—THE EFFECT OF VARYING STRENGTHS OF NaOH ON THE RATE OF COAGULATION OF CLAY BY $Al_2(SO_4)_3$.

Tenn. No. 3 Ball Clay—Temperature ca 23° C.
Milliequivalents of NaOH added.

Milliequivalents of Al.	0.00		0.049		0.09		0.18		0.36	
	Turbidity.									
	1 hr.	1½ hrs.	1 hr.	2 hrs.	1 hr.	2 hrs.	1 hr.	2 hrs.	1 hr.	1½ hrs.
0.0	420	420	420	400	420	400	450	400	450	400
.02	420	400	--------	--------	420	360	--------	--------	--------	--------
.06	400	400	--------	--------	400	360	450	420	--------	--------
.09	150	75	420	400	350	375	420	420	--------	--------
.13	125	75	150	100	175	50	300	240	400	400
.17	125	50	100	90	275	150	200	75	--------	--------
.18	100	50	100	85	375	175	200	40	350	350
.37	100	--------	100	85	450	350	400	400	--------	--------
.55	125	50	100	80	300	250	420	375	75	60
.74	--------	--------	--------	--------	--------	--------	--------	--------	400	275
.92	150	60	100	75	240	100	420	125	300	200
1.11	--------	--------	--------	--------	--------	--------	--------	--------	75	75
1.29	150	75	90	50	200	50	350	100	300	125
1.47	--------	--------	--------	--------	--------	--------	--------	--------	250	90
1.66	--------	--------	--------	--------	150	50	--------	--------	190	90
2.03	--------	--------	--------	--------	--------	--------	--------	--------	125	50

TABLE 11—COMPARISON OF ca$(OH)_2$, $Ba(OH)_2$, COLLOIDAL FE AND $Al_2(SO_4)_3$ AS COAGULANTS.

Tenn. No. 3 Ball Clay—Temperature ca 23° C.
Milligram equivalents.

$Al_2(SO_4)_3$.	Turbidity.	$Ca(OH)_2$.	Turbidity.	$Ba(OH)_2$.	Turbidity.	Fe.	Turbidity.
.02	400	.26	400	.13	400	.38*	400
.06	400	.43	390	.66	400	3.9	400
.09	400	.60	350	.79	375	4.6	350
..13	375	.69	350	1.05	100	6.1	200
.17	50	.86	150	1.32	60	6.9	100
.37	40	1.03	100	-----	-----	8.1	40
-----	-----	1.38	50	-----	-----	9.2	40
-----	-----	1.72	50	-----	-----	-----	-----

* Parts per million.

TABLE 12—EFFECT OF Na_2CO_3 ON THE COAGULATION OF A CLAY SUSPENSION BY $Al_2(SO_4)_2$.

Tenn. No. 1 Ball Clay—Temperature ca 24° C.
Milliequivalents of Na_2CO_3 added.

Milliequivalents of Al.	0.5		1.0	
	Turbidity.			
	1½ hrs.	14 hrs.	1½ hrs.	14 hrs.
0	400+	150	400+	150
.30	125	10	400	150
.45	125	0	125	10
.60	175	0	65	0
.75	400	0	125	0
.90	400	0	100	0

TABLE 13—EFFECT OF $NaHCO_3$ ON THE COAGULATION OF A CLAY SUSPENSION BY $Al_2(SO_4)_3$.

Tenn. No. 1 Ball Clay—Temperature ca 24° C.

Milliequivalents of Al.	Milliequivalents of $NaHCO_3$ added.							
	.03		0.6		1.0		1.5	
	1½ hrs.	13 hrs.	1½ hrs.	13 hrs.	1½ hrs.	13 hrs.	1½ hrs.	13 hrs.
0	400+	325	400	400	400	300	400+	300
.03	400+	275	400	375	-----	-----	-----	-----
.06	400+	150	400	300	400	200	400+	250
.09	400	150	400	275	-----	-----	-----	-----
.12	350	75	300	100	350	200	400	150
.15	275	75	225	65	-----	5	-----	-----
.18	125	50	175	50	125	40	250	150
.24	60	10	180	10	100	10	75+	25
.30	60	10	75	10	60	10	75+	10
.36	-----	-----	60	5	60	5	60	5
.42	-----	-----	60	0	60	5	75	5
.48	-----	-----	65	0	60	0	50	0
.54	-----	-----	65	0	60	0	60	0
.60	-----	-----	-----	-----	60	0	60	0
.66	-----	-----	-----	-----	-----	-----	60	0
.78	-----	-----	-----	-----	-----	-----	60	0
.90	-----	-----	-----	-----	-----	-----	50	0

TABLE 14—ACCELERATING EFFECT OF Na_2SO_4 ON THE COAGULATION OF CLAY SUSPENSION BY $Al_2(SO_4)_3$.

Tenn. No. 3 Ball Clay—Temperature ca 24° C.
Milliequivalents of Na_2SO_4 added.

Milli-equivalents of Al.	1		2		3		4	
	Turbidity.							
0	1*	24	1	24	1	24	1	24
.0	400	350	400	350	400	150	400	40
.03	375	150	—	—	—	—	400	25
.06	350	35	—	—	—	—	200	0
.09	350	10	125	0	—	—	60	0
.12	25	0	60	0	—	—	50	0
.15	—	—	50	0	—	—	—	—
.18	—	—	40	0	—	—	—	—

* Time expressed in hours.

TABLE 15—EFFECT OF NaCl ON THE COAGULATION OF CLAY SUSPENSIONS BY ALUM.

Tenn. No. 3 Ball Clay—Temperature ea 24° C.—Tenn. No. 1 Ball Clay.
Milliequivalents of NaCl added.

Milli-equiva-lents of Al.	1		3		10		1		2	
	Turbidity.									
0	1*	24	1	24	1	24	1½	12	1½	12
.0	—	200	—	150	—	150	400	300	400	250
.03	400	150	350	10	50	0	400	200	400	200
.06	350	15	175	0	50	0	100	100	400	60
.09	100	0	50	0	50	0	90	0	80	0
.12	25	0	40	0	50	0	80	0	—	—

*Time expressed in hours.

TABLE 16—THE EFFECT OF VARYING STRENGTHS OF H_2SO_4 ON THE RATE OF CLAY BY $Al_2(SO_4)_3$.

Tenn. No. 3 Ball Clay—Turbidity 420—Temperature Ca 23° C.
Milliequivalents of H_2SO_4 added.

Milli-equiva-lents of Al.	0.0		0.049		0.09		0.18		0.36	
	Turbidity.									
	1 hr.	2 hrs.	1 hr.	2 hrs.	1 hr.	1½ hr.	1 hr.	1½ hr.	1 hr.	1½ hr.
0.000	420	420	420	420	420	400	420	400	420	250
.02	420	400	—	—	400	375	400	400	—	—
.06	400	400	375	200	370	310	290	150	360	350
.09	150	75	—	—	200	60	240	100	150	90
.13	125	75	150	50	150	60	140	60	100	60
.17	125	75	—	—	—	—	—	—	—	—
.18	100	50	150	50	140	50	75	50	150	50
.37	—	—	100	60	125	50	75	50	200	50
.55	125	50	—	—	100	50	50	50	200	50
.74	—	—	—	—	—	—	—	—	—	—
.92	150	60	—	—	—	—	—	—	—	—

TABLE 17—EFFECT OF $MgSO_4$ AND $Mg(HCO_3)_2$ ON THE COAGULATION OF CLAY SUSPENSIONS BY $Al_2(SO_4)_3$.

Tenn. No. 1 Ball Clay—Temperature ca 24° C.
Milliequivalents of $MgSO_4$ added.

Milliequivalents of Al.	1		2		3	
	Turbidity.					
	1½ hrs.	14 hrs.	1½ hrs.	14 hrs.	1½ hrs.	14 hrs.
0	400	100	350	50	325	15
.009					400	15
.018			200	25	175	10
.030	150	10			150	0
.036			125	10	125	0
.060	150	0	125	0	100	0
.090	125	0	125	0		
.120	125	0	100	0		

TABLE 18—MILLIEQUIVALENTS OF $Mg(HCO_3)_2$ ADDED.

Milliequivalents of Al.	1		2		3	
	Turbidity.					
	1½ hrs.	14 hrs.	1½ hrs.	14 hrs.	1½ hrs.	14 hrs.
0	400	150	400	85	350	65
.009					350	30
.018				80	300	25
.030	350	125	350	35	275	20
.045					250	15
.060	250	25		10	125	15
.090	175	15	150	0		
.120	125	10				

TABLE 19—EFFECT OF $CaCl_2$ THE COAGULATION OF CLAY SUSPENSIONS BY $Al_2(SO_4)_3$.

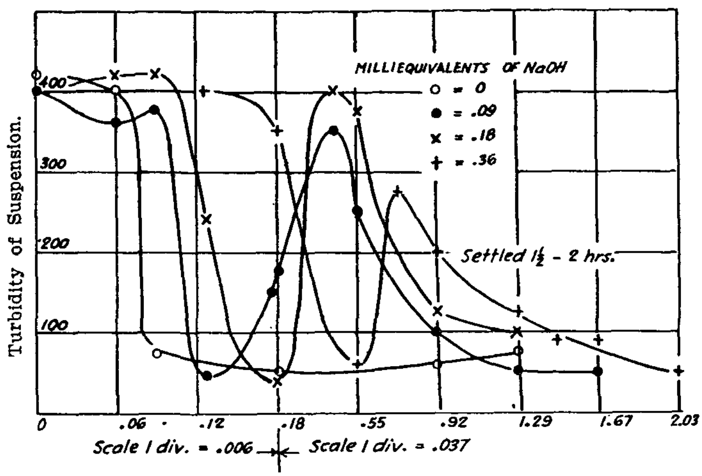
Tenn. No. 1 Ball Clay—Temperature ca 24° C.
Milliequivalents of CaCL,.

Milliequivalents of Al.	1		2		3	
	Turbidity.					
	1½ hrs.	14 hrs.	1½ hrs.	14 hrs.	1½ hrs.	14 hrs.
0	400	125	185	10	175	10
.009					175	10
.010			185	5	175	5
.030	300	25	180	0	200	0
.045					175	0
.060	175	10	175	0	125	0
.090	125	5	175	0		
.120	175 (?)	0	175	0		

TABLE 20—EFFECT OF ca$(HCO_3)_2$ ON THE COAGULATION OF CLAY SUSPENSIONS BY $Al_2(SO_4)_3$.

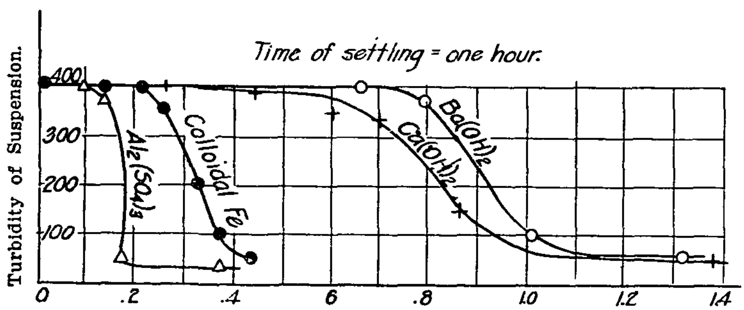
Tenn. No. 1 Ball Clay—Temperature ca 23° C.
Millliequivalents of $Ca(HCO_3)_2$.

Milliequivalent of Al.	0		1		0		2	
	Time in hours and turbidity.							
	1½	13	1½	13	1½	13	1½	13
0	325	-----	325	125	200	-----	200	25
.009	-----	-----	-----	-----	200	175	75	10
.018	-----	-----	-----	-----	150	10	50	5
.030	325	125	200	15	150	0	40	0
.045	-----	-----	-----	-----	125	0	25	0
.060	325	70	75	10	-----	-----	-----	-----
.090	75	10	50	5	-----	-----	-----	-----
.120	50	0	50	0	-----	-----	-----	-----



Milliequivalents of Aluminium.

Figure 3.—Effect of NaOH on the coagulation of a clay suspension by $Al_2(SO_4)_3$.



Milliequivalents of Aluminium.

Figure 4.—Comparison of $Al_2(SO_4)_3$, colloidal Fe, $Ca(OH)_2$, $Ba(OH)_2$ as coagulants.

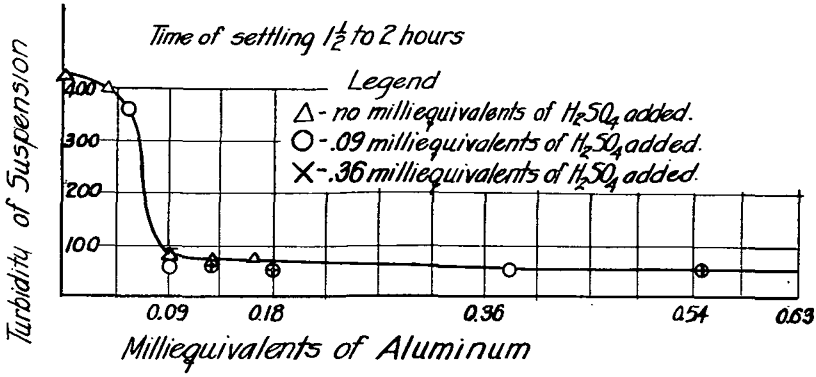
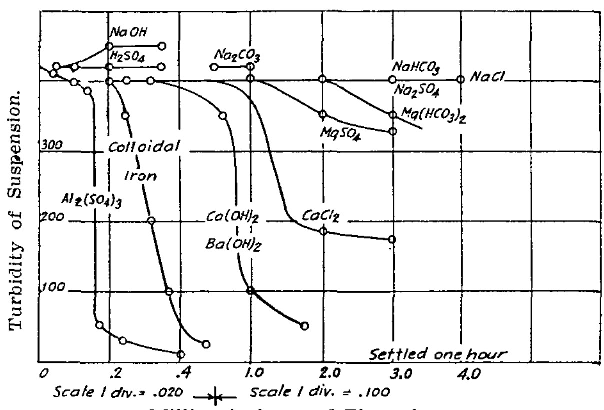
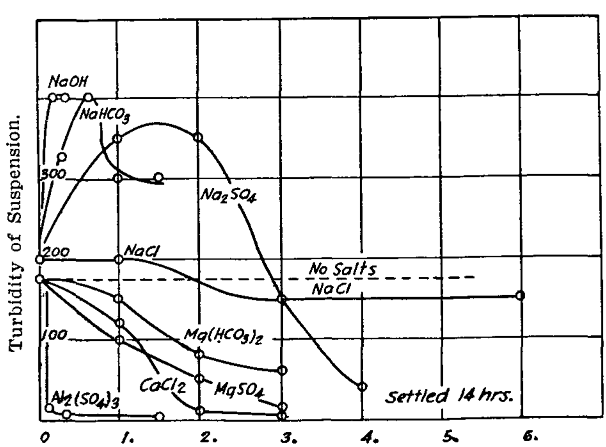


Figure 5.—Effect of H_2SO_4 on the coagulation of clay suspension by $A1_2(SO_4)$,.



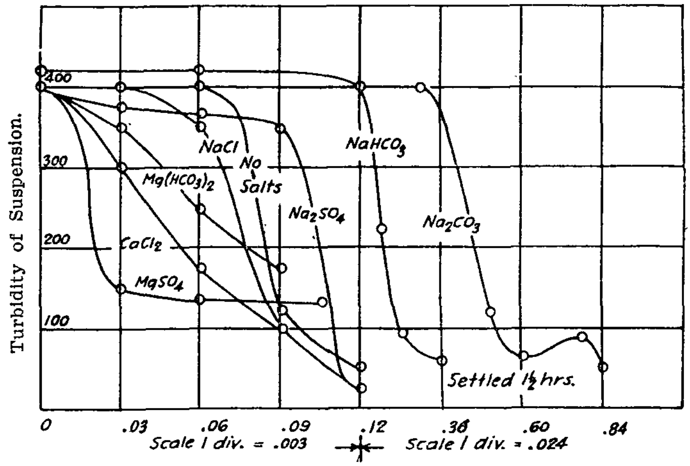
Milliequivalents of Electrolytes.

Figure 6.—Effect of electrolytes on the coagulation and settling of clay suspensions.



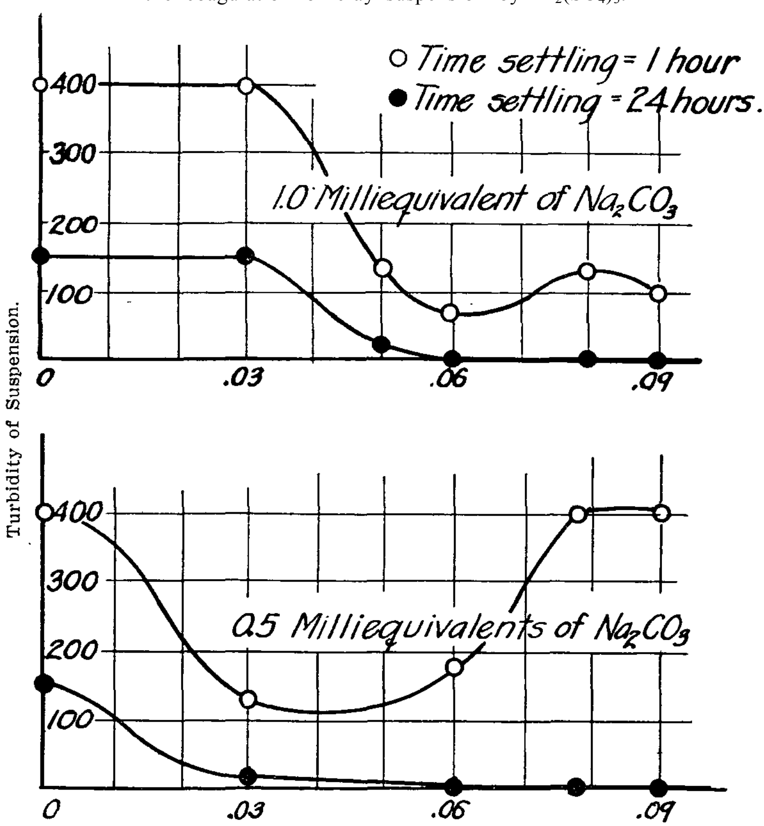
Milliequivalents of Electrolytes.

Figure 7.—Effect of electrolytes on the coagulation and settling of ciay suspensions.



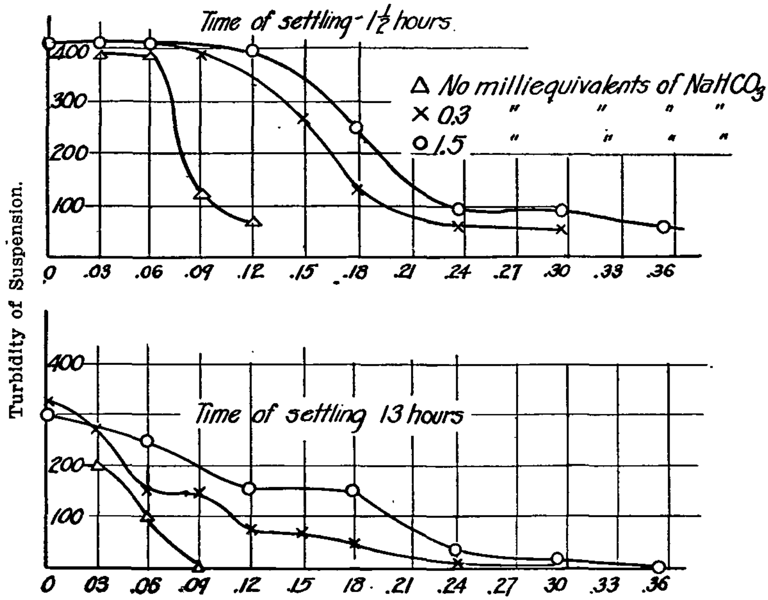
Milliequivalents of Aluminium.

Figure 7 "A".—The effect of the addition of one milliequivalent of electrolytes on the coagulation of clay suspension by $Al_2(SO_4)_3$.



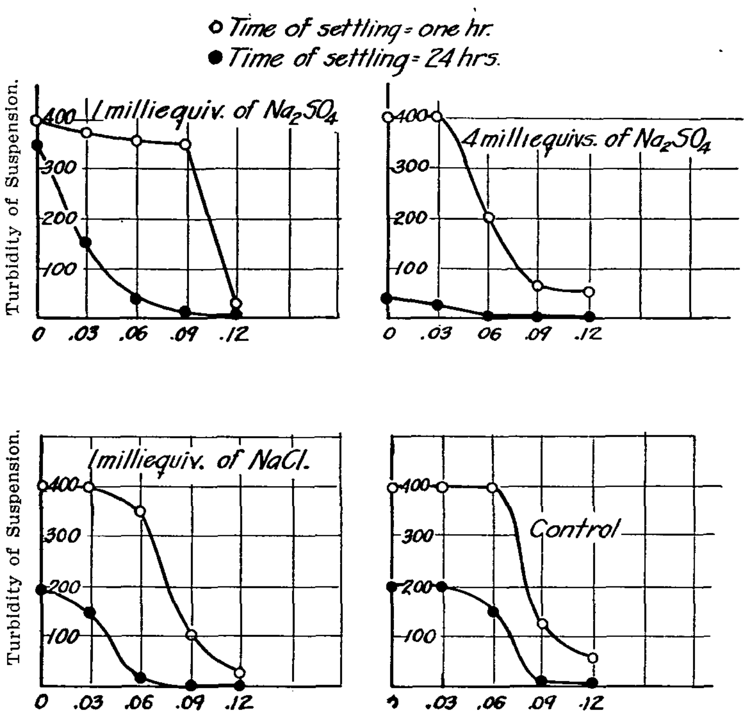
Milliequivalents of Aluminium.

Figure 8.—Effect of Na_2CO_3 on the coagulation of clay suspensions by $Al_2(SO_4)_3$.



Milliequivalents of Aluminium.

Figure 9.—Effect of $NaHCO_3$ on the coagulation of clay suspension by $Al_3(SO_4)_3$.



Milliequivalents of Aluminium.

Figure 10.—Effect of Na_2SO_4 and NaCl on the coagulation of clay suspension by $Al_2SO_4)_3$.

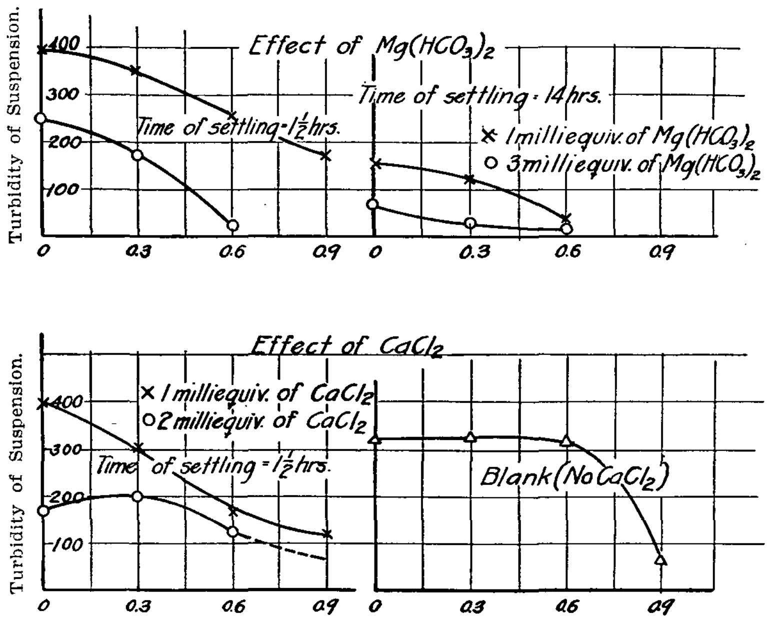
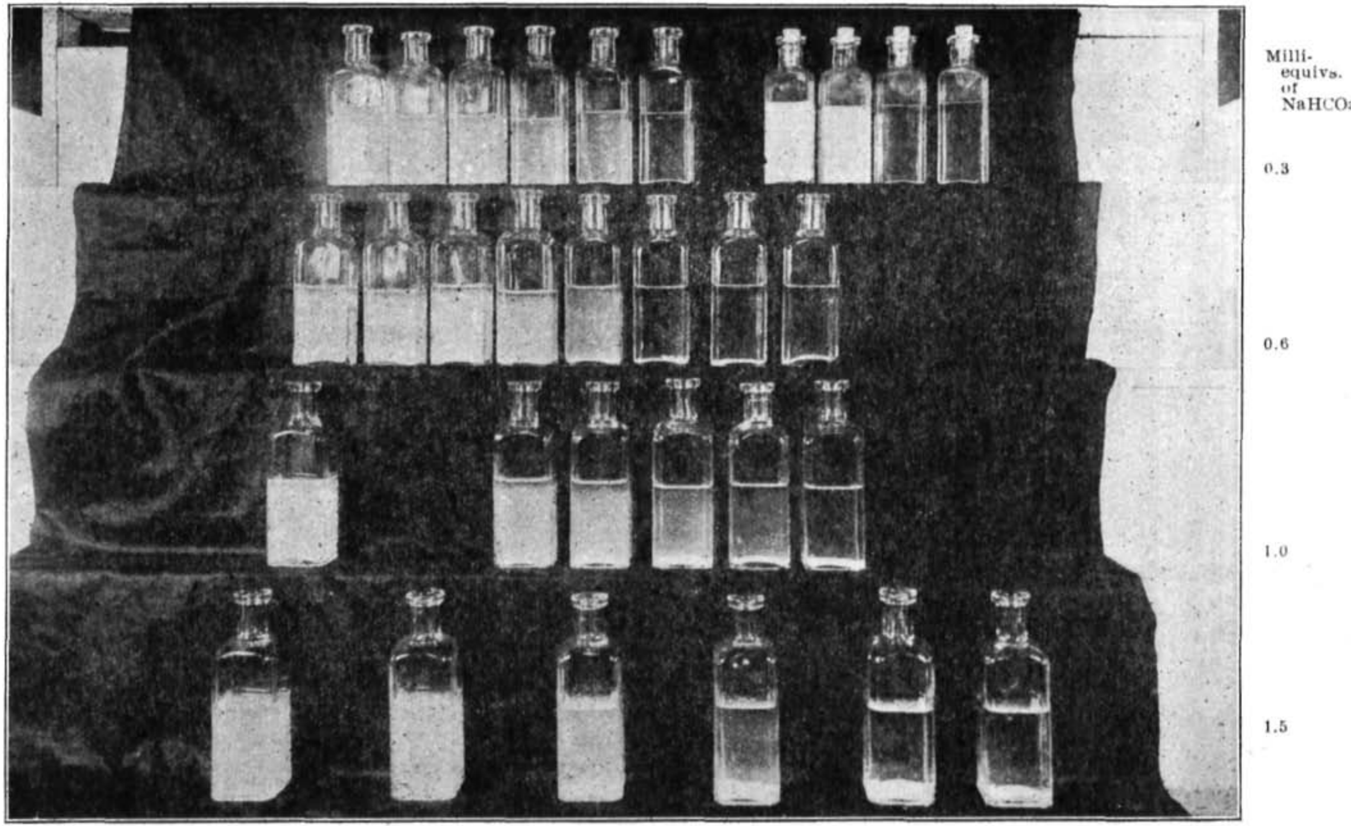
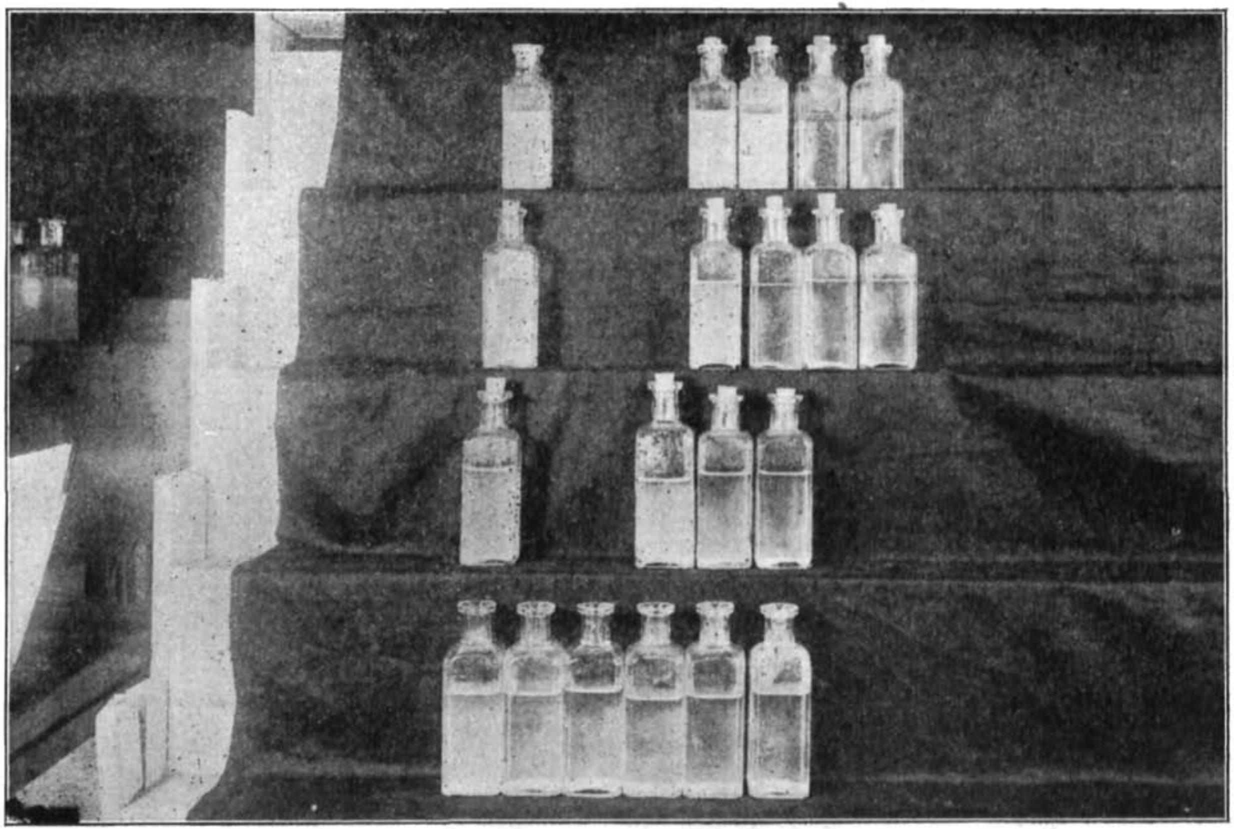


Figure 11.—Effect of $Mg(HCO_3)_2$ and of CaCl, on the coagulation of clay suspension by $Al_2(SO_4)_3$.



0—Increasing Amounts of A1,$(S0_4)_3$.
Figure 12.—The effect of $NaHCO_3$ on the coagulation of clay suspensions by Al,$(SO_4)_3$.



Milliequivalents of Mg $(HCO_3)_2$

0

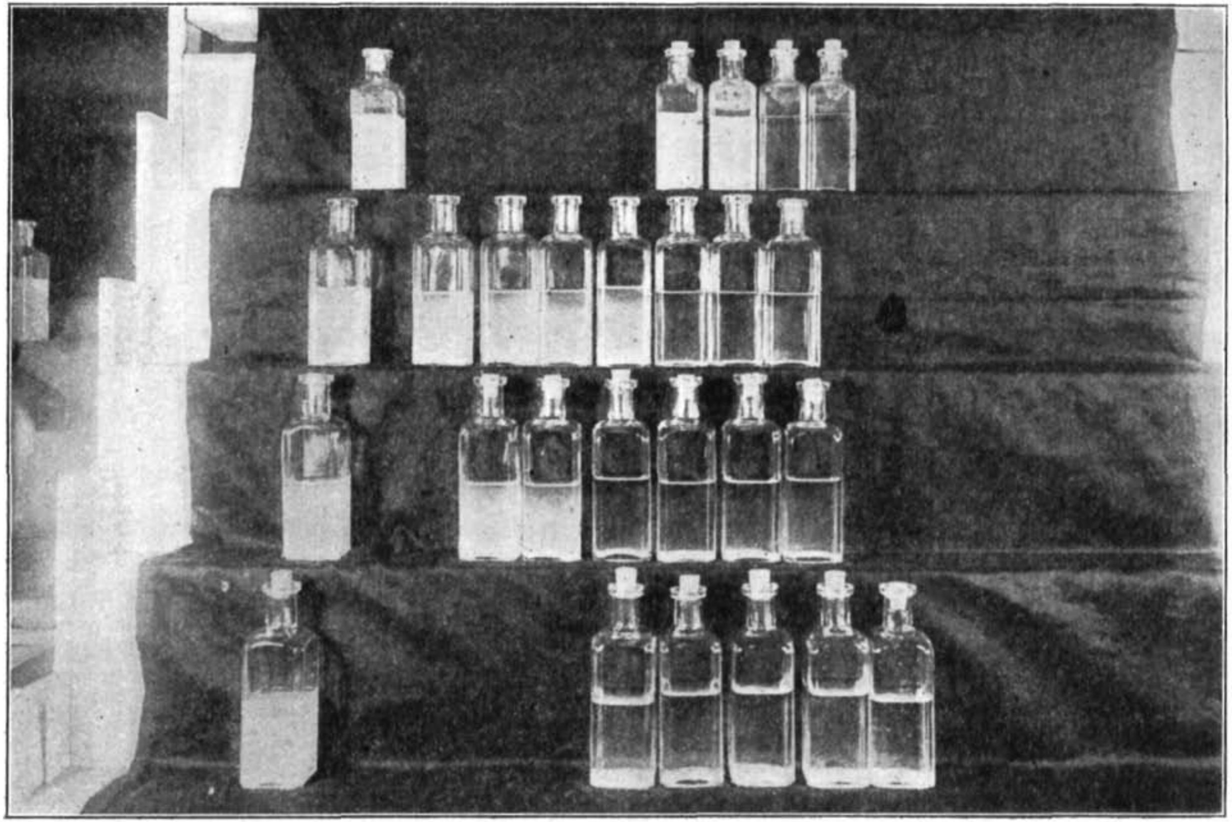
1

2

3

0—Increasing $Al_2(SO_4)_3$.

Figure 13.—The effect of $Mg(HCO_3)_2$ on the coagulation of clay suspensions by $Al_2(SO_4)_3$.



Milliequiv-
alents of
$CaCl_2$.

0

1

2

3

0—Increasing Amounts of $Al_2(SO_4)_3$.
Figure 14.—The effect of $CaCl_2$ on the coagulation of clay suspensions by $Al_2(SO_4)_3$.

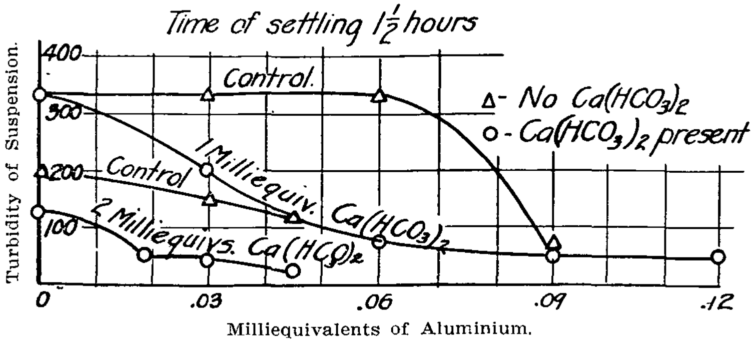


Figure 15.—Effect of $Ca(HCO_3)_2$ on the coagulation of clay suspensions by" $Al_2(SO_4)_3$.

As would be expected the presence of the trivalent and bivalent ions aid in the coagulation, sodium chloride and sulfuric acid have little effect at low concentrations, while the addition of the sodium salts causes a behavior similar to that produced by the action of sodium hydroxide (Figure 3).

As the content of sodium hydroxide is increased the amount of aluminium sulfate must be increased in order to produce coagulation and to combat the dispersive power of the sodium compound. This same effect is quite noticeable with sodium carbonate but less so with sodium acid carbonate and sulfate.

The point of coagulation is not dependent on the alkalinity of the solution. The results of these experiments are partly in accordance with work and theories of Rohland.[40,42] There seems to be no question but that coagulation is a function of the concentration of the hydroxyl ion and alkali metal ions as well as the valencies of the cation.

The monovalent ion of the alkalies is intimately connected with the dispersive or protective action of sodium salts in the coagulation of clay suspensoids and with the peculiar (Protective) effect of silicic acid in preventing the formation of aluminium hydroxide by the action of aluminium chloride and sodium hydroxide. If calcium is substituted for sodium these peculiar effects are not produced.

The effect of silicic acid on the coagulation of clay suspensions by aluminium sulfate is shown in Tables 21, 22, and 23, and Figures 15 to 19. A suspension containing 62 parts per million of dialyzed silicic acid and appropriate amounts of electrolytes were coagulated with alum and the rate of reaction compared with a suspension containing no added silicic acid. In all cases the effect of the added silicic acid was to retard the reaction, and more aluminium sulfate was required to produce coagulation than before—regardless of the presence or absence of electrolytes. Photographs (Figures 20 and 31) were taken five days after the addition of the aluminium sulfate. Silicic acid was added to the samples on the right. The data given in Tables 19 and 20 was obtained from this experiment.

The aluminium consumed is a function of the silicic acid added, but the mathematical relationship is not a simple one and varies with the clay used. This relationship is shown in Figures 15 and 17, which have been plotted from data in Tables 21 and 22. In general the amount of aluminium required to coagulate, per unit amount of silicic acid added, is larger at low than at high concentrations. Silicic acid does not seem to stabilize or disperse the clay particles, nor does its presence influence the rate of sedimentation. In this respect it differs from the alkali salts.

TABLE 21—RETABDING EFFECT OF SILICIC ACID ON THE COAGULATION OF CLAY SUSPENSION BY $Al_2(SO_4)_3$.

Tenn. No. 3 Ball Clay—Temperature ca 24°C.
Silicic Acid (SiO_2) added.

Milligram equivalents.	0 ppm.*		12.4 ppm.		24.8 ppm.		37.2 ppm.		49.6 ppm.	
	Turbidity.									
	1½**	13	1½	13	1½	13	1½	13	1½	13
.0	400	225	400	225	400	250	400	275	400	275
.03	400	150								
.06	400	125	400	175	400	250	400	275	400	275
.09	125	10	400	150						
.12	75	5	50	10	125	75	175	125	225	125
.15			50	10	50	20				
					50	10	50	20	50	25
							60	10	50	10
							50	10	40	10
									25	10

The Amount of Alum Necessary to Produce a Definite Clarification in 13 Hours in the Presence of Silicic Acid.

SIO2 added.	$Al_2(SO_4)_3$ added to reduce turbidity to	
	100 ppm.	50 ppm.
10 ppm.	.07t	.084†
12.4 ppm.	.102	.111
24.8 ppm.	.112	.129
37.2 ppm.	.126	.153
49.7 ppm.	.129	15.3

* Parts per million.'
** Time expressed in hours.
†Milligram equivalents.

TABLE 22—RETARDING EFFECT OP SILICIC ACID ON THE COAGULATION OF CLAY SUSPENSION BY $Al_2(SO_4)_3$.

Tenn. No. 3 Ball Clay—Temperature ca 24°C.
Silicic Acid (SiOa) added.

Milligram equivalents.	0 ppm.*		12.4 ppm.		24.8 ppm.		37.2 ppm.		49.6 ppm.	
	Turbidity.									
	1**	24	1	24	1	24	1	24	1	24
.03	400	200	--------	--------	--------	--------	--------	--------	--------	--------
.06	400	150	--------	--------	--------	--------	--------	--------	--------	--------
.09	175	5	350	100	--------	--------	350	--------	--------	--------
.12	30	5	325	50	350	50	350	100	--------	--------
.15	--------	--------	200	25	350	50	350	100	--------	--------
.18	--------	--------	75	5	350	50	350	100	--------	--------
.21	--------	--------	40	5	125	25	212	40	200	75
.24	--------	--------	40	5	50	10	100	30	--------	--------
.27	--------	--------	--------	--------	50	5	50	20	100	50
.30	--------	--------	--------	--------	50	5	40	5	--------	--------
.33	--------	--------	--------	--------	--------	--------	40	5	50	20
.39	--------	--------	--------	--------	--------	--------	--------	--------	25	15
.45	--------	--------	--------	--------	--------	--------	--------	--------	20	12
.51	--------	--------	--------	--------	--------	--------	--------	--------	20	10

The Amount of $Al_2(SO_4)_3$ Necessary to Produce a Definite Clarification in One Hour in the Presence of Silicic Acid.

SiO_2 added.	$Al_2(SO_4)_3$ added to reduce turbidity to	
	100 ppm.	50 ppm.
0	.105+	.115+
12.4 ppm.	.174	.200
24.8 ppm.	.210	.240
37.2 ppm.	.240	.270
49.6 ppm.	.270	.330

* Parts per million.
** Time expressed in hours.
\+ Milligram equivalents.

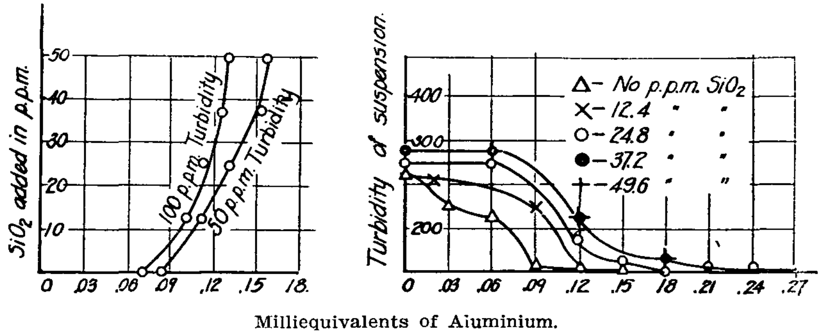
TABLE 23—KETARDING EFFECT OF SILICIC ACID ON THE COAGULATION OF CLAY SUSPENSIONS BY $A1_2(SO_2)_3$ IN THE PRESENCE OF ELECTROLYTES.

Tenn. No. 1 Ball Clay—Turbidity 400 parts per million—Temperature ca 21° C—Time 3 hours.

Milli-equivalent of Al.	Milligram equivalents of salts.									
	.18 NaOH.		1.5 $NaHCO_3$.		2 NaCl.		2 Na_2SO_4		2 $Mg(HCO_3)_2$.	
	Dialyzed silicic acid, parts per million as SiO_2.									
	0	62	0	62	0	62	0	62	0	62
.03						350				400
.06				400		350		400		400
.09		400			350	325	75	400		
.12						225		350		350
.15		400					25	25		
.18	400		400	400	35	125				300
.21	25	350					10	10		
.27	25	25								
.30			85	400	35	15				
.36	125	10								
.39			65	350						
.45		0								
.60			65	300						

Milli-equivalent of Al.	Milligram equivalents of salts.							
	2 $MgSO_4$.		0.7 $Ca(OH_2)$.*		1.0 $Ca(HCO_3)_2$.		0.7 $CaOH_2$† 1.0 ca $(HCO_3)_2$.	
	Dialyzed silicic acid, parts per million as SiO_2.							
	0	62	0	62	0	62	0	62
.03		400	85	180	350	400	175	400
.06	50	400	85	180	100	400		
.09			85	170	65	400	250	350
.12	50	150	125	170	65	400		
.15			100	160			175	325
.18	25	65						
.21							150	250
.27								
.30								
.36								
.39								
.45								
.60								

• 13 hours.
t Readings expressed as turbidities.



The amount of Aluminium necessary in the presence of silicic acid to produce a definite clarification.

Figure 16.—Effect of silicic acid on the coagulation of clay suspension by $Al_2(SO_4)_3$.

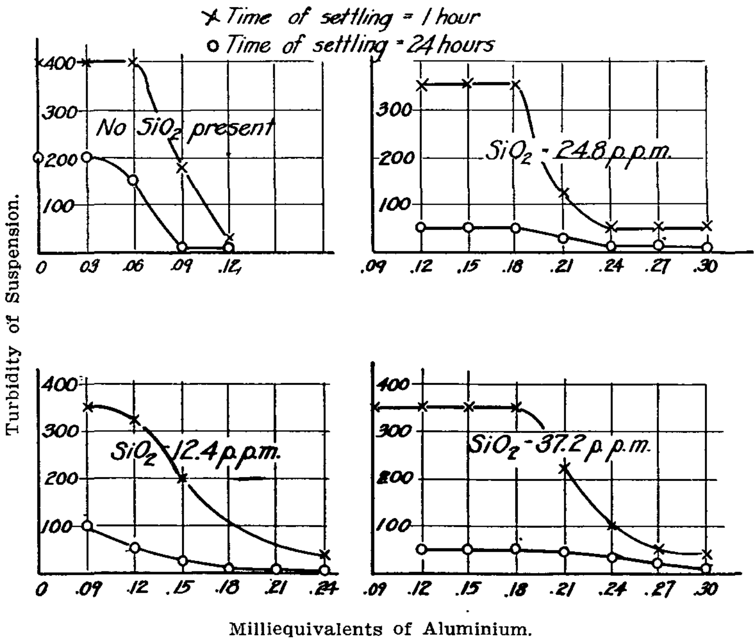


Figure 17.—Effect of silicic acid on the coagulation of clay by $Al_2(SO_4)3$.

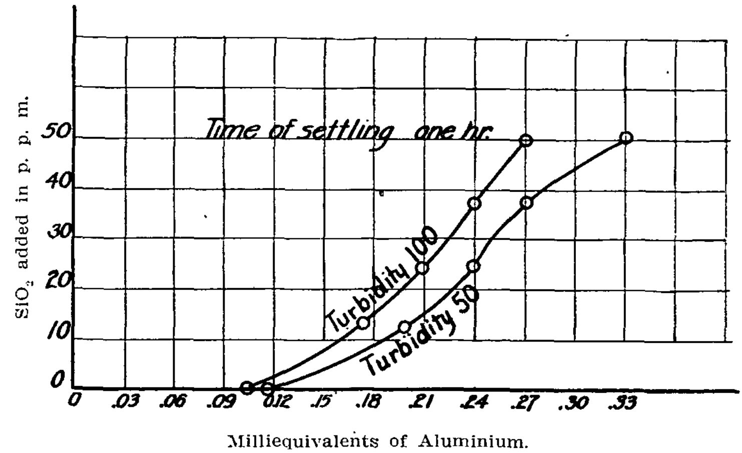


Figure 18.—Al necessary to produce a definite clarification in the presence ot silicic acid. Plotted from Figure 14.

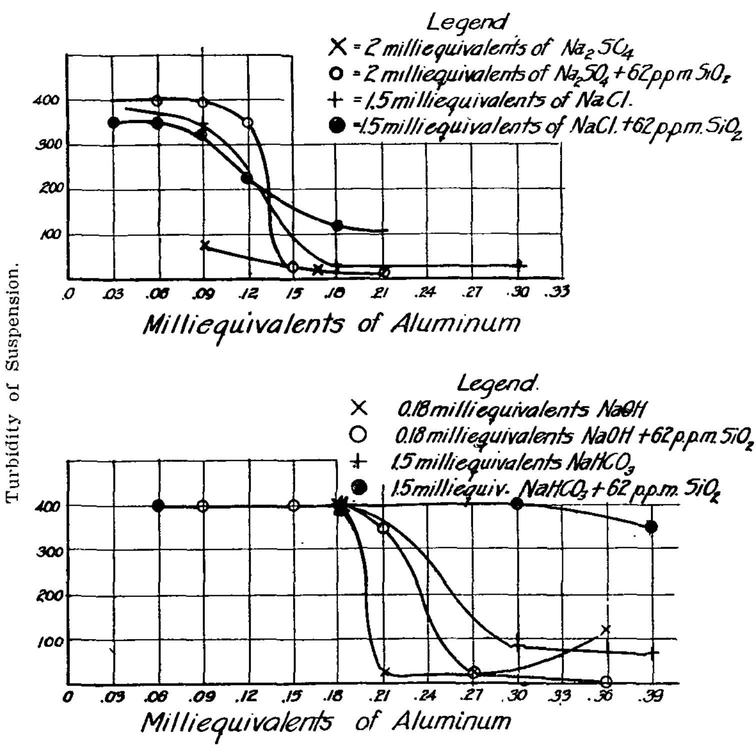


Figure 19.—Effect of sodium salts on the coagulation of clay suspension by $Al_2(SO_4)_3$ in the presents of silicic acid,

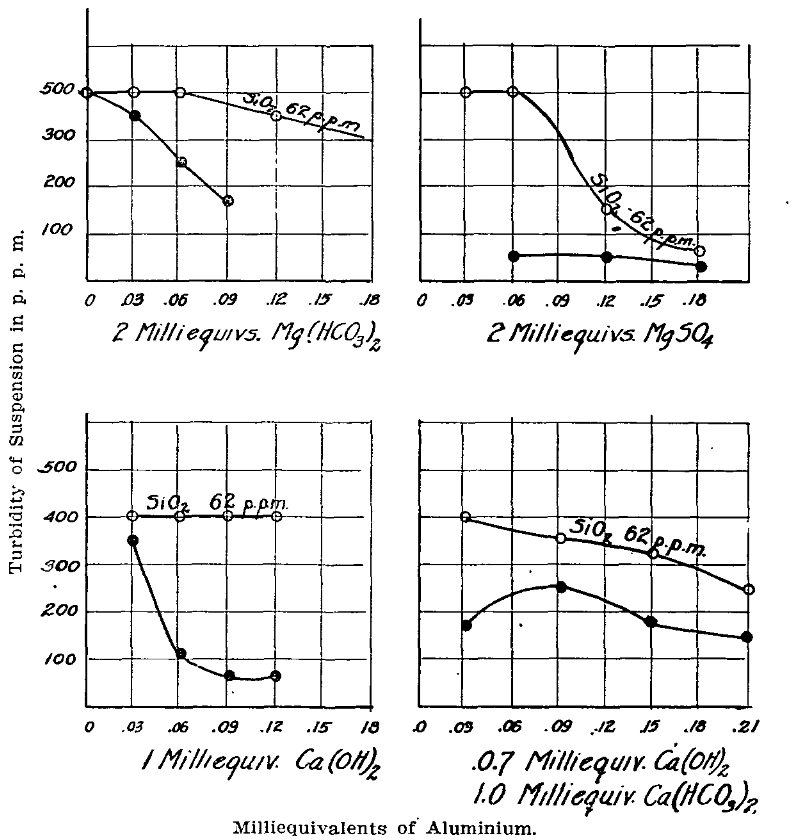
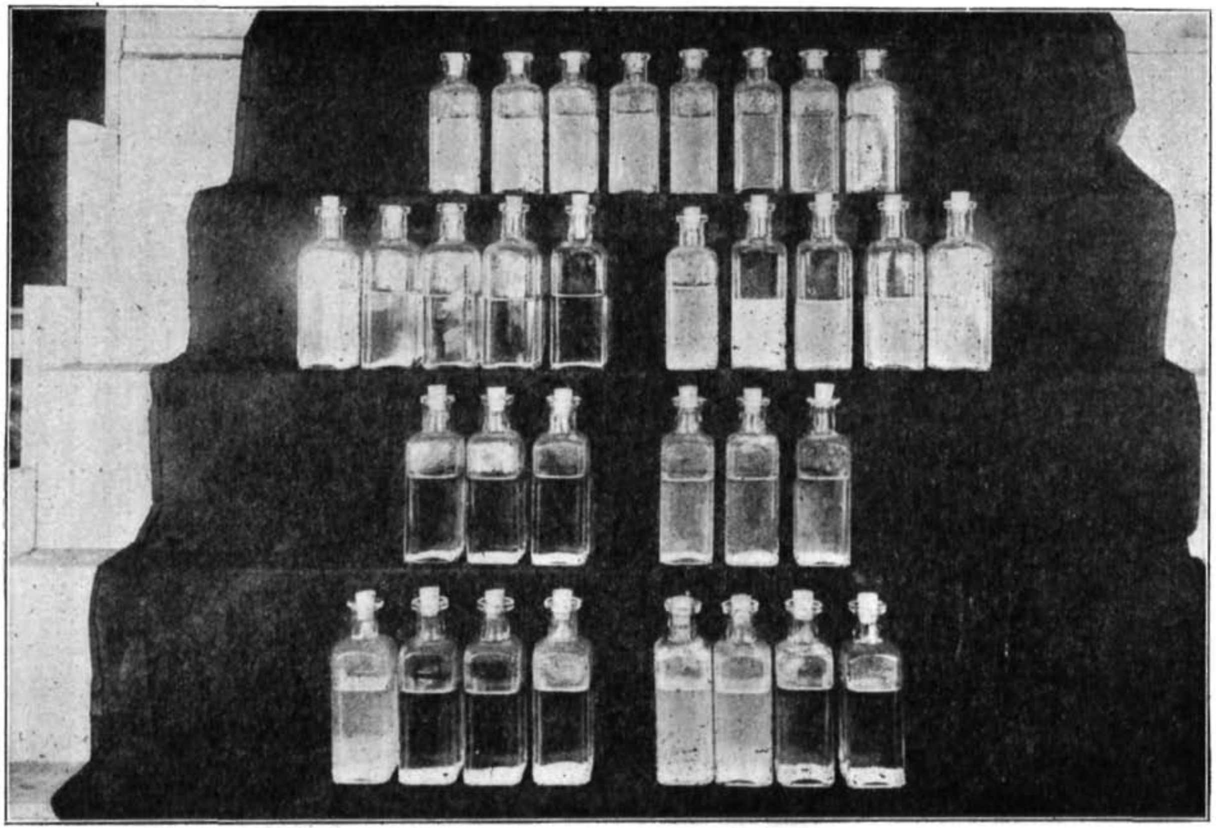


Figure 20.—Effect of silicic acid on the coagulation of clay suspensions in the presence of Electrolytes.

—12 W S



Standards of Turbidity.

Electrolyte $Ca(HCO_3)_2$

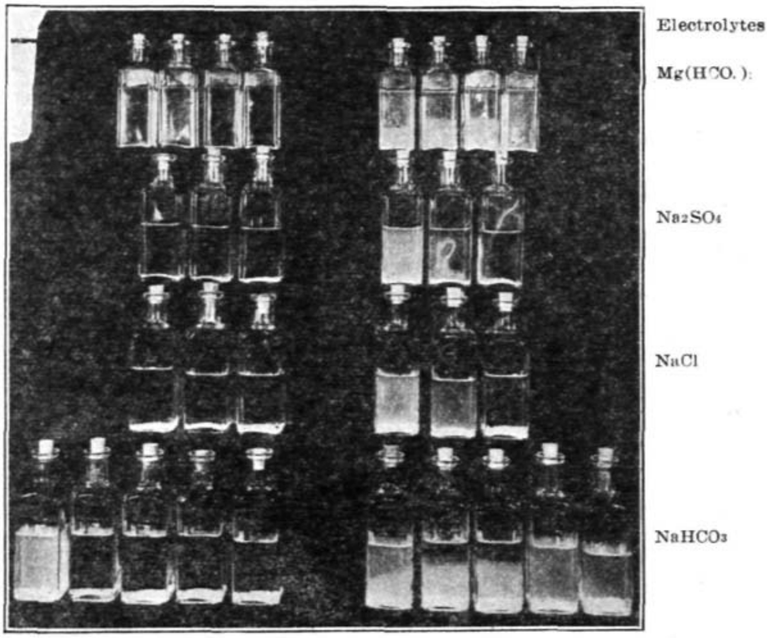
$MgSO_4$

$Ca(OH)_2$

Absent. Present.

Colloidal Silicic Acid.

Figure 21.—The effect of silicic acid on the coagulation of clay suspensions by $Al_2(SO_4)_3$.



Absent. Present.

Colloidal Silicic Acid.

Figure 22.—The effect of silicic acid on the coagulation of clay suspensions by $Al_2(SO_4)_3$.

APPLICATION.

Removal of Silicic Acid From Water to be Used for Boiler Purpose.

The experiment on a natural water already referred to indicates that silicic acid could be most economically removed by aluminium hydroxide formed in the reaction of aluminium sulfate with calcium hydroxide in a solution whose Ph value is 8.0 — 9.0, and that the precipitation is more or less directly related to the ratio of (Ca + Mg) : Na. The higher this ratio the more complete is the removal. By the proper treatment with aluminium sulfate and line it is possible to reduce the silicic acid content from 82.6 to 30 parts per million.

The Coagulation of Waters Containing Colloidal Clay.

The stability of a suspension of clay seems to be intimately connected with the amount of monovalent cations and bivalent anions present. Thus the alum needed to coagulate will be greater the larger the concentration of sodium ions except in the case when the anion is mainly chlorine. Less alum will be needed as the ratio of the Ca + Mg ions to the sodium ion increases. As the silicic acid content increases more alum will be required to coagulate. In concentrations up to 20 parts per million, from 0.015 to 0.03 milligram equivalents of aluminium (Al) per 10 parts of SiO_2 is needed to combat the influence of the silicic acid.

Bate of Reaction.—Water containing bivalent ions when treated with alum gives a sharp, abrupt reaction, an increase of 0.3 milligram equivalents of aluminium, Al, coagulates, but when silicic acid or alkalies are present, other factors being constant, a much larger amount of alum is necessary to produce the same clarification and the abruptness of the reaction becomes less as the amount of the silicic acid and alkalies approaches a certain maximum where the magnitude of the change produced per unit amount of alum is much smaller than in the former case.

This is well shown in Figures 8, 9, 12, 14, 15, and 21. This phenomenon is exactly similar to that which occurs when "colloidal waters" are coagulated by alum and lime.

These experiments justify the addition of an excess of calcium hydroxide, $Ca(OH)_2$ and allowing it to react with the water for some time (8 to 12 hours) before the addition of the alum or ferrous sulfate. This procedure has been effective in purification of water from the Arkansas River at Little Rock, Arkansas when the suspended material is in a colloidal state.

SUMMARY.

1. Colloidal silicic acid in dilute solution can be precipitated by aluminium hydroxide.

2. Dilute solutions of dialyzed and undialyzed silicic acid behave towards electrolytes in the same manner as concentrated solutions—with the exception that proportionately more reagent is needed.

3. The optimum hydrogen ion concentration for the precipitation of the aluminium hydroxide and the removal of silicic acid by aluminium hydroxide is a concentration of 1×10^{-8}.

4. The limiting values of the hydrogen ion concentration, between which the solid aluminium hydroxide phase is present are 1×10^{-4} and 11 x 10-".

5. The presence of silicic acid prevents the formation of a precipitate of aluminium hydroxide, when the sodium hydroxide, equivalent to the aluminium chloride present, is added all at once. The silicic acid probably as a protective colloid prevents precipitation of the aluminium hydroxide. The presence of bivalent cations destroys this protective power.

6. The action of electrolytes on clay suspensoids is the same in dilute as in concentrated suspensions. (Slips).

7. Sodium hydroxide, acid carbonate, and sulfate stabilize or disperse clay suspensions at one concentration and coagulate at another.

8. The ratio of the coagulating power of calcium and barium hydroxide to aluminium hydroxide is about 1 to 5.

9. Coagulation of clay suspensions is aided by the bivalent and hindered by monovalent cations in the presence of acid carbonate, carbonate, sulfate and hydroxyl anions.

10. Silicic acid retards coagulation of clay suspensoids.

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SOME FACTORS IN THE PURIFICATION OF SEWAGE BY THE ACTIVATED SLUDGE PROCESS.

By Gerald C. Baker.*

INTRODUCTION.

The activated sludge method of sewage disposal consists in the aeration of sewage in the presence of accumulated sludge which has been developed from the sewage itself by aeration followed by sedimentation for the removal of the resulting clear, supernatant liquid.

Much work has been carried on, both on the practical and theoretical phases of the process. More attention has been paid to the practical development of the process, but a few investigators have attempted to explain its nature, with the result that various theories have been suggested.

From their early work Ardern and Lockett[2] came to certain conclusions concerning the successful operation of the process, the purifying action of which they attributed to oxidation of the organic matter and nitrification of the ammonium compounds.

(a) In order that the final nitrification changes might take place without hindrance, it is necessary that the alkalinity or basicity of the sewage should be rather more than equal to the nitric acid resulting from the nitrification of the ammonium salts. Our experiments indicate that this is not the ease.

(b) It is necessary that the activated sludge should be kept in intimate contact with the sewage during aeration.

(c) That the relation of the volume of the activated sludge to the volume of sewage treated is of importance, as it affects the rate of nitrification.

Ardern and Lockett noted, too, a rapid initial effect upon the oxidizable matter. The oxidation they divided into two types:

1. Oxidation of the carbonaceous material, the initial effect—
2. Oxidation or nitrification of the nitrogen compounds.

They noted, working with the fill and draw method, that if the activated sludge was called upon to treat further samples of crude sew-

* Abstract of thesis submitted in partial fulfillment of the requirements for the degree of Master of Science, University of Illinois, 1919. The investigation was carried out under direction of Professor W. F. Monfort.

age, prior to the complete nitrification of the previous sample dealt with, its activity was gradually decreased. They later showed that purification, however, is not directly dependent upon the nitrification.[1]

They found the oxidation processes were maintained within a fairly wide range of temperature. At temperatures below 10° C. a very marked deterioration in the results was observed, especially with regard to the removal of colloidal matter. Nitrification was also practically inhibited. Temperatures as high as 30 ° C. did not seem to seriously interfere with the process.

They noted the high bacterial content of the activated sludge, and by reason of its nitrifying power suggested the presence of nitrifying organisms and the part that they might play in the purification processes. From the sludge they also isolated Protozoa, and suggested that they did not play an important part in the purification but rather indicated a particular condition of the activated sludge.

They found that activated sludge sterilized with steam produced no purification whatever, but they realized that the physical characteristics of the activated sludge might be seriously altered by the steaming process. They stated that "the period of aeration depended upon the strength of sewage treated and the degree of purification required:" The superiority of air diffusers over aeration with perforated pipes was recognized.

They also concluded that the success of the process was dependent upon the maintenance of the activity of the nitrifying organisms.

Melling[22] stated that while there was a material reduction in the oxidizable matters, the process appeared to be more physical than biochemical. He based his conclusions upon Salford sewage which had a sludge content of 9.67 per cent iron. He said, "The iron has possibly acted as a catalyst in bringing down the colloidal matter."

Fowler and Mumford[17] suggested that "M-7," a peculiar organism precipitating iron as $Fe(OH)_3$ from iron salt solutions might play some part in the purification. At Salford it was also noted that when copperas ($FeSO_4$ $5H_2O$) was added at the rate of 16 grains per gallon of sewage to accelerate the process, the purification was accelerated.

Most investigators agree that bacteria play an important part in the purification process. Russell[8] states that a combination of nitrifying bacteria with the other varieties present in sewage will purify sterile sewage but that nitrifying bacteria alone will not purify sterile sewage; Hatton[18] suggests that the sludge "must contain sufficient reducing and nitrifying organisms and adequate" food and lodging therefore, to break down the organic nitrogen into free ammonia and nitrogen and oxidize these to nitrates;" contrary to early suppositions Bartow[6] and Mohlman found that the worms aeolosoma hemprichi, often found in activated sludge, were not essential to the purification process. Lederer[19] thinks the mechanical features of the process outweigh the biological features. He says "The highly putrescible colloids have simply been wiped out of suspension by continuous agitation." He recognizes, however, that there is some biological activity.

F. Dienert[12] attributes the purifying action of the activated sludge to the absorption of the organic matter by the precipitated $CaCO_3$, but this appears unlikely.

This work was undertaken with the object of proving, if possible, the various factors involved in the purification process, and the relative importance of each in the whole process.

EXPERIMENTS AND DISCUSSIONS.

Behavior of Colloids of Sewage and Activated Sludge When Treated with Various Disinfectants.

An attempt was made to sterilize both the sewage and activated sludge, without changing the colloidal properties of either, hoping to show the role played by bacteria in the purification process, and the role played by physical phenomena.

(a) *Formaldehyde.*—Formaldehyde was used in varying amounts. Sterility was produced in both the sludge and sewage by the addition of enough formaldehyde to make a .15 per cent solution, if let stand for a period of forty-eight hours. As shown by cataphoresis experiments, the colloidal state of both the sewage and sludge, macroscopically and electrically, was apparently undisturbed.

(b) *Chloroform.*—Attempted disinfection with cholorform was a failure with both sewage and sludge. Amounts as high as ten cubic centimeters per liter for forty-eight hours did not apparently change the colloidal state of either the sewage or sludge, and the sludge at the end of that time had started to become septic.

(c) *Phenol.*—Phenol did not materially change the colloidal properties of either the sewage or sludge, when added in varying amounts up to a saturated 5 per cent solution, although there was only slight movement towards the cathode when cataphoresis experiments were run. Sterility was not produced.

(d) *Mercuric Chloride.*—Sterility was produced by mercuric chloride, one part in one thousand in both sewage and sludge in forty-eight hours, but in each case the colloidal properties were changed. When mercuric chloride was placed in the sewage and put into solution by aeration, almost immediately coagulation of the colloids took place. The sludge was similarly affected, Cataphoresis experiments were not run since it was known that there had been changes in the colloidal state.

(e) *Heat.*—Both sewage and activated sludge were heated at 60° C. for one hour. Some coagulation took place in the sewage, and the colloidal state was changed. The activated sludge rose to the top of the solution. Cataphoresis experiments were not run as it was evident that there had been a change in the colloidal properties. Sterility was not obtained.

(f) *Pressure.*—High pressure was applied by means of liquid carbon dioxide. The sewage and sludge were placed together in a small pressure tank which had been previously lined with paraffin. This tank was connected to a tank of liquid carbon dioxide and the full pressure (56-57 atmospheres at 20°) turned on. The sewage and sludge was subjected to this pressure for twenty-four hours. At the end of this time the pressure was released as gradually as possible. Apparently there had been very little change in the colloidal state of either the sewage or the activated sludge. Sterility was not produced.

Effect of Addition of Clay Colloids Upon the Colloidal State of Sewage.

Twenty grams of very finely divided clay was added to 2,000 cc. of fresh sewage. This amount was considered to be equivalent to the dry matter in the activated sludge required for purification by the activated sludge process. The calculations were based upon 25 per cent of sludge, containing 96 per cent moisture. Analysis by Hatfield[6] has shown that the water content of thoroughly settled activated sludge is 96 per cent. The sewage so treated was placed in a 2,500 cubic centimeter bottle and gently shaken and the contents allowed to settle for twenty-four hours. A major portion of the sewage colloids were removed from the solution.

Removal of Sewage Colloids by Salting Out Agents.

By saturation of sewage with ammonium sulfate it was possible to salt out most of the colloids within two hours. By saturation with sodium chloride there was some salting out action, but only a fractional part of the colloids were removed. This would show a selective action, which might indicate the albuminous character of the sewage colloids.

Effect of Disinfecting Agents Upon the Purification of Sewage by Activated Sludge.

During the progress of this work the original experimental activated sludge plant of the Illinois State Water Survey has been kept in operation. The plant which is located in the basement of the University power plant, has been described by Bartow and Mohlman.[7] The sludge and sewage used in the laboratory experiments have been obtained from this plant. The laboratory experiments were carried out in glass cylinders, 24 inches in height, 6 inches in diameter and having a capacity of about 3 gallons. In all the aeration experiments 7,500 cc. of sewage and 2,500 cc. of activated sludge, collected after thirty minute settling, have been used. Compressed air from the University supply was blown into the mixture thru a Hodkinson type filter strainer. Check results with untreated sludge and sewage have been run in all cases. In all the experiments the decrease in the turbidity, based upon a thirty minute settlement period after aeration, has been taken as a measure of the degree of purification. The degree of sterility has been determined by plating on plain agar with an incubation period of 48 hours, at 37° C.

(a) *Formaldehyde.*—It had been found that the addition of enough formaldehyde to either sewage or sludge to make a .15 per cent solution would produce sterility in 48 hours. Seventy-five hundred cc. of sewage and 2,500 cc. of sludge were so sterilized and placed in the aerating cylinder described above, and aeration carried out. (See Table 1).

TABLE 1—AEARATION AFTER STERILIZATION OF SEWAGE AND SLUDGE WITII .15 PER CENT FORMALDEHYDE.

	Sterilized.	Check (not sterilized).
Turbidity of original sewage	250 ppm.	250 ppm.
Turbidity at end first hours aeration	270 ppm.	75 ppm.
Turbidity at end second hours aeration	330 ppm.	65 ppm.
Turbidity at end third hours aeration	380 ppm.	50 ppm.
Turbidity at end fourth hours aeration	450 ppm.	40 ppm.

The turbidity of the sterilized sewage gradually increased, while the unsterilized at once showed removal of turbidity. Increased aeration of the sterilized material did not give clarification. At the end of 40 hours sterility was maintained. Apparently the power of purification had been destroyed.

This same sterilized mixture was seeded with types of bacteria known to be present in sewage and activated sludge to see if purification could be obtained. The sterilized mixture was seeded with the B. subtilis group of organisms. After incubation for 24 hours at room temperature, the mixture contained 5,000 colonies per cc. growing on agar at 37° C. Aeration of the seeded mixture gave no purification. (See Table 2).

TABLE 2—AERATION AFTER ADDITION OF B. SUBTILIS GROUP OF BACTERIA SEWAGE AND SLUDGE STERILIZED WITH .15 PER CENT FORMALDEL-HYDE.

Turbidity at start of aeration. . . . . .210 ppm. (settlement for 30 hrs.)
Turbidity at end 2 hours aeration. .500 ppm.
Turbidity at end 4 hours aeration. .850 ppm.
Turbidity at end 8 hours aeration. .950 ppm.

To a similarly sterilized and aerated mixture, nitrifiers and other typical sludge flora were added in the form of a small amount of activated sludge (100 cc.) digested for 1 hour, and aerated. Purification was accomplished, but more slowly. At the end of 35 hours the turbidity was reduced from 450 to 40 ppm. (See Table 3).

TABLE 3—AERATION AFTER ADDITION OF FRESH ACTIVATED SLUDGE TO SEWAGE AND SLUDGE STERILIZED WITH .15 PER CENT FORMALDE-HYDE.

Turbidity at start of aeration. . . . . .450 (settlement for 15 hrs.)
Turbidity at end of 2 hours aeration. .450 ppm.
Turbidity at end of 5 hours aeration. .440 ppm.
Turbidity at end of 10 hours aeration.. 280 ppm.
Turbidity at end of 20 hours aeration. .200 ppm.
Turbidity at end of 30 hours aeration. . 120 ppm.
Turbidity at end of 35 hours aeration.. 40 ppm.
Turbidity at end of 40 hours aeration. .less than 25 ppm.

To see if sewage itself contained the proper bacterial flora necessary for purification, fresh activated sludge was sterilized with formaldehyde, giving a solution of 15 per cent. This sludge (2,500 cc.) after standing 48 hours with the disinfectant was added to 7,500 cc. of fresh sewage in the aeration cylinder and aerated. (See Table 4).

TABLE 4—AERATION OF SEWAGE AND SLUDGE AFTER STERILIZATION OF THE SLUDGE, WITH .15 PER CENT FORMALDEHYDE.

Turbidity of sewage at start of aeration. .250 ppm.
Turbidity at end of 1st hours aeration. . . . . .260 ppm.
Turbidity at end of 5th hours aeration. . . . . .340 ppm.
Turbidity at end of 10th hours aeration. . . . . .380 ppm.
Turbidity at end of 24th hours aeration. . . . . .480 ppm.
Turbidity at end of 30th hours aeration. . . . . .660 ppm.
Turbidity at end of 36th hours aeration. . . . . .540 ppm.
-Turbidity at end of 50th hours aeration. . . . . .320 ppm.
Turbidity at end of 80th hours aeration. . . . . .180 ppm.

Turbidity at end of 95th hours aeration	110 ppm.
Turbidity at end of 100th hours aeration	85 ppm.
Turbidity at end of 120th hours aeration	40 ppm.

Purification was slow, but at the end of 120 hours the turbidity had been reduced from 250 to 40 ppm.

Thus it was shown that the sewage itself contains the necessary bacterial flora for the purification process, and that sterilized sludge must have retained the proper physical condition. The two preceding experiments have shown that the colloidal state of the sewage and sludge had not been materially changed by the treatment with formaldehyde and by over-aeration, and that both the sludge and the sewage contain the bacterial flora necessary for purication.

(b) *Effect of Chloroform.*—It has been found that a saturated solution of chloroform would not sterilize either the sewage or the sludge. Fifteen cc. of chloroform were added to 2,500 cc. of the sludge and 45 cc. to 7,500 cc. of sewage and let stand for 48 hours, at the end of which time they were placed in the aeration cylinder and aerated. (See Table 5).

TABLE 5—AERATION AFTER TREATMENT OF SEWAGE AND SLUDGE WITH CHLOROFORM.

		Check.
Turbidity of sewage at start of aeration	250 ppm.	255 ppm.
Turbidity at end 1st hours aeration	250 ppm.	90 ppm.
Turbidity at end 2nd hours aeration	280 ppm.	60 ppm.
Turbidity at end 3rd hours aeration	250 ppm.	50 ppm.
Turbidity at end 4th hours aeration	260 ppm.	30 ppm.
Turbidity at end 10th hours aeration	260 ppm.	
Turbidity at end 20th hours aeration	290 ppm.	

By aeration for 20 hours no reduction in turbidity was obtained.

The choloroform had killed most of the bacteria except spore formers. After treatment with chloroform, but before aeration, 150 colonies developed on agar at 37° C. from 1 cc. of sewage and 400 from 1 cc. of sludge.

Fresh activated sludge (100 cc.) was added to the above mixture and aerated. (See Table 6).

TABLE 6—AERATION AFTER ADDITION OF FRESH ACTIVATED SLUDGE TO SEWAGE AND SLUDGE TREATED WITH CHLOROFORM.

Turbidity at start of aeration	240 ppm.
Turbidity at end 4 hours aeration	220 ppm.
Turbidity at end 10 hours aeration	140 ppm.

Turbidity at end 15 hours aeration........................60 ppm.
Turbidity at end 18 hours aeration........................40 ppm.

At the end of 18 hours the turbidity was reduced from 240 to 40 ppm.

The colloidal state was not destroyed by the treatment with chloroform. The spore-forming bacteria may take some part in the purifica-, tion process, since continued aeration did not break up the activated sludge to give increased turbidity. (See Table 5).

(c) *Phenol.*—By the addition of sufficient phenol to 2,500 cc. of activated sludge and 7,500 cc. of sewage to produce a 2.5 per cent solution, it was found that sterility was not obtained. The sewage contained 120 bacteria per cc. and the activated sludge 395. The turbidity increased rapidly with aeration, rising from 500 to 1,400 in 8 hours. (See Table 7).

TABLE 7—AERATION OF SEWAGE AND SLUDGE TREATED WITH PHENOL TO MAKE 2.5 PER CENT SOLUTIONS.

		Check.
Turbidity of sewage at start of aeration.....	500 ppm.	500 ppm.
Turbidity at end 1st hours' aeration........	1,000 ppm.	150 ppm.
Turbidity at end 4th hours aeration.........	1,200 ppm.	60 ppm.
Turbidity at end 8th hours aeration........	1,400 ppm.	
Turbidity at end 20th hours aeration........	1,600 ppm.	
Turbidity at end 30th hours aeration........	1,650 ppm.	

Addition of (100 cc.) activated sludge to above mixture gave no purification after additional aeration, nor did the addition of 500 cc. additional activated sludge produce clarification. Here we were dealing with a disinfectant which was non-volatile by aeration, and the excess of phenol was not eliminated. It is possible that there might have been a slight attack on the albuminous matter, but by inspection the flocculent state of the activated sludge did not seem to have been altered. There was little if. any migration of the colloids under the effect of the electric current, and it is possible that there may have been a change in the physical state.

(d) *Mercuric Chloride.*—Mercuric chloride was added to sewage to make a solution of 1 part in 1,000. The mixture was aerated to facilitate the solution of the $HgCl_2$. Coagulation almost immediately took place. After aerating for one-half hour and letting settle for thirty minutes a turbidity of 10 was obtained. The turbidity of the original sewage was 300 ppm. Sterility was produced in 48 hours.

The mercuric chloride apparently coagulated the albuminous matter of the sewage and produced clarification, hence the question is brought up, is clarification in any way connected with the coagulation of the albuminous matter?

(e) *Heat.*—7,500 cc. of sewage and 2,500 cc. of activated sludge were heated at 60° for one hour. Slight coagulation of the sewage occurred, while the activated sludge rose to the top of the mixture. Sterility was not produced. The sewage contained 2,200 bacteria per cc. and the activated sludge 5,000. Even though the sludge and sewage was not sterilized by the heating the turbidity increased with aeration . in 10 hours from 340 to 625. (See Table 8).

TABLE 8—AERATION AFTER HEATING SEWAGE AND SLUDGE—AT 60° C. FOE ONE HOUR.

		Check.
Turbidity of sewage at start of aeration	340 ppm.	340 ppm.
Turbidity at end 1st hours aeration	420 ppm.	180 ppm.
Turbidity at end 2nd hours aeration	510 ppm.	95 ppm.
Turbidity at end 3rd hours aeration	590 ppm.	75 ppm.
Turbidity at end 4th hours aeration	625 ppm.	45 ppm.
Turbidity at end 10th hours aeration	650 ppm.	

Fresh activated sludge (100 cc.) was added and after letting stand for one hour, aeration was continued. (See Table 9).

TABLE 9—AERATION AFTER ADDITION OF FRESH ACTIVATED SLUDGE TO SEWAGE AND SLUDGE HEATED AT 60° C.

Turbidity at start	590 ppm.
Turbidity at end 1st hours aeration	590 ppm.
Turbidity at end 4th hours aeration	600 ppm.
Turbidity at end 10th hours aeration	580 ppm.
Turbidity at end 25th hours aeration	390 ppm.
Turbidity at end 33rd hours aeration	280 ppm.
Turbidity at end 45th hours aeration	280 ppm.

Apparently the colloidal state of the activated sludge had been so affected that complete clarification could not be obtained, altho after the introduction of the fresh activated sludge some purification was effected. (See Table 9).

(f) *High Pressures (Carbon Dioxide).* In these experiments 1,000 cc. activated sludge and 3,000 cc. of sewage were placed in a small pressure tank which was then connected to a liquid carbon dioxide cylinder, and the full pressure turned on. The mixture was subjected to this pressure for four hours, at the end of which time the pressure was released as gradually as possible. The mixture which had assumed a greenish color due to the iron which had gone into solution by the action of CO, upon the cylinder was then aerated. (See Table 10). Sterilization was not produced by the pressure. Bacteria remaining were 530.

TABLE 10—AERATION AFTER TREATMENT OP SEWAGE AND SLUDGE WITH HIGH PRESSURE.

		Cheek.
Turbidity of sewage at start . . . .,..,.	200 ppm.	200 ppm.
Turbidity at end of 1st hours aeration	80 ppm.	135 ppm.
Turbidity at end of 3rd hours aeration	90 ppm.	80 ppm.
Turbidity at end of 4th hours aeration	90 ppm.	20 ppm.

With aeration the turbidity was reduced from 200 to 90 ppm. in 4 hours.

It was thought that probably the iron which the mixture had taken up due to action of the $C0_2$ upon the walls of the cylinder, might have had something to do with the action upon aeration. Accordingly the above experiment was repeated after the tank had been lined with paraffin. The turbidity rose from 200 to 210 in 4 hours and to 800 in 40 hours, showing probable action of the iron. (See Table 11).

TABLE 11—AERATION AFTER TREATMENT OF SLUDGE AND SEWAGE WITH HIGH PRESSURE (TANK LINED WITH PARAFFIN).

		Check.
Turbidity of sewage at start	200 ppm.	200 ppm.
Turbidity at end of 2nd hours aeration	220 ppm.	]00 ppm.
Turbidity at end of 3rd hours aeration.	200 ppm.	70 ppm.
Turbidity at end of 4th hours aeration	210 ppm.	30 ppm.
Turbidity at end of 10th hours aeration	400 ppm.	
Turbidity at end of 25th hours aeration	650 ppm.	
Turbidity at end of 40th hours aeration	800 ppm.	

Five hundred cc. fresh activated sludge were added and aeration continued. (See Table 12).

TABLE 12—AERATION AFTER ADDITION OF FRESH ACTIVATED SLUDGE TO SEWAGE AND SLUDGE TREATED WITH HIGH PRESSURES.

Turbidity at start of aeration	740 ppm.
Turbidity at end of 4th hours aeration	720 ppm.
Turbidity at end of 8th hours aeration	510 ppm.
Turbidity at end of 23rd hours aeration	140 ppm.
Turbidity at end of 25th hours aeration	100 ppm.
Turbidity at end of 30th hours aeration	50 ppm:

The high pressure had evidently killed all the bacteria except the spore bearing forms. Again clarification was produced after seeding with the proper bacterial flora. In aeration after the treatment there is noted an increasing turbidity even with the spore-forming bacteria present (Table 11), which was not the case with the sewage treated with chloroform. It is possible that the CO_2 had temporarily changed the colloidal state due to a change of the hydrogen ion concentration of the solution. The CO_2 evidently was driven off on aeration and after seeding with activated sludge, clarification was made possible. It is also noted that iron or other mineral constituents may play some role in the precipitation and sedimentation processes.

Effect of Aeration With Different Gases Upon Purification of Sewage by Activated Sludge.

An attempt was made to prove whether it was only the intimate contact of the activated sludge with the sewage that produced the purification, or whether the air used in the aeration played any part. Accordingly experiments were made with CO, using 7500 cc. sewage and 2,500 cc. sludge, with the result that very little purification resulted. (See Table 13). It was thought if the oxygen of the air was responsible for the purification, that oxygen itself might cause more rapid purification; accordingly experiments were made using oxygen. (See Table 13). In 4. hours oxygen gave slightly better results than were obtained with air.

TABLE 13—SUBSTITUTIONS OF CARBON DIOXIDE OR OXYGEN FOR AIR.

	Oxygen	Air.	Carbon dioxide.
Turbidity of sewage at start of aeration	210 ppm.	210 ppm.	210 ppm.
Turbidity at end of 1 hours aeration	80 ppm.	90 ppm.	130 ppm.
Turbidity at end of 2 hours aeration	45 ppm.	65 ppm.	160 ppm.
Turbidity at end of 3 hours aeration	45 ppm.	55 ppm.	170 ppm.
Turbidity at end of 4 hours aeration	40 ppm.	55 ppm.	190 ppm.
Turbidity at end of 18 hours aeration	....	...	510 ppm.

Thus it would seem that the oxygen was necessarily responsible for the purification. The slight reduction of the turbidity at the end of the first hour's treatment with CO, may have been due to the oxygen dissolved in the sewage.

Sulfur Dioxide.—It was thought the activated sludge process might be comparable with the Miles acid treatment. Accordingly an attempt was made to determine whether there was a change of hydrogen ion concentration during the purification process. Fresh sewage was aerated for 5 days and the hydrogen ion concentration determined on each successive day. (See Table 14).

TABLE 14—EFFECT OF AERATION UPON THE HYDROGEN ION CONCENTRATION OF SEWAGE.

	Hydrogen ion concentration.
Sewage as collected	7.6
After 24 hours aeration	8.0
After 48 hours aeration	8.2
After 72 hours aeration	8.1
After 96 hours aeration	8.2
After 120 hours aeration	8.2
Treated with activated sludge	7.7
Filtered activated sludge	7.4

The method used in determining the hydrogen ion concentration was a modification of the method of Levy, Rowntree and Marriott.[20] Three cc. of sewage to be tested and .2 cc. of a .01 per cent phenol sulphonephthalein indicator were placed in a glass tube 100 by 10 mm. inside measurements. The color produced was compared with a series of standards prepared from this indicator.

Substitution of sulfur dioxide for air gave no purification of sewage by activated sludge. Later, air was blown thru the mixture. Purification could not be accomplished and the sludge was partly disintegrated. The slight change in the hydrogen ion concentration and the action of carbon dioxide and sulfur dioxide indicates that acidity production by bacteria is not a factor in the removal of the colloidal matter from sewage in the activated sludge process.

Effect of Mechanical Agitation Upon the Purification of Sewage by Activated Sludge.

Experiments were made to see if oxygen was necessary for the purification, or whether intimate contact of the sewage and activated sludge would alone produce clarification. One experiment was made with gentle shaking at intervals of 15 minutes for three and one-half hours and after each interval letting the mixture settle for thirty minutes. A second experiment was made with continuous vigorous shaking for three and one-half hours with a final settlement of thirty minutes. Four hundred cc. of activated sludge and 1,600 cc. of sewage was placed in 2,500 cc. bottles. (See Table 15).

TABLE 15—MECHANICAL AGITATION OF SEWAGE IN THE PRESENCE OF ACTIVATED SLUDGE.

	Vigorous shaking.	Gentle shaking.	Check aeration.
Turbidity of sewage at start	320	320	320
Turbidity at end 4 hours	500	150	50

By the gentle shaking some clarification was produced, probably due to some oxidation by the dissolved oxygen of the sewage, and also due to the mechanical absorption of the sewage colloids by the activated sludge. The vigorous shaking seemed to have partially broken up the flocculent state of the activated sludge.

Attempted Purification by Dried Activated Sludge.

Activated sludge dried by Hatfield in 1917, was ground up very finely and placed in 2,500 cc. of distilled water. The amount used was equivalent to the dry matter in an equal quantity of fresh activated sludge. (125 g in 2,500 cc.) This prepared solution was added to 7,500 cc. of raw sewage in the aeration cylinder and air blown thru the mixture. (See Table 16).

TABLE 16—TREATMENT OF SEWAGE WITH DRIED ACTIVATED SLUDGE.

		Check.
Turbidity of sewage at start of aeration	170 ppm.	170 ppm.
Turbidity at end 4 hours aeration	280 ppm.	40 ppm.
Turbidity at end 10 hours aeration	320 ppm.	
Turbidity at end 20 hours aeration	320 ppm.	
Turbidity at end 30 hours aeration	330 ppm.	
Turbidity at end 40 hours aeration	320 ppm.	

The sludge did not regain any of its flocculent properties and no purification was effected. The turbidity increased and at the end of 4 hours had risen from 170 to 280 and at the end of 40 hours to 320.

Biological Action is Necessary For Purification.

Almost from the beginning of sewage purification the importance of microorganisms has been recognized. Upon filtration of sewage, Dunbar and Calvert[13] attribute the clarification to an absorption of the colloids by gelatinous films formed around the sand grains. These films contain many bacteria and other low forms of life. The gelatinous coatings become thicker and thicker and it is assumed that they have a honey-comb structure, and therefore possess an exceedingly large surface. They have an internal as well as an external surface and can absorb large quantities of gases, including oxygen, and many organic and inorganic substances. After absorption oxidation takes place and the organic matter is partially broken down.

It is possible that such a process is taking place in the purification of sewage by activated sludge since the sludge is flocculent and porous in character, and absorbs the sewage colloids, possibly by an accumulation of the gelatinous forms caused by surface attraction and direct suction. A direct suction might be produced when the absorbed oxygen of the sludge is used up and replaced by fresh oxygen from the air in the pores. This might cause a partial vacuum in the pores of the sludge, and the surrounding air is drawn in with considerable energy.

Interference by Oil.—During the progress of this work, some difficulties have arisen in the successful operation of the experimental activated sludge plant from which all the activated sludge and sewage was obtained for the laboratory experiments. At times the sewage was contaminated with large quantities of oil which was pumped into the tank with the sewage. During these periods purification was greatly interfered with, but by skimming off the oil, much better clarification could be obtained. It is possible that the oil may have absorbed the oxygen and may have in some way affected the colloidal state of the sewage,

CONCLUSIONS.

1. The purification of sewage by activated sludge is due to oxidation.
2. The oxidation is largely carried on by aerobic bacteria.
3. Sewage itself contains the bacterial flora necessary for purification independent of the types present in activated sludge.
4. The biological oxidation is attended by absorption of the sewage colloids by the activated sludge.
5. For good clarification the activated sludge must be kept in intimate contact with the sewage, and the sludge itself must be in proper physical condition.
6. The removal of the colloids from sewage by activated sludge is directly dependent upon bacteria, and may be due to a secretion of enzymes by the bacteria.
7. The colloids of sewage are, at least, for the greater part positively charged and may be largely removed by the introduction of negatively charged colloids.
8. The colloids may be largely salted out with a saturated solution of ammonium sulfate, but it is not practical.
9. The activated sludge process is not comparable to the Miles acid treatment since purification is not dependent upon acidity produced.

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A NEW SAMPLER FOR COLLECTING DISSOLVED OXYGEN SAMPLES.

By R. E. Greenfield and F. L. Mickle. .

When samples are collected for the determination of dissolved oxy-' gen it is necessary to take precautions against aeration. Standard Methods of Water Analysis advises collection of the sample in a two hundred and fifty cubic centimeter glass stoppered bottle. This bottle is to be connected to a liter bottle in such a manner that when the two bottles are immersed in the water to be sampled, both bottles will be filled, all the water passing through the small bottle before entering the large. In this manner the sample finally obtained in the small bottle will not have been aereated during the displacement of the air by the water.

Such an apparatus while quite workable is easily broken, due to the fragility of the connecting tubes, and we have found, fills very slowly, since the connecting tubes are *pi* necessity quite small in order that they may pass through the neck of the smaller bottle.

To obviate these difficulties several forms of apparatus have been suggested embodying the same principles but entirely or partially built of metal. At least two of these devices are very good, one is described in Whipple's Microscopy of Drinking Water, (1914) page 26, and the other in Hygienic Lab. Bull. No. 104. It is necessary to have either of these devices built to order because they are of such nature that they can not be constructed from ordinary laboratory material. This laboratory was called upon to do a large number of dissolved oxygen determinations and did not have sufficient time to have one of the above mentioned types of apparatus constructed. An apparatus was improvised from ordinary laboratory material which proved so satisfactory that it was used frequently for over a year. A wide mouth, common stoppered bottle such as is used as a container for solid reagents was selected. The bottle had a capacity of about fifteen hundred cubic centimeters and a mouth wide enough to accommodate a number thirteen rubber stopper. A number thirteen rubber stopper was pierced with two holes, one near the center and the other on one side. A thin walled brass tube, of such a size that it could be inserted in the neck of a two hundred and fifty cubic centimeter sample bottle without completely blocking the

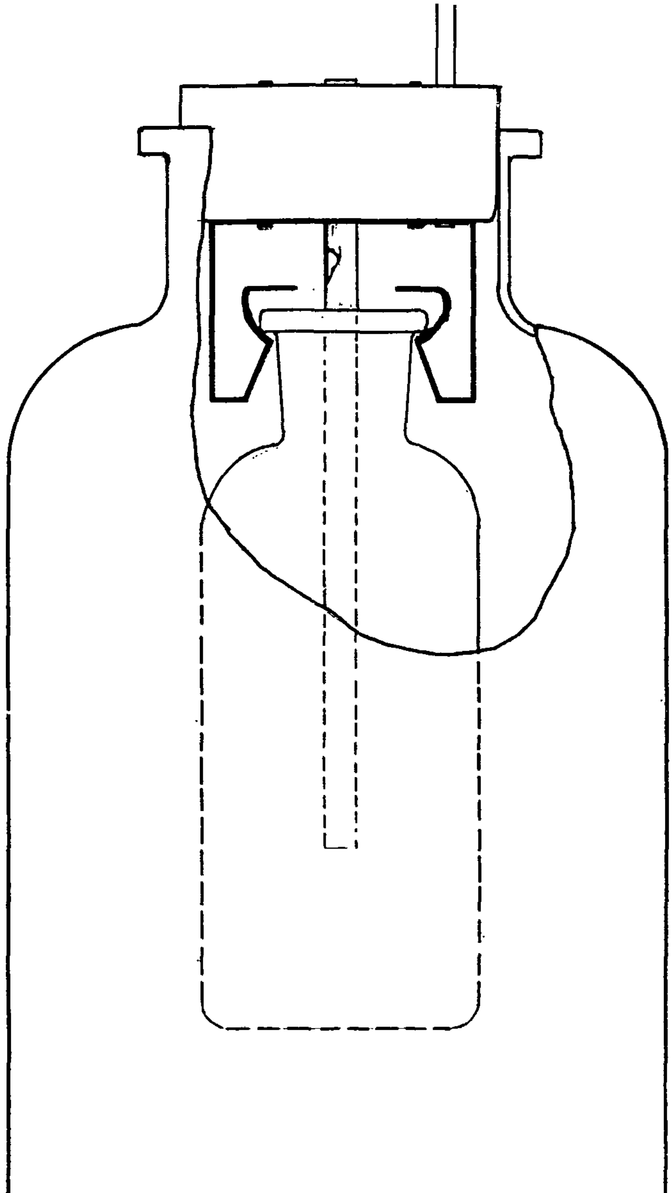

Figure 1.—Dissolved Oxygen Sampler that may be made from materials found in the Laboratory.

neck, was inserted in the center hole, the top being made flush with the top of the stopper, this tube was cut off so as to be about one quarter inch shorter than the height of the small sample bottle (see Figure 1), a shorter piece of the same tubing was inserted in the other hole, the bottom of this shorter piece being flush with the bottom of the stopper and extending about two inches above the stopper. A clamp of bent brass to hold the small sample bottle by the neck was made and attached to the lower side of the stopper in such a manner that the bottle might be suspended about one quarter inch below the stopper with the long brass tube extending in to it. If the stopper with attached bottle is

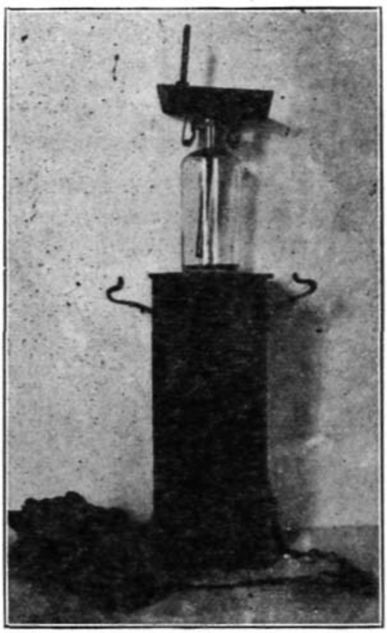

Figure 2.—Dissolved Oxygen Sampler constructed entirely of Metal.

placed in the large bottle and the entire apparatus immersed in water the water will enter the small bottle through the longer brass tube filling the small bottle and overflowing into the larger, the air escaping through shorter brass tube. This flow will continue until the larger bottle is full. Using a large bottle with a capacity of fifteen hundred cubic centimeters something more than a liter of water will have passed through the sample bottle before the action ceases; the flushing out of the small bottle will be as perfect as with the apparatus specified in Standard Methods of Water Analysis even though the small bottle does take up part of the capacity of the large bottle. For use this apparatus was clamped firmly on a stand, heavy enough to cause the whole to sink rapidly. A chain for lowering into the water was attached to the stand. In use this apparatus proved to be very satisfactory as it was easily manipulated and filled fairly rapidly; the rapidity of filling could be controlled by shortening or lengthening the brass tube which extended above the stopper. The longer the tube the faster will be the filling. The rate of filling was made slow enough so that the apparatus could be lowered rapidly to the desired depth before much filling could take place. The apparatus did not prove to be at all fragile as the large bottles of this kind are quite thick and stand considerable abuse, in addition it was compact and easily carried.

The operation of this sampler proved to be so satisfactory that a device of practically the same design was built entirely of metal. A picture of this is shown (see Figure 2). The metal sampler must be weighted with lead to make it sink properly. The advantage of the metal sampler over the glass bottle is, of course, entire freedom from chance of breakage.

The metal sampler consists of a copper box $3^7/_8$ inches square by 10 inches deep with a flat heavy flange riveted to the top. The cover, a square brass plate, is clamped to the flange of the box by four easily operated spring clamps. The cover carries the same arrangement of tubes and bottle holding clamp as did the rubber stopper in the original apparatus. It may be also provided with a hole for holding a thermometer. We have found however that due to the chance of breaking the thermometer, it is usually better to take the temperature of the water in the sampler after is has been brought to the surface. The details of construction are given in Figure 3.

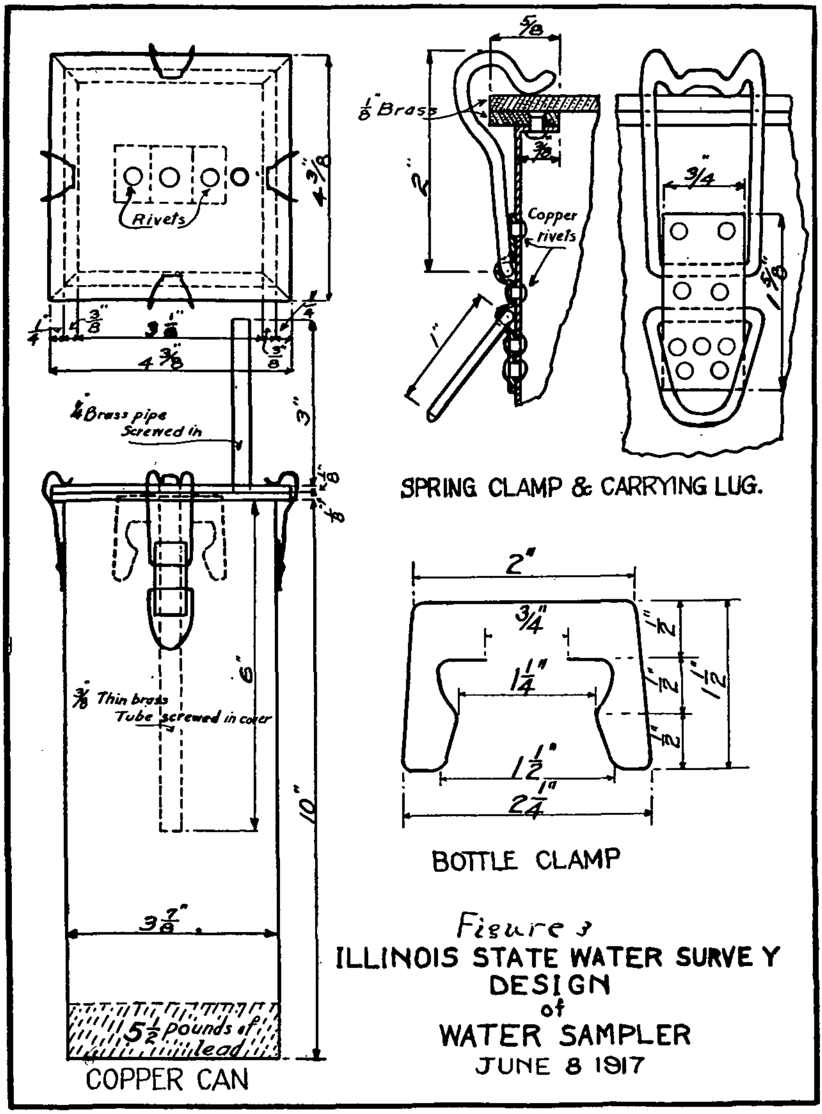

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Figure 3.—Details of Construction of Dissolved Oxygen Sampler.

PREPARATION OF AMMONIA FREE WATER.

By Gerald C. Baker.

Large quantities of ammonia free water are required for nitrogen determinations. The preparation of ammonia free water is usually a tedious and troublesome task. Distilled water is usually the starting point and many methods are used to free it from ammonia.

The main methods of preparation include:

1. Digestion of distilled water with enough bromine water to produce a yellow coloration, followed by the addition of sufficient sodium hydroxide (NaOH) or sodium carbonate (Na_2CO_3) to remove the excess bromine and then redistilling. The bromine forms non-volatile compounds with the nitrogenous constituents. Potassium iodide (KI) may be added before distillation if necessary to remove any undecomposed hypobromous acid (HOBr).

2. Re-distillation of distilled water after the addition of sodium carbonate (Na_2CO_3), rejecting the first portion of the distillate which contains all of the ammonia.

3. Re-distillation of distilled water to which alkaline potassium permanganate ($KMnO_4$) has been added, rejecting the first portions of the distillate. In this case the nitrogenous compounds are oxidized.

4. Re-distillation of distilled water after the addition of sulfuric acid. In this case the sulfuric acid forms non-volatile salts with the nitrogenous compounds.

5. Re-distillation of distilled water after the addition of potassium permanganate in the presence of an electric current. Free alkali and permanganic acid are produced, and it is claimed that oxidation of the nitrogenous compounds is hastened.

In the laboratories of the State Water Survey Division at Urbana, Illinois, a large quantity of ammonia free water is required for the nitrogen determinations. Until recently the bromine water and sodium hydroxide method has been used. The distillation was made in a copper still and the process required much time and attention, and was quite expensive. Since January 1, 1918, ammonia free water has been prepared by passing distilled water through permutit.

In 1917 Folin and Bell[1] found that when urine and permutit were shaken together the ammonia was quantitatively absorbed, and that it could be again quantitatively liberated by treatment with sodium hydroxide (NaOH).

It was thought that permutit might be employed in the preparation of ammonia free water on a larger scale. Consequently an apparatus embodying the principles of the permutit water softening installation was fitted up. A glass aspirator bottle 30 inches high and 8 inches in diameter was used as a container for the permutit. A layer of glass beads, 1½ inches deep was placed in the bottom; 12 to 14 inches of permutit were placed on top of the beads. During operation the distilled water enters the top of the bottle through a tube connected to a faucet. For back flushing, a tube to carry distilled water, equipped with a valve, enters the bottom of the bottle. This tube serves also as a bottom drain through which the ammonia free water passes to a tube rising almost to the height of the water in the bottle and containing an opening in the top to prevent siphoning effects. An over flow pipe is provided for use during the back flushing of the filter. A *2* gallon glass bottle having an opening at the bottom elevated above the filter is used for containing the salt solution and feeding it to the filter while regenerating. The distilled water is distributed over the surface of the permutit by a perforated glass bulb. The water is allowed to flow slowly through the permutit at the rate of about one gallon per hour. With three gallons of permutit it has been possible to prepare, before regenerating, 100 gallons of ammonia free water, having started with a distilled water containing .7 parts per million of ammonia.

Regeneration is accomplished by passing two gallons of a 10 per cent common salt solution on to the filter, and letting it stand over night, then washing the filter in a manner similar to the washing of any permutit machine. (The accompanying Figure 1 shows the working parts).

It is a question whether the removal of ammonia by this reagent is strictly a displacement phenomenon, or whether the displacement is accompanied by some mechanical absorption of the ammonia. The permutit itself is, of course, a complex hydrated sodium aluminium silicate containing easily replaceable sodium. If we represent such a typical hydrated silicate, chabasite, which has the formula $Na_2Al_2Si_4O_{12}H_2O$, by its empirical graphical formula[2] $(OH)_3Si\text{-}O\text{-}Si(OH)_2OAl(O)\ (ONa)$ we get an idea of the ease of replaeability of the sodium.

In practice much of the replaceable sodium remains when the machine begins to deliver a water containing ammonia for it will still remove large quantities of hardening constituents before re-charging.

It is quite evident that there is a mass relationship between the ammonia absorbed and the ammonia present in the water and when a certain amount of sodium is replaced an equilibrium is established when the removal of ammonia is not quantitative.

It was not possible to make ammonia free water from the University of Illinois supply, a relatively hard water, even though the water was

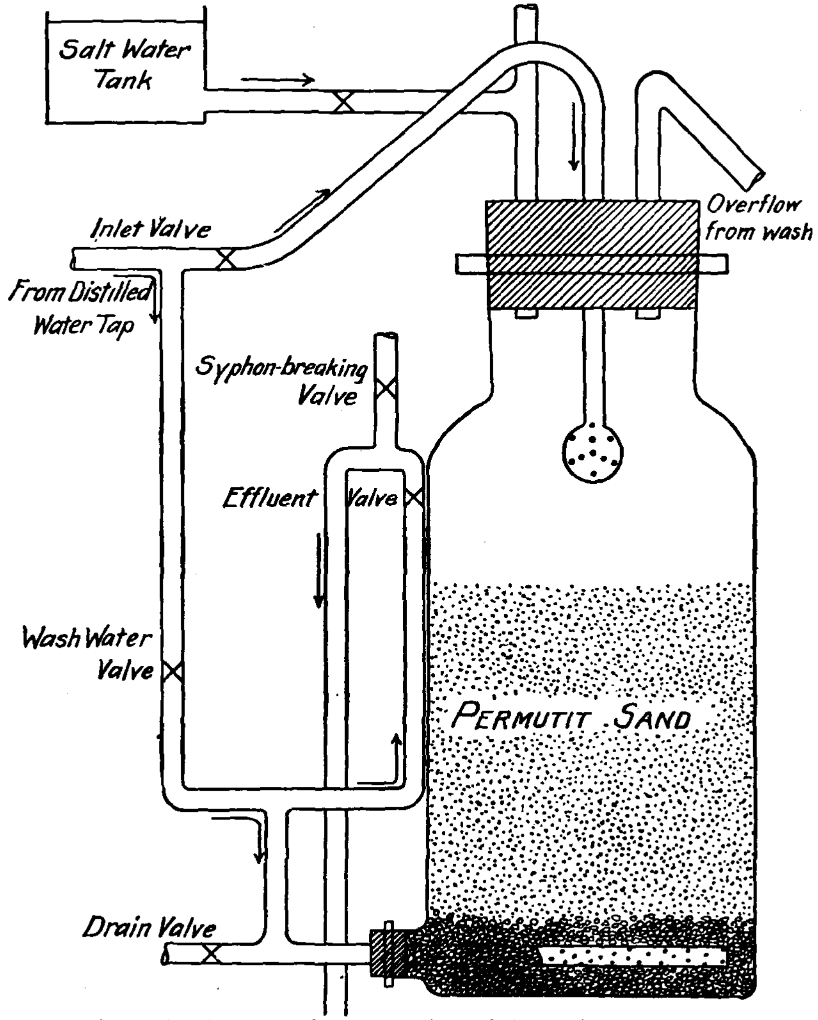

Figure 1.—Apparatus for Preparation of Ammonia Free Water.

passed through the permutit at as slow a rate as possible. This would indicate that there is also a mass relationship between the removal of the ammonia and the salts present in the water.

An analysis of a representative sample of the distilled water used in the preparation of ammonia free water showed a mineral content of 17 parts per million, largely sodium carbonate, (Na_2CO_3).

The permutit used in the preparation of ammonia free water has not deteriorated appreciably with use, and is as active as when first put in use two years ago. The permutit is, however, appreciably soluble and at times deposits are formed on the walls of the storage vessels. It is necessary to remove these deposits at intervals of two to three months as the deposits contain an appreciable amount of ammonium salts.

This method of preparing ammonia free water is applicable if distilled water is used. It has advantages over other methods of preparation in the ease of operation and production of large quantities at minimum expense. The disadvantages of the method are that it gives a water of higher mineral content and does not remove nitrate, nitrite or albuminoid nitrogen.

Investigations made thus far would indicate that the American permutit, except the prepared Folin permutit, will not quantitatively remove ammonia. German permutit has proven very satisfactory and indications are that the English permutit is equally efficient. There is a possibility that refinite and borromite may possess similar properties.

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EXPERIMENTS ON THE PRESERVATION OF MUD SAMPLES.

By Minna E. Jewell.

The following experiments were conducted to determine a suitable method for preserving mud samples for the determination of ammonia and total nitrogen.

In each case a mud sample was collected, thoroughly mixed and 80 grams weighed into each of several four-ounce, wide-mouth, glass-stoppered bottles. The first, last, and median bottles filled were set aside as controls and the preservatives added to the others. Two ten-gram samples were taken from each control for immediate analysis. Determinations were always run in duplicate.

After the first experiment, only ammonia determinations were run, as the total nitrogen was found to be less sensitive and to vary within the limits of the controls with all preservatives employed in subsequent experiments.

Experiments were also attempted using 5 cc. of 40 per cent formaldehyde to 80 grams of mud. These were not continued, however, as the formaldehyde distills over with the ammonia and quickly precipitates Nessler's reagent.

The samples for these experiments were obtained from the bone yard, a small creek flowing through Champaign and Urbana and the grounds of the University of Illinois, and from a drainage ditch, northeast of Urbana, which receives the sewage from the two cities.

A greater increase in ammonia is found in the higher concentrations of acid than in the lower ones, but in no case is the original ammonia content preserved. (See Table 1).

An improvement was found in the higher concentrations of sodium Benzoate over the lower concentrations suggesting that high enough concentrations were not employed. The addition of small amounts of H_2SO_4 which frees some Benzoic acid in the solution improved its preservation. (See Table 2).

Satisfactory preservation of the mud was obtained by a sufficient amount of the benzoic acid either with or without the addition of sulfuric acid. (See Table 3).

TABLE 1—RESULT OF EXPERIMENTS WITH MUD FROM DRAINAGE DITCH.

Preservative.		Immediate NH_3.		Analysis O. N.		4th day NH_3.		6th day O. N.		7th day NH_3.		12th day NH_3.	
Name.	Amt.	Reading.	Mgms.	cc acid.	Mgms.	Reading.	Mgms.	Per cent acid.	Mgms.	Reading.	Mgms.	Reading.	Mgms.
Control	------	2.0	.80	58.6	16.5	2.7	1.08	------	------	------	------	------	------
Control	------	2.0	.80	58.4	16.35	------	------	------	------	------	------	------	------
Control	------	2.1	.84	65.1	18.2	------	------	65.1	18.2	------	------	------	------
H_2SO_4	1 cc.	------	------	------	------	2.3	.92	59.1	16.5	2.3	.92	2.3	.92
	2 cc.	------	------	------	------	2.5	1.0	58.4	16.3	2.5	1.00	2.4	.98
	5 cc.	------	------	------	------	3.6	1.44	58.2	16.28	------	------	------	------
	10 cc.	------	------	------	------	3.8	1.52	46.7	13.1	------	------	------	------
HCl	1 cc.	------	------	------	------	2.7	1.08	54.8	15.3	2.4	.98	2.6	1.04
	2 cc.	------	------	------	------	2.7	1.08	62.3	17.4	------	------	------	------
	5 cc.	------	------	------	------	4.0	1.60	55.3	15.5	------	------	------	------
	10 cc.	------	------	------	------	4.5	1.80	52.3	14.7	------	------	------	------
$CHCl_3$	5 cc.	------	------	------	------	2.5	1.0	55.3	15.5	------	------	------	------

TABLE 2—EXPERIMENTS WITH MUD FROM BONE YARD—SERIES 1.

Preservative.		NH_3 immediate analysis.		NH_3 8th day.		NH_3 10th day.	
Name.	Amount.	Reading.	Mgms.	Reading.	Mgms.	Reading.	Mgms.
Control	----------	1.6	.64	2.4	.96	2.5	1.0
Na Benzoate	1gm	----------	----------	3.0	1.2	----------	----------
	2gm	----------	----------	3.0	1.2	----------	----------
	3gm	----------	----------	2.5	1.0	----------	----------
	4gm	----------	----------	2.0	.80	2.2	.88
Na Benzoate + .1cc H_2SO_4	1gm	----------	----------	2.5	1.0	----------	----------
	2gm	----------	----------	2.5	1.0	----------	----------
	3gm	----------	----------	1.6	.64	1.6	.64
	4gm	----------	----------	1.6	.64	1.7	.68
H_2SO_4	1 cc	----------	----------	2.3	.92	2.3	.92
	2 cc	----------	----------	1.6	.64	1.6	.64

TABLE 3—EXPERIMENTS WITH MUD FROM BONE YARD—SERIES 2.

Preservative.	Immediate. NH_3.		3 days.		8 days.		10 days.		14 days.	
	Reading.	Mgms.	Reading.	Mgms.	Reading.	Mgms.	Reading.	Mgms.	Reading.	Mgms.
Control	2.0	.80	2.5	1.0	3.0	1.2	3.0	1.2	3.0	1.2
5gms. Na. Benzoate	------	--------	2.2	.88	2.0	.80	2.0	.80	2.0	.80
5gms. Na Benzoate + .2cc H_2SO_4	------	--------	2.0	.80	2.0	.80	2.0	.80	2.0	.80
2cc H_2SO_4	------	--------	2.2	.88	2.3	.92	2.5	1.0	2.7	1.08

SOME ATYPICAL COLON-AEROGENES FORMS ISOLATED FROM NATURAL WATERS.*

By W. F. Monfort and M. C. Perry.

The 1917 edition of Standard Methods[16] presents a tentative scheme of work with certain inferences as to the source' of the bacilli of the colon group.

CLASSIFICATION OF B. COLI GROUP WITH REFERENCE TO SOURCE.

	Methyl Red.	Voges Pros-kauer.	Gelatin Lique-faction.	Adonite.	Indol.	Saccha-rose.
Fecal B. Coli...	+	—	—	—	+(—)	—(+)
Fecal Aerogenes	—	+	—	+	—(+)	+
Non-fecal do, probably	—	+	—	—	—(+)	+
B. Cloacae origin	—	+	+	+	—(+)	+

An attempt to bring cultures isolated from routine samples in the laboratory of the Illinois State Water Survey within this classification, reveals certain inadequacies of the scheme.

The correlation of the methyl-red reaction in the dextrose-dipotassium-acid-phosphate-peptone broth, with the Voges-Proskauer reaction, has been adjudged satisfactory by Levine,[9] Winslow and Cohen,[18] Rogers, Clark, and Lubs.[14] However Levine's[8] classification (1916) is characterized by the frequent occurrence of the term "usually" and the correlation between the methyl-red negative and Voges-Proskauer positive and between methyl-red positive and Voges-Proskauer negative is most uncertain.

Rogers, Clark and Lubs[14] found difficulty in recovering aerogenes in human feces; they report its isolation from stools of 3 persons out of 18; the 46 cultures recovered were adonite positive; but 17 low ratio cultures (12.98 per cent) proved adonite positive also. The latter fact is not to be reconciled with the above scheme of classification. Darling[3] 1919, studying feces of man and of animals, emphasizes the general conditions found by other investigators: viz., the absence of the relatively

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small number of B. aerogenes in feces, citing numerous references in confirmation of his finding: of 113 coli-like cultures isolated from feces of men and various animals, none were B. aerogenes. We have, however, determined the adonite reactions of all cultures.

Since indol reactions are characterized as "usually" positive (or negative), this can not be regarded as a discriminative character of this order. Saccharose fermentation is "usually negative" with fecal B. coli; but B. communior, according to the older discriminations, was saccharose positive, and the reactions of this sugar would be common to most of the organisms of the colon-aerogenes group. Indol was omitted from the general routine, and saccharose, save in special cases.

TABLE 1—COLON-AEROGENES VARIANTS.

Ref. No.	Lac.	Endo.	Lac.	Methyl-Red.		Ad.	Uric acid.	Spores.	Number of cultures in series.		
				0.50 per cent.	0.75 per cent.				1	2	Total.
1	+	+	—	—	—	—	+	—	16	--------	16
2	+	+	—	+	—	—	+	—	2	--------	2
3	+	+	+	—	—	—	+	—	19	6	25
4	+	+	+	—	—	—	+	+	1	--------	1
5	+	+	+	+	—	—	+	—	4	4	8
6	+	+	+	+	+	—	+	—	6	3	9
7	+	+	—	—	—	+	+	—	4	--------	4
8	+	+	+	—	—	+	+	—	27	6	33
9	+	+	+	+	—	+	+	—	11	5	16
10	+	+	+	+	+	+	+	—	16	14	30
11	+	+	+	+	+	+	—	—	15	5	20
12	+	+	+	+	—	+	—	—	3	--------	3
13	+	+	+	+	+	—	—	—	84	113	197
14	+	+	+	+	—	—	—	—	5	--------	5
15	+	+	+	+	+	—	—	+	1	--------	1
16	+	+	+	—	—	—	—	—	2	--------	2
17	+	+	—	+	+	—	—	—	8	2	10
18	+	+	?	+	+	—	—	+	2	--------	2
19	+	+	—	—	—	—	—	—	7	--------	7
									233	158	391

Koser[7] (1919), studying 74 strains of B. coli and 50 of B. aerogenes in a medium which contained no nitrogen except in the form of uric acid, showed no growth of the former while the latter grew well. Rettger and Chen[13] (1919), found this reaction satisfactory "with few exceptions among soil strains." This reaction was added to our routine. In the examination of routine samples 233 cultures were isolated which gave gas in lactose broth, characteristic colonies on Endo's medium and usually gas in lactose broth, after transferring from Endo's medium colonies. These cultures were tested as to their reactions with methyl-red broths (Difco peptone, 0.5 per cent and 0.75 per cent respectively) after two days, with adonite, and with uric acid broth. The cultures appear to fall in 19 groups. Table 1, Series 1, summarizes the results. Variety 8 is a typical fecal B. aerogenes; Variety 3 is a typical non-fecal B. aerogenes; Variety 13 is a typical fecal B. coli.

The remaining 16 varieties are intermediate forms which do not conform to the Standard Methods' classification, exhibiting various degrees of divergence in their reactions with the different media used.

A second series of 158 cultures were isolated from similar sources and subjected to rejuvenation whenever the cultures delayed their reaction with the media. Perhaps this rejuvenation, somewhat reduced the number of varieties, but it was impossible by ordinary means to convert them to typical forms. Table 1, Series 2, summarizes the results.

TABLE *2*—VARIETIES OF COLON-AEROGENES IN SAMPLES FROM ONE SOURCE.

Lab.	Lactose.	Endo Med.	Lactose.	Methyl-red Difco.		Adonite.	Uric Acid.	Spores.	Cultures grouped by reference numbers.								
				0.5 Per cent.	0.75 Per cent.				No. 3.	No. 5.	No. 8.	No. 9.	No. 10.	No. 11.	No. 13.	No. 17.	No. 19.
40696	+	+	+	−	−	+	+	−	----	----	1	----	----	----	----	----	----
	+	+	+	−	−	+	+	−	----	----	1	----	----	----	----	----	----
	+	+	+	−	−	−	+	−	1	----	----	----	----	----	----	----	----
40789	+	+	+	+	+	+	+	−	----	----	----	----	1	----	----	----	----
	+	+	+	+	+	+	−	−	----	----	----	----	----	1	----	----	----
	+	+	+	+	+	+	−	−	----	----	----	----	----	1	----	----	----
	+	+	+	+	+	+	−	−	----	----	----	----	----	1	----	----	----
	+	+	+	+	+	−	−	−	----	----	----	----	----	----	1	----	----
	+	+	+	+	+	−	−	−	----	----	----	----	----	----	1	----	----
40798	+	+	+	−	−	+	+	−	----	----	1	----	----	----	----	----	----
	+	+	+	−	−	−	+	−	1	----	----	----	----	----	----	----	----
	+	+	+	−	−	−	+	−	1	----	----	----	----	----	----	----	----
	+	+	+	+	−	+	+	−	----	----	----	1	----	----	----	----	----
	+	+	+	+	+	+	−	−	----	----	----	----	----	1	----	----	----
	+	+	+	+	+	−	−	−	----	----	----	----	----	----	1	----	----
	+	+	−	+	+	−	−	−	----	----	----	----	----	----	----	1	----
40854	+	+	+	−	−	+	+	−	----	----	1	----	----	----	----	----	----
	+	+	+	−	−	+	+	−	----	----	1	----	----	----	----	----	----
	+	+	+	−	−	−	+	−	1	----	----	----	----	----	----	----	----
	+	+	+	−	−	−	+	−	1	----	----	----	----	----	----	----	----
	+	+	+	+	+	−	−	−	----	----	----	----	----	----	1	----	----
	+	+	−	−	−	−	−	−	----	----	----	----	----	----	----	----	1
40890	+	+	+	−	−	+	+	−	----	----	1	----	----	----	----	----	----
	+	+	+	−	−	+	+	−	----	----	1	----	----	----	----	----	----
	+	+	+	−	−	+	+	−	----	----	1	----	----	----	----	----	----
	+	+	+	−	−	+	+	−	----	----	1	----	----	----	----	----	----
	+	+	+	−	−	−	+	−	1	----	----	----	----	----	----	----	----
	+	+	+	+	−	−	+	−	----	1	----	----	----	----	----	----	----
	+	+	+	+	+	+	−	−	----	----	----	----	----	1	----	----	----
40918	+	+	+	+	+	+	+	−	----	----	----	----	1	----	----	----	----
	+	+	+	+	+	−	−	−	----	----	----	----	----	----	1	----	----
	+	+	+	+	+	−	−	−	----	----	----	----	----	----	1	----	----
	+	+	+	+	+	−	−	−	----	----	----	----	----	----	1	----	----
	+	+	+	+	+	−	−	−	----	----	----	----	----	----	1	----	----
40952	+	+	+	+	−	−	+	−	----	1	----	----	----	----	----	----	----
	+	+	+	+	−	+	+	−	----	----	----	1	----	----	----	----	----
	+	+	+	+	+	+	−	−	----	----	----	----	----	1	----	----	----
	+	+	+	+	+	+	−	−	----	----	----	----	----	1	----	----	----
	+	+	+	+	+	−	−	−	----	----	----	----	----	----	1	----	----
40978	+	+	+	+	+	−	−	−	----	----	----	----	----	----	1	----	----
	+	+	−	+	+	−	−	−	----	----	----	----	----	----	----	1	----
41007	+	+	+	+	−	+	+	−	----	----	----	1	----	----	----	----	----
	+	+	+	+	+	−	−	−	----	----	----	----	----	----	1	----	----
	+	+	+	+	+	−	−	−	----	----	----	----	----	----	1	----	----
									6	2	9	3	2	7	12	2	1

It is apparent that the methyl-red reaction if taken as sufficient evidence of fecal B. coli, applies to a very large number of the colon-aerogenes group in the above data. A large number of methyl-red positive cultures gave only deferred fermentation of lactose, which is in line with the observations of Bronfenbenner and Davis[1] (1918). This deferred development has been observed by Hall and Ellef son[5] and ascribed to the inbibitive effect of gentian violet. It may have been attributable to the inhibitory effect of lactose itself, inasmuch as the concentration of lactose in the medium is one of the factors involved. (Bronfenbenner and Davis,[1] 1919).

Assuming that the reaction with uric acid is characteristic of organisms of the aerogenes type, there is an overlapping of this with the methyl-red positive reaction, characteristic of B. coli of fecal origin. The adonite reaction is likewise variable throughout both series.

Nine of these samples were from the same source, from wells in the same city, two being from the city supply, and the remaining seven samples from a single well. Table 2 shows the varieties isolated from each sample, the number of cultures found in each and the number of each variety. The varieties found in a single sample vary from 2 to 6; the total number of varieties in these samples were nine. (Table 2).

A number of additional reactions were determined on the variants of Series 2. (See Table 3). Their reactions with a number of sugars and alcohols commonly used in discriminating between organisms of the colon-aerogenes group, illustrate the fact that members of the same variety show considerable divergence in their ability to split certain sugars. If the reactions with gelatin, and with sugars and alcohols are regarded as a sufficient basis for subdivision of the varieties, the 19 varieties are to be increased by subdivisions. In the reactions with the various sugars both the standard 1 per cent and a 0.2 per cent sugar broth were used with identical results.

If the variants be arranged according to their reactions toward uric acid, adonite and methyl-red, they fall into three general groups. (Table 1).

1 to 6 Non-fecal aerogenes (uric acid +, adonite —) with varying methyl-red reactions.

7 to 10 Fecal aerogenes (uric acid +, adonite +) with varying methyl-red reactions.

11 to 18 Fecal B. coli (uric acid —, adonite —) with varying methyl-red reactions.

TABLE 3—PULL DATA, INCLUDING BOTH ORIGINAL REACTIONS, REPETITIONS OF METHYL-RED REACTIONS WITH VARYING PEPTONE CONCENTRATIONS, SUGAR AND ALCOHOL FERMENTATIONS, GELATIN LIQUEFACTION. (ATYPICAL FORMS IN SERIES TWO.)

Ref. No.	Laboratory number.	Lactose.	Endo's media.	Lactose.	Methyl-red reactions. Difco. Witte. Days 2, Per cent peptone 0.50	Days 2, 0.75	Days 2, 0.50	Days 2, 0.75	Days 5, 0.50	Days 5, 0.75	Days 2, 0.50	Days 2, 1.00	Days 5, 0.50	Days 5, 1.00	Days 2, 0.50	Days 2, 1.00	Days 5, 0.50	Days 5, 1.00	Adonite.	Uric acid.	Spores.	Dextrose.	Lactose.	Sucrose.	Raffinose.	Maltose.	Dulcite.	Mannite.	Adonite.	Starch.	Glycerine.	Gelatine.
4	40709-5	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	+	+	+	+	+	+	+	—	+	—	—	—	+
5a	41020-1	+	+	+	+	—	+	—	—	—	+	+	+	—	+	+	+	—	—	+	—	+	+	+	+	+	—	+	—	—	+	—
b	41100-3	+	+	+	+	—	+	—	+	—	+	+	+	+	+	—	+	—	—	+	—	+	+	—	+	+	—	+	—	—	+	—
6a	41012-B	+	+	+	+	+	+	+	+	—	+	+	+	—	+	+	+	—	—	+	—	+	+	—	—	+	+	+	—	—	+	—
a	41100-2	+	+	+	+	+	+	+	+	+	+	+	+	—	+	—	+	—	—	+	—	+	+	—	—	+	+	+	—	—	+	—
b	41087-A	+	+	+	+	+	+	+	+	+	+	+	+	—	+	+	+	—	—	+	—	+	+	+	+	+	+	+	—	—	+	—
9a	40972-1	+	+	+	+	—	+	+	—	—	—	—	—	—	—	—	—	—	+	+	—	+	+	+	+	+	+	+	+	—	+	—
b	41053-4	+	+	+	+	—	+	—	—	—	+	+	—	—	+	+	+	—	+	+	—	+	+	+	+	+	+	+	+	—	+	—
b	41048-B	+	+	+	+	—	+	—	+	—	+	+	+	+	+	+	+	+	+	+	—	+	+	+	+	+	+	+	+	—	+	—
b	41048-1	+	+	+	+	—	+	—	+	—	+	+	+	+	+	—	+	—	+	+	—	+	+	+	+	+	+	+	+	—	+	—
c	41007-5	+	+	+	+	—	+	—	—	—	—	—	—	—	+	—	—	—	+	+	—	+	+	+	+	+	—	+	+	—	+	—
10a	41072-1	+	+	+	+	+	+	+	—	—	+	+	+	+	+	+	+	—	+	+	—	+	+	+	—	+	—	+	+	—	+	—
b	41022-1	+	+	+	+	+	+	+	—	—	+	+	—	—	+	+	+	—	+	+	—	+	+	+	+	+	—	+	+	—	+	—
b	41032-1	+	+	+	+	+	+	+	—	—	+	+	—	—	+	—	+	—	+	+	—	+	+	+	+	+	—	+	+	—	+	—
b	41004-1	+	+	+	+	+	+	+	+	—	+	+	+	—	+	+	+	—	+	+	—	+	+	+	+	+	—	+	+	—	+	—
b	41020-5	+	+	+	+	+	+	+	+	—	+	+	+	+	+	+	+	—	+	+	—	+	+	+	+	+	—	+	+	—	+	—
b	41071-1	+	+	+	+	+	+	+	—	—	+	+	+	+	+	+	+	+	+	+	—	+	+	+	+	+	—	+	+	—	+	—
b	41077-A	+	+	+	+	+	+	+	+	+	+	+	—	—	+	—	+	—	+	+	—	+	+	+	+	+	—	+	+	—	+	—
b	41100-5	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	+	+	+	+	+	—	+	+	—	+	—
c	41004-A	+	+	+	+	+	+	+	+	—	+	+	—	—	+	+	+	+	+	+	—	+	+	+	+	+	—	+	+	—	+	+
d	41050-1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	+	+	—	+	+	+	+	+	+	+	+	—	—	—
d	41050-3	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	+	+	—	+	+	+	+	+	+	+	+	—	—	—
d	41050-4	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	+	+	—	+	+	+	+	+	+	+	+	—	—	—
d	41049-3	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	+	—	+	+	—	+	+	+	+	+	+	+	+	—	—	—
d	41049-4	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	+	+	—	+	+	+	+	+	+	+	+	—	—	—
11a	41013-1	+	+	+	+	+	+	+	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	+	+	+	—	+	+	—	+	—
b	41028-A	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	+	—	—	+	+	—	—	+	—	+	+	—	+	—
b	41034-2	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	+	—	—	+	+	—	—	+	—	+	+	—	+	—
c	41049-2	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	+	—	—	+	+	+	+	+	+	+	+	—	—	—
c	41050-2	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	+	—	—	+	+	+	+	+	+	+	+	—	—	—
15	40732-A	+	+	+	+	+	+	+	+	—	+	+	+	—	+	+	—	—	—	—	+	+	+	+	+	+	—	+	+	+	+	+
17	40978-1	+	+	—	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—	?	—
18a	40712-2	+	+	?	+	+	+	+	—	—	+	+	—	—	+	+	—	—	—	—	+	—	—	—	—	—	—	—	—	—	—	+
b	40853-A	+	+	?	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	+	—	—	—	—	—	—	—	—	—	—	+

The "non-fecal aerogenes" group (uric acid + adonite —) includes several varieties which show progressive increase in net acid production to the limit of B. coli, but vary considerably in their reactions with sugars. In Table 3 the first six cultures may be regarded as illustrating this variation: the references numbers at the left indicate 4, 5a, 5b, 6a and 6b as ranging from spore-formers to vegetative forms of varying cultural characters, which may be but variants of No. 3 (non-fecal aerogenes) in Tables 1 and 3.

In the so-called "fecal aerogenes" group (uric acid + adonite +) • fall several cultures which have been studied: 9a, 9b, 9c differ both in the rate of acid reversion in the methyl-red reaction and in their behavior with sugars. Similarly 10a, 10b, 10c, and 10d show characters common to both aerogenes and B. coli in their marked persistence of acidity up to pH 5.8.

The cultures marked 11a, 11b, and 11c failed to grow in uric acid broth, and while still adonite +, approach B. coli (No. 13). No. 15 is a spore-former, active in fermenting most of the sugars and alcohols used, and liquefying gelatine. The later cultures (18a and 18b) are spore-formers, liquefying gelatine, but sluggish or entirely lacking ability to ferment sugars.

The spore-forming organisms above listed are especially described in a paper shortly to appear in the American Journal of Public Health (Perry and Monfort,[12] 1921).

Our experience in attempting to reduce these various cultures to the hard and fast scheme of current classification repeats the results of Burton and Rettger[2] (1917), who found biometric methods inapplicable to gas formers of the colon-aerogenes group isolated from 1,000 samples of soil, sand, twigs, leaves, berries, etc., collected from sources for the most part unpolluted.

The methyl-red broth in use for routine work was 0.5 per cent Difco peptone with a 2-day incubation period. The methyl-red as originally recommended stipulates 0.5 per cent Witte peptone and an incubation period of 5 days. Hence it was thought worth while to check the reactions of the variants, using varying concentrations of Difco and of Witte's peptone for *2* and 5 day incubation periods. The results using the 1 per cent Difco peptone with a 2-day incubation period show complete agreement with 0.5 per cent Witte peptone for 5 days as prescribed by Standard Methods. In Table 3 the first two columns under "methyl-red reactions Difco" in 0.5 per cent and 0.75 per cent for two days show the original reaction at the time the cultures were isolated. The methyl-red reaction in 0.5 per cent, 0.75 per cent and 1 per cent Difco peptone, 0.5 per cent and 1 per cent Witte peptone for two and five-day periods was determined after the organisms had been cultivated on artificial media for several weeks. During this time some of the organisms had apparently undergone slight modification, showing a tendency to become more closely allied with either one or the other groups.

As with sugars, so with peptone-phosphate-dextrose broth there seems to be a high degree of irregularity. If the Koser uric acid broth be accepted as reliably discriminating B. aerogenes from B. coli, the methyl-red reaction of water-borne cultures with standard Witte or other peptones is rendered of doubtful value, even with prolonged (5-day) incubation.

Smirnow[15] (1916) studying the inhibition of cultural characters of some strains of B. coli by glucose and by phenol, by sodium chloride and by sodium sulfate, found that there was no well defined nor constant sequence of events either during the process of modification or reversion, and no relationship between the changes produced in the various enzymes; in a general way indol production is the first to disappear, then the fermentations of various carbohydrates, growth on potato, and finally acid production. When complete the change is more lasting, but there was always a strong tendency for the modified bacteria to return to their former biological activities. Occasionably complete reversion did hot take place, in which case the organisms remained permanently devoid of one or more characteristics.

Loehnis and Smith[10] (1916) discussing life cycles of bacteria, especially of B. azobacter, stated that a single species may pass through as many as 12 to 14 distinct morphological forms, varying from tiny filterable gonidia to large unorganized masses of synplasm formed by the fusion of smaller elements. Kellerman and Scales[6] (1916) in a preliminary report on the life cycle of B. coli, studied 12 strains from widely different sources, which were found to produce all the types described by Loehnis and Smith[10] except the spore-bearing forms. Meyer[11] (1918) and Ewing[4] (1919) have isolated a spore-forming B. coli. Sporeformers occurring in this investigation have already been described.

The list of varieties recorded here is probably incomplete. Voisenet[17] reports finding in bitter wine and in water, an organism which differs from B. coli in that it ferments glycerol with the formation of acrolein.

If these different varieties be considered as transition forms from the colon and aerogenes types, the difficulty of sanitary interpretation is very great. An organism which requires long rejuvenation to restore it to conventional reactions with sugar broths and various other media, is far removed from the typical fecal organism and can not be regarded as an indicator of dangerous pollution.

Considering the great variety of food stuffs taken into the alimentary tract, and the opportunity offered for change from the original character to approximately type forms, a conclusion as to what should be regarded as the essential indicator of pollution must take into account the wide variation of bacilli of the general colon-aerogenes group which occur in water; nor can it be stated that prolonged rejuvenation under conventional conditions will give fair results; rather it may tend toward the acquirement by organisms long away from fecal environment of characters not distinguishable from those of typical fecal inhabitants.

The right tendency should be toward the simplification of methods to determine with the least possible rejuvenation, the characteristics of the organisms present, rather than the present methods which tend toward this: that no characterization can be considered valid until the mean is determined around which the different strains vary. This means that if an organism can be brought by a series of reactions to eventually assume the characteristics of fecal B. coli or fecal B. aerogenes, the Bacillus so identified, after acquiring new characteristics should have attributed to it all these characters as originally present in a water supply.

Any of the lactose-fermenting organisms, 351 of the 391 under discussion, would be characterized as indicative of pollution according to the Treasury Department Standard if more than two were present per 100 cubic centimeters of water. Of these 351 only 231 are typical fecal organisms; the remaining 120 are modified forms which may or may not be associated with recent pollution.

The tendency of the past two years is toward hard and fast attempts to compel the water-borne members of the colon-aerogenes group to assume the characteristics of two or three types, which are themselves, factitious. Prom the systematisfs point of view this may be satisfactory. It is one thing to say these forms are of common remote origin, and a very different thing to say they (the existent, feebly reacting, yet convertible forms) are identical and of equal diagnostic importance, as showing recent pollution, with organisms freshly isolated from feces, which under fixed artificial conditions give certain reactions. The speed of the reaction is probably more important than the reactions themselves.

SUMMARY.

The study of 391 cultures isolated from various waters is reported in considerable detail without averages or percentages. The attempt to reduce the members of the colon-aerogenes group to four types (non-fecal and fecal aerogenes, cloacae, and B. coli) appears impossible with the cultures here reported. There are intermediate forms, of varying methyl-red reaction, furnishing transitions from one to the other type.

Difco peptone (1 per cent) with phosphate and dextrose, incubated for two days affords at least as fair an approximation to the discrimination of aerogenes from B. coli as does the 0.5 per cent Witte-phosphate-dextrose broth for 5 days of Standard Methods 1917. The methyl-red reaction of organisms requires further study and development before this can be regarded as a truly discriminative character. The methyl-red reaction, whether carried out with Standard Methods broth or with

1 per cent Difco broth, correlates but imperfectly with the Koser uric acid reaction, which seems to be discriminative of aerogenes.

The aerogenes characters (adonite — and adonite +) are of slight value as criteria of fecal and non-fecal types.

The sugar reactions of members of the larger group can be equally well tested with 0.2 per cent sugars as with 1 per cent sugars of the Standard Methods procedure. The widely varied reactions with sugars divide the group into numerous subdivisions, thus far admitting of no correlation with pollution.

The colon-aerogenes group probably comprises many spore-forming members other than the four reported here. It may be necessary to invoke the Loehnis hypothesis, supported by the work of Kellerman and Scales, to unite in one system such numerous departures from the current classification.

The purpose of sanitary bacteriology of water supplies is distinct from that of systematic bacteriology. Variations from types now accepted as indicative of fecal pollution are so manifold that further study of these variants prior to rejuvenation is essential to their correlation with known pollution.

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CHLORAMINE AND CRENOTHRIX.*

By W. F. Monfort and O. A. Barnes.

The application by Rideal of chloramine as a sterilizing agent for water and sewage has led to renewed interest in the reactions of chlorine with ammonium salts and with ammonia. Much earlier work has since been repeated in the hope of developing control of the reactions and preventions of losses. The fundamental work of Raschig has been commonly overlooked.

Chloramine (chloramine, monochloramine) is formed[4] by treating dilute solutions of hypochlorites with dilute ammonia, which Raschig expresses in the following equation, $NH_3 + NaOCl = NH_2Cl + NaOH$.

By subjecting such a mixture to distillation in a vacuum at about 40°, after adding $ZnCl_2$, solution to remove free ammonia and sodium hydroxide, there is obtained a concentrated solution whose analysis yields values agreeing with the formula NH_2Cl, From concentrated mixtures under greatly reduced pressure, chloramine is often Obtained as pale yellow globules floating in the aqueous distillate. Because of instability in concentrated form, no attempt was made to obtain it pure. Chloramine escapes readily from its aqueous solution, has the odor of nitrogen trichloride and vigorously attacks the eyes. (C. A. 2, 1533.)

With ammonia and sodium hypochlorite in equivalent amounts (in $^1/_3$ normal solution) there is some decomposition; liberation of nitrogen Or reversion to ammonia is hastened by the presence of hydorxyl ions.

If calcium hypochlorite in equivalent amounts be substituted for sodium hypochlorite the reaction may be thus understood:

$$2CaOCl_2 + 2NH_4OH = 2NH_2Cl + CaCL, + Ca(OH)_2$$

With strong solutions reacting there is here a tendency to produce nitrogen trichloride and nitrogen.

It is apparent that a solution of chloramine of only • relatively low concentration can be prepared; that if stronger solutions of bleach and of ammonia are used, the reaction must take place in the presence of considerable amounts of diluting water.

Experiments were undertaken to determine the stability of chloramine solutions of different strengths. There are two methods of determining the velocity of the reaction: (1) the content of chloramine remaining in the solution after the lapse of each period of test, and (2) the total volume of nitrogen evolved in a gas burette at the end of each period. The results of the experiments are given in Table 1.

* Read before the Illinois Section of Am. Water Works Association, March 25, 1919, J. Am. W. W. Assoc., 6, 196 (1919).

TABLE 1—DECREASE IN AVAILABLE CHLORINE OF A CHLORAMINE SOLUTION.

Hours.	Chlorine.	Nitrogen evolved from 50 cc. solution.	Hours.	Chlorine.	Nitrogen evolved from 50 cc. solution.
	p,p,m,	cc.		p,p,m,	cc.
0	1003.443	0	23	860.09	
1	1003.443	0	24	850.00	0.51
2	1003.443	0	25	850.84	
3	1003.443	0	26		0.63
4	984.68	0.01	28		0.69
5	980.86	0.05	29	841.28	
6		0.09	32		0.73
7	975.12	0.12	51	707.44	
8		0.15	54		1.6
8½	965.56		73	554.48	
10		0.17	76		2.5
11½		0.27	98	430.20	
17	889.08		101		3.25
19	879.52		145	296.36	
20		0.37	148		4.10
21	869.96		170	213.00	
22		0.44	173		4.50

The amount of nitrogen evolved is a function of the rate of disappearance of available chlorine, which finds expression in the equation:

$$3NH_2Cl = N_2 + NH_4Cl + 2HCl$$

A series of determinations was made of the rate of decomposition of chloramine solutions of different strengths, as given in Table 2.

TABLE 2—DECOMPOSITION OF CHLORAMINE SOLUTIONS.

Hours.	Series.	Available chlorine.		Hours.	Series.	Available chlorine.	
		Parts per million.	Loss.			Parts per million.	Loss.
0	1	10200	0	0	2	8160	0
1	1	7275	28.68	1	2	7388	9.46
2	1	6900	32.35	2	2	7013	14.06
3	1	6413	37.13	3	2	6619	18.88
7	1	4875	52.26	7	2	5438	33.36
11	1	3844	82.90	11	2	2194	45.76
24	1	1744	82.90	24	2	2194	73.11
32½	1	1125	88.97	32½	2	1819	77.71
53½	1	300	97.06	53½	2	469	93.03
0	3	6120	0	0	4	4080	0
1	3	5513	9.92	1	4	3750	8.09
2	3	5250	14.21	2	4	3638	10.83
3	3	4988	18.50	3	4	3516	13.82
7	3	4350	28.92	7	4	3169	22.33
11	3	3788	38.10	11	4	2897	29.00
24	3	2175	64.46	24	4	2016	50.59
32½	3	1538	74.87	32½	4	1603	60.71
53½	3	563	90.80	53½	4	863	78.85
0	5	3060	0	0	6	2040	0
1	5	2775	9.31	1	6	1875	8.09
2	5	2700	11.76	2	6	1844	9.61
3	5	2625	14.22	3	6	1813	11.13
7	5	2391	21.86	7	6	1706	16.37
11	5	2231	27.09	11	6	1638	19.71
24	5	1688	44.84	24	6	1350	33.82
32½	5	1397	54.35	32½	6	1194	41.47
53½	5	853	72.12	53½	6	863	57.69

The most concentrated solution used (10.2 grains available chlorine per liter, or 0.2877 normal) foamed vigorously at the start; the succeeding one less, and so through the several series, with the velocity of the decomposition diminishing in each case as the period of experiment was prolonged, as indicated both by the volume of gas evolved and the concentration of available chlorine. A precipitation of calcium hydroxide varied in the series of reactions from very heavy in the first to relatively slight in the last.

From these data it is apparent why the application of chloramine should be made under such conditions that the concentration of the mixed reagents shall not exceed 1 ppm. A solution even of this low concentration should not be stored longer than' twenty-four hours and is best made up as used. Not only do hydroxyl ions in solutions prepared from bleach and ammonia reduce the stability of chloramine; their reactions with bicarbonate ions in the treated water convert the latter to bivalent carbonate ions, and cause a copious precipitation of calcium carbonate.

$$\overline{OH} + H\overline{CO_3} = H_2O + \overline{\overline{CO_3}}$$

This has resulted in incrustation of feed pipes and of lines carrying the treated water from the point of applying chloramine.

Some experiments were carried on in preparing chloramine with dilute chlorine water and dilute ammonium compounds, NH_4OH, $(NH_4)_2$, CO_3, etc., with varying results. While it is theoretically possible that some chloramine might be formed under these conditions, the diverse possibilities of reaction, indicated by Bray and Dowell[2] offer little hope that direct addition of ammonia and liquid chlorine to a water can be so controlled and the distribution of the sterilizing agent be made so efficient as to insure the full chlorine equivalent in chloramine.

Rideal[5] found that when chlorine was introduced into sewage it was rapidly consumed, but that after free chlorine had entirely disappeared there persisted a strong germicidal power. The same results were obtained when bleaching powder was added to a water containing a small amount of ammonia. It seemed probable that the ammonia did not increase the oxidizing power of chlorine, since readily oxidizable organic matter in water absorbed much less chlorine from ammonia and hypochlorite than from hypochlorite alone. Furthermore the bleaching effect on dyestuffs indicated that ammonia and bleach together had only 2 per cent of the oxidizing (bleaching) power of hypochlorite alone. While chloramine has little oxidizing value it is still able to displace iodine from potassium iodide, giving the usual starch-iodide reaction; its chlorine can be precipitated by silver nitrate, and its ammonia equivalent determined with the strongly alkaline Nessler's reagent. Rideal showed that chloramine has a phenol coefficient of 6.6, three times that of chlorine.

According to Dakin[3] the germicidal value of hypochlorite in sewage is due to chloramine derivatives produced by the action of chlorine on amino acids and proteins. The proteins present in sewage contain amino groups which may react with chlorine to form substituted chloramines containing the NCl group. When chlorine or bleaching powder is added to sewage, there may occur'a primary oxidation and a secondary formation of toxic chloramines from the reaction of aminobodies. When chloramine is added to sewage the initial rapid oxidation is eliminated, and the germicidal action begins at once. Dakin attributes the latter action to the chloramine group.

It is possible that proteins of living cells may so react, and that the killing of microorganisms by hypochlorites is due to chemical changes of this character within the living cell, either by direct action of the germicide or by secondary products of similar nature.

Action of Chloramine on Crenothrix. The pronounced success of chloramine treatment in the destruction of vegetative bacterial cells suggested its application to an especially troublesome water pest. Crenothrix is one of the iron bacteria, so called, because of their occurrence in iron-bearing waters. It belongs with the true bacteria (eubacteria). Its cylindrical cells are united in unbranched threads, enlarged toward the free end, covered with a thick sheath which becomes infiltrated with ferric hydroxide. Reproduction takes place by the division of the cells in three planes, with the formation of round gonidia. It is still in dispute whether the organism receives its energy from oxidation of ferrous to ferric iron[6] or whether the separation of ferric hydroxide is an independent mechanical phenomenon not connected with the life processes of the cell.

It occurs in numerous sections of the State of Illinois in surface waters and in some well supplies, as at Freeport and Champaign-Urbana. In 1917 the latter supply was rendered unsightly and unfit for some domestic purposes by the development and decay of the organisms in the distribution system.

In carrying on the experiments upon the action of chloramine on crenothrix it was impossible to plate the treated water on media, as is done with ordinary water bacteria, since no medium had been discovered upon which it can be surely grown.

Chloramine was first tried on water from the University well, which furnishes an iron-bearing water already inoculated with crenothrix. The first tests demonstrated in duplicate 800 cc. samples the germicidal action of 1 ppm. available chlorine in freshly prepared chloramine. At the end of a week there was no growth in the treated samples, while control samples, untreated, showed an abundant reddish growth on the bottom.

In later series 11-liter samples were used: one set with chloramine in amounts equivalent to 0.5, 0.75 and 1 ppm.; a second with bleaching powder equivalent to 1 ppm. available chlorine. Control samples stored without treatment showed an abundant growth at the end of one week. At the end of three weeks water treated with bleach alone showed a velvet growth, identified as crenothrix by microscopical examination. Samples treated with 1, 0.75, and 0.5 ppm. of available chlorine in chloramine gave no growth at this time nor within six months thereafter. The odor in the last mentioned samples was pleasant, noticeably better than that of untreated or bleach-treated samples; nor was there at any time a noticeable taste, save in those which had received the largest application of chloramine (1 ppm.), in which there was a slight flavor as of chloramine. In the controls and in the bleach-treated waters, the taste and odor were offensive.

These tests were repeated with similar results. A chloramine addition corresponding to 0.5 ppm. was effective in preventing development of crenothrix, the residual matter did not become offensive even after prolonged storage.

These results, gotten in a small way, indicated that the acute troubles arising from crenothrix in iron-bearing waters may be eliminated by the germicidal action of chloramine, thus reducing the problem of treatment to one of iron removal without complications. It was intended to apply the experiment in a large way at the 2,000,000-gallon plant of the Champaign-Urbana Water Company immediately after the conclusion of the first experiments. There was at the time (January, 1918) difficulty in commanding a supply of ammonia and of reliable bleaching powder. The method substituted, the use of liquid chlorine, is described by Amsbary.[1]

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SOME SPORE-BEARING COLON-AEROGENES FORMS ISOLATED FROM WATERS.*

By Margaret C. Perry and W. F. Monfort.

Meyer,[6] in 1918, reported a spore-bearing aerobe isolated from waters at, and in the vicinity of Newport, Ky. The same form has since been reported by Ewing[2] as occurring in the water supply of Baltimore.

In the course of routine examinations of waters from various Illinois sources we have found on several different occasions spore-bearing forms more or less closely related to the colon-aerogenes group. They were usually found in shallow wells of questionable surroundings, but which were free from typical B. coli. Their behavior in lactose broth and on Endo's medium do not serve to distinguish them from the ordinary forms. In two cases the fermentation of lactose after transfer from Endo's medium was very slow, which suggests that the original rapid gas formation might have been due to symbiotic action. Their sanitary significance remains to be established, but they are interesting as suggesting anew the fallacy of presumptive tests.

ISOLATION OF CULTURES.

It has been the custom in this laboratory to streak Endo plates from all lactose tubes showing positive gas formation, confirming positive colonies by transfer from Endo to lactose broth, methyl-red medium, and agar slants. Stains are made from the agar slant cultures to determine the presence or absence of spores and also whether or not a pure culture is obtained.

Five cultures were obtained from five different sources, all gave gas in lactose broth, typical colonies on Endo plates, and gas in lactose on transfer from the Endo plates; three of the cultures, 40712-2, 40732-A, and 40853-A, gave a positive methyl-red test and should, therefore, be B. coli; two 40709-5 + 41974-3 gave negative tests in the methyl red broth and, according to the Standard Methods[9] 1917 classification, were B. aerogenes. Stains of 48-hour cultures by Gram's method showed that all were gram negative; 40709-5 and 41974-3 were slender rods with central spores, 40732-A, 40712-2, and 40853-A were short plump rods with central spores and grew in long chains.

* Read at Meeting of Am. Pub. Health Assn., New Orleans, Sept, 1919.

RESISTANCE TO HEAT.

Cultures 41974-3 and 40709-5 lived and formed gas after being subjected to a temperature of 95° C. for twenty minutes, 41974-3 formed gas after being subjected to the temperature of boiling water for 10 minutes, but was killed when exposed to this temperature for 15 minutes. 40709-5 was killed only after exposure to the latter temperature for 30 minutes. 40853-A, 40712-2, and 40732-A did not form gas after heating to 95° C. for 20 minutes, but were not killed even after exposure to the temperature of boiling water for one hour.

For these tests 72-hour cultures were used, standard lactose broth tubes were placed in a water bath and brought to the desired temperature and regulated to within 1° C. for the entire time; 0.1 cc. of a light suspension, in lactose broth from agar slants, was added and the time noted. At stated intervals, two tubes for each culture were withdrawn, and cooled quickly. The tubes were examined after 72 hours incubation at 37° C, gas formation recorded, and, in case of no gas formation, agar streaks were made to determine the presence of living organisms.

MORPHOLOGY OF CULTURES.

Stains made from smears at the end of 24 hours showed chiefly vegetative cells for each culture, short plump rods with rounded ends for 40732-A, 40712-2, and 40853-A and slender rods with rounded ends for 40709-5 and 41974-3; at the end of 48 hours spore-bearing forms predominated in all five cultures; and at the end of 72 hours all stained cultures showed a predominance of free spores. The organisms were all non-motile and no chromogenesis was noted for any of the organisms on any of the media used.

APPEARANCE AND REACTIONS IN VARIOUS MEDIA.

Culture No. 40709-5 was methyl-red negative, adonite negative, uric acid positive; the organism was in so far identical with the so-called non-fecal aerogenes of the tentative classification of Standard Methods 1917. It fermented with acid formation, dextrose, lactose, saccharose, raffinose, levulose, maltose, and mannite; did not ferment dulcite, adonite, glycerol, starch or inulin, litmus milk was rendered acid and curdled. There was a moist heavy echinulate growth along the entire line of inoculation of the agar slant, also growth along the entire line of inoculation of the agar stab. A gelatin stab showed slight liquefaction at the end of 48 hours; liquefaction was stratiform. On gelatin plates the colonies were small and round, showing slight liquefaction at the end of 48 hours; at the end of 72 hours there was decided liquefaction, the colonies were round and the edges smooth. On agar plates the colonies presented a typical curled structures; on Endo, at the end of 24 hours **the colonies** were round, smooth edged, red and had some sheen; at the end of 48 hours the color of the colonies had begun to fade. In 0.1 per cent peptone to which 0.02 per cent $NaNO_3$ had been added, incubated for four days at 37° C. the nitrate was reduced with the production of nitrite. No indol was detected; 1 per cent Witte peptone with a four-day incubation period at 37° C. was used. For determining the limiting hydrogen ion concentration Clark's glucose-peptone-phosphate medium was used after adjusting it with NaOH and HC1 to the desired hydrogen-ion concentration. There was growth but no gas production at a pH 4. There was both gas formation and growth from pH 5 —pH 9.8 inclusive although the growth at pH 9.8 was very scant.

Culture No. 41974-3 was methyl-red negative, adonite negative, uric acid positive. It fermented with acid formation glucose, levulose, raffinose, maltose, sucrose, lactose, inulin, starch, glycerol, and mannite. There was neither acid nor gas and very little growth in both dulcite and adonite. There was a very light veiled growth on an agar slant, but growth along the entire line of inoculation of the agar stab. Liquefaction had begun at the end of 48 hours on the gelatine stab; at the end of 72 hours there was liquefaction along the entire line of inoculation, the liquefaction was greater at the top giving the appearance of an inverted cone. On gelatine plates the colonies were small and round, there was incipient liquefaction at the end of 48 hours; at the end of 72 hours liquefaction, colonies round, edges regular. A thin smooth colony was formed on agar plates. On Endo the colonies were pink at the end of 24 hours, and at the end of 48 hours the colonies were red, had an irregular contour, and possessed- a typical sheen, there was also some sheen in the surrounding medium. There was no reduction of nitrates to nitrites and no indol was formed. There was neither growth nor gas formation in Clark's glucose-peptone-phosphate medium (pH 4); there was both growth and gas formation from pH 5 —pH 9.8 inclusive, although the growth at 9.8 was very scanty.

From a 35-foot well was isolated an organism, Culture No. 40732-A, which gave brassy colonies on Endo; was methyl-red positive, uric acid negative; it fermented with acid formation, dextrose, lactose, saccharose, raffinose, levulose, maltose, mannite, glycerol and starch. Dulcite and inulin were not fermented. Litmus milk became acid with curdling. Both agar slant and stab showed a comparatively heavy growth along the entire line of inoculation. Liquefaction of a gelatine stab had begun at the end of 48 hours, the liquefaction was stratiform. The colonies on gelatine resembled those of 40709-5. An amoeboid-like colony was formed on the standard agar plate. Nitrates were reduced with the formation of nitrites but there was no indol produced.

Culture No. 40712-2 was isolated from a 35-foot well. It was methyl-red positive, uric acid negative, fermented none of the sugars listed above within 48 hours; lactose was fermented in three days; it formed acid with dextrose, maltose, and glycerol. Litmus milk was made acid and coagulated. There was growth along the entire line of inoculation on an agar slant and the edges were smooth, there was typical aborescent growth along the line of inoculation of an agar stab, liquefaction of the gelatin stab had begun at the end of 24 hours, liquefaction was stratiform. It presented a typical amoeboid growth on an agar plate, on gelatine plates the colonies were small and round, showing incipient liquefaction at the end of 48 hours. On Endo's medium the colonies were large and irregular in shape, possessing a deep pink color with but little sheen, at the end of 48 hours the color had faded to a lighter pink and the colonies were dry. Nitrates were reduced with the production of nitrites; there was no indol formed.

Culture No. 40853-A was isolated from a 23-foot well. It differed from No. 40712-2 in that it gave no apparent action with litmus milk, although it formed acid with dextrose, saccharose, and maltose, but not with glycerol. The growth on agar stab, slant, and plate, gelatin stab and plate, and on Endo's medium resembled that of No. 40712-2. In their slow fermentation of lactose the last two organisms were like the culture described by Bronfenbenner and Davis[1] (1918), and by Voisenet[10] (1918).

The place of these organisms in the system of bacteriology is undetermined. Save for their spore-forming tendency 40712-2, 40732-A, and 40853-A are closely allied to B. coli typical, of fecal origin; and 40709-5 and 41974-3 are of the type "non-fecal" B. aerogenes of Standard Methods 1917.

Revis[7] (1911) considered atypical forms of "coli" not as degenerate forms, but as stages in the variation of organisms belonging to the colon-typhoid group. Varieties which occur he considered as determined by our media and their concomitants.

Loehnis and Smith[5] (1916) presented evidence that bacteria of a single species may pass through as many as twelve to fourteen distinct morphological forms. This work, done principally on B. azobacter, was confirmed with respect to B. coli by Kellerman and Sales[4] (1917) who studied twelve strains of B. coli from widely different sources, and found them "to produce all the types described by Loehnis and Smith except the spore-bearing forms."

Scales[8] (1917) confirmed the occurrence of several forms, according to the medium they were on and the incubation temperature. , Whether the formation of spores by members of the colon-aerogenes group is a function of the hydrogen ion concentration, of temperature and of nutrition, as has been shown for B. subtilis by Itano and Neill[3] (1919) is a question which remains for solution.

The suggestion lies near at hand that organisms of original sources outside the alimentary tract of warm-blooded animals may lose their habit of spore-formation when brought into environment favorable to vegetative growth, and conversely, the type forms which have been described from cultures derived from the alimentary tract may revert to their former atypical behavior when environment becomes unfavorable to the extent that resistant (spore) forms alone can persist for long.

It is inconceivable that the occurrences here reported and those of Meyer[6] and of Ewing[2] above referred to, are isolated phenomena, not to be paralleled or repeated under similar conditions. Bather we are to expect a still larger number of occurrences to follow when attention is directed to the few instances already known.

COMPARISON OF AEROBIC LACTOSE FERMENTING SPORE-FORMERS.

	Meyer's culture.	41974-3	40709-5	40732-A	40712-2	40853-A
Routine Examination—						
Lactose broth	+	+	+	+	+	+
Endo's medium	+	+	+	+	+	+
Lactose broth	+	+	+	+	+	+
Methyl-red reaction	—	—	—	+	+	+
Adonite	----------	—	—	—	—	—
Uric acid broth	----------	—	—	—	—	—
Spore-formation	+	+	+	+	+	+
Gas formation—						
Dextrose	+	+	+	+	slow	slow
Lactose	+	+	+	+	slow	slow
Saccharose	+	+	+	+	—	—
Raffinose	+	+	+	+	—	—
Levulose	+	+	+	+	—	—
Maltose	+	+	+	+	—	—
Dulcite	—	—	—	—	—	—
Mannite	+	+	+	+	—	—
Adonite	----------	—	—	+?	—	—
Glycerol	+	+	—	+	—	—
Starch	+	+	—	+	—	—
Inulin	+	+	—	—	—	—
Acid formation—						
Dextrose	+	+	+	+	+	+
Lactose	+	+	+	+?	—	—
Saccharose	+	+	+	+	—	+
Raffinose	+	+	—	—	—	—
Levulose	+	+	+	+	—	—
Maltose	+	+	+	+	+	+
Dulcite	—	—	—	—	—	—
Mannite	+	+	+	+	—	—
Adonite	----------	—	—	—	—	—
Glycerol	+	+	—	+	+	—
Starch	+	+	—	—	—	—
Inulin	+	+	—	—	—	—
Milk—						
Acid	+	+	+	+	+	—
Curdled	+	+	+	+	+	—
Gelatin liquefied	+	+	+	+	+	+
Indol	—	—	—	—	—	—
Nitrates reduced	—	—	+	+	+	+
Gram Stain	—	—	—	—	—	—
Morphology—	Slender rods with small central spores.		Short plump rods, in long chains, with large round central spores.			

COMPARISON OF AEROBIC LACTOSE-FERMENTING SPORE-FORMERS —Continued.

Resistence to heat.	Meyer's culture.		41974-3		40709-5		40732-A		40712-2		40853-A	
	G	L	G	L	G	L	G	L	G	L	G	L
95°C 20 min.	+	+	+	+	+	+	—	+	—	+	—	+
Temperature of boiling water 10 min.	±	±	—	±	—	+	—	+	—	+	—	+
15 min.	—	—	—	—	—	+	—	+	—	+	—	+
20 min.	------	------	------	------	------	+	—	+	—	+	—	+
25 min.	------	------	------	------	------	+	—	+	—	+	—	+
30 min.	------	------	------	------	------	—	—	+	—	+	—	+
35 min.	------	------	------	------	------	—	—	+	—	+	—	+
40 min.	------	------	------	------	------	------	—	+	—	+	—	+
45 min.	------	------	------	------	------	------	—	+	—	+	—	+
50 min.	------	------	------	------	------	------	—	+	—	+	—	+
55 min.	------	------	------	------	------	------	—	+	—	+	—	+
60 min.	------	------	------	------	------	------	—	+	—	+	—	+
Limiting hydrogen Ion Concentration.	G	L	G	L	G	L	G	L	G	L	G	L
pH 4	------	------	—	—	—	+	—	+	—	+	—	+
pH 5	+	+	+?	+	+	+	—	+	—	+	—	+
pH 7	+	+	+	+	+	+	—	+	—	+	—	+
pH 9	+ sl	+ sl	+	+	+	+	—	+	—	+	—	+
pH 9.8	------	------	+?	+ sl	+	+	—	+	—	+	—	+

NOTE.—G=Gas formation.
L=Living organisms as determined by streaking from broth culture or agar slant.
sl=Slight reaction.

SUMMARY.

From five different sources cultures are described which are in all respects allied with the colon-aerogenes group, save that they are spore-bearing.

Of these, three are methyl-red positive, uric acid negative, and in so far typical fecal B. coli according to the tentative classification of Standard Methods,[9] 1917. Two are methyl-red negative, uric acid positive, adonite negative, and belong to the non-fecal type of the same scheme.

Their behavior with respect to various sugars, to glueose-peptone-phosphate medium of divers hydrogen ion concentrations, to heat variations, to litmus milk, gelatin, formation of indol, and reduction of nitrates with formation of nitrtites are recorded in the accompanying tables.

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THE QUALITY OF WATER IN THE SANGAMON RIVER.

By Minna E. Jewell.

INTRODUCTION.

A survey of the Sangamon River with special reference to the region between Decatur and Springfield was made from August 8, 1918, to September 3, 1919. The purpose of this investigation was three fold: (1) to determine by chemical analysis, the condition of the water at various distances below the source of pollution and under various conditions of temperature and water level; (2) to make a biological survey of the region studied in order to determine the effect upon animal life of the pollution of the river; (3) to correlate, so far as possible the distribution of species found with the chemical condition of the water, as shown by the sanitary analysis.

The Sangamon River, an important tributary of the Illinois, rises in McLean County, flows in a southwesterly direction to Decatur, from there almost due west to Springfield and thence northwest discharging into the Illinois River south of Havana. Although, the Sangamon may attain at flood times a width of a mile, the river above its junction with the South Fork some 100 miles (by river) below Decatur, is normally a small stream consisting of alternate pools from three to ten feet deep and riffles a few inches in depth. The water reaches Decatur in a relatively normal unpolluted condition and provides the public water supply of that town. As the water consumption of Decatur is greater than the flow of the river at low water, there are several weeks each summer, and a few weeks in a dry winter; when no water whatever passes the Decatur Dam. This means that at such times the entire flow in the river below Decatur is crude undiluted sewage, while, excepting at times of high water, the dilution is grossly inadequate. As the Sangamon receives no important tributaries for at least 100 miles (by river), the changes which take place progressively between Decatur and the junction of the South Fork are primarily due to the decomposition of sewage.

A biological survey was made on the river above Decatur, in order to ascertain the normal inhabitants of the stream and their abundance. The region between Decatur and Springfield was traversed by boat, specimens being identified in the field and then preserved for further study in the laboratory. Plankton samples were condensed by straining through a No. 20 Millers Bolting Cloth Filter.

During the summer of 1918 the only chemical determinations made were of dissolved oxygen, alkalinity, and hydrogen ion concentration (pH). These determinations were made in the field at the same time as the biological survey. Later on it seemed desirable to run a more complete sanitary analysis of the water and make a study of the mud deposits of the bottom. Through the courtesy of Mr. W. J. Spaulding, commissioner of Public Property, of Springfield, a temporary laboratory was equipped in the city hall at Springfield so that it was possible often to begin the analysis of samples within an hour of the time of their collection and before they had undergone any appreciable change in temperature, thus avoiding the great changes especially in free ammonia content, which are known to occur in a water allowed to stand, even for a few hours, after collection. During the summer of 1919 water samples were returned to the laboratory at Champaign, preserved by the addition of 2 cc. Conc. H_2SO_4 per liter, it having been determined that such preservation destroys all bacteria and holds the free ammonia, organic nitrogen and nitrate apparently unchanged. Mud samples, when returned to Champaign for analysis, were preserved by the addition of 6 grams sodium benzoate and 0.3 cc. Conc. H_2SO_4 per 100 grams of mud. In computing the dry weight and organic content (loss. on incineration) of such muds, correction was made for the sodium benzoate added. Experiments showed this method of preservation to be satisfactory. For determining the ammonia content of a mud sample 250 cc. ammonia free water was added to 10 grams of mud in a Kjeldahl flask. The solution was made alkaline by the addition of Na_2CO_3 and the ammonia distilled off as in water analysis 200 cc. of the distillate was collected and the ammonia determined by nesslerizing an aliquot part.

THE RIVER ABOVE DECATUR.

The Sangamon River was studied at three points above Decatur, Mahomet, Monticello and Fairies Park, on August 1 to 3, inclusive, 1918. At Mahomet the river had a width of 25 to 40 feet and a flow of about 16.8 cubic feet per second. Riffles 6 to 8 inches deep alternated with ponds three to eight feet in depth. In the former the bottom was of pebbles, coarse gravel and mollusk shells; in the latter the gravel was frequently covered to a depth of several inches by a deposit of fine sand, soil and decaying leaves.

The water which had an alkalinity to methyl orange of 222 ppm. and pH of 8 was of a greenish hue, due to the presence of phyto-plankton, and transparent to a depth of a foot or more. A typical square yard of bottom from a riffle was estimated to contain the following animals: Snails, Pleurocera elevatum 40; Clams, various species 3; Insect larvae, Chironomid larvae 40; Ephemerid nymphs (heptagenia) 30; Coleopterous larvae 10.

Closer to shore where a layer of organic deposit covered the gravel the number of Pleurocers per square yard might rise locally to as high as 350. Cray fish *Cambarus propinquus,* were also abundant in such situations. The pools were characterized by the number of burrowing Mayfly nymphs, (Hexagenia) which literally honey-combed the margins, and the abundance of clams (Uninidae) of the following species:

Lampsilis luteola	Tritigonia tuberculata
Quadrula pustulosa	Symphynota costata
Quadrula undulata	Strophitus edentulus
Quadrula rubiginosa	Anadonta grandis

Sphaeriidae were common and a few specimens of the large snail Campeloma subsolidum were found.

Numerous fish 12 to 16 inches long could be seen swimming a short distance below the surface. One buffalo (16 inches) ; one carp (14 inches); and three channel cat (4 to 5 inches) were taken during the afternoon. The river here is said to have been stocked with small fish some two years ago, and minnows, carp, cat, sunfish, suckers, bass, buffalo, and. crappie are said to abound in the order named.

Except for an increase in volume the river at Monticello and Fairies Park is essentially the same as at Mahomet. The same species were found in practically the same abundance. Although the sewage of Monticello is discharged into the river after preliminary treatment in a septic tank, the effect is purely local, disappearing entirely within three quarters of a mile.

DECATUR TO SPRINGFIELD.

The biological survey of this area was made by boat or canoe supplemented by a few railway trips to points where further examination was desired. The region between Decatur and Smith's Mill was studied October 4 to 14, 1913.

This trip was taken near the close of a long comparatively dry autumn so that sufficient time had elapsed since the early summer rains to allow typical low water conditions to extend down stream throughout the area studied. At the time of starting, October 4, the small amount of water passing the Decatur dam provided scarcely a 1 to 1 dilution for the sewage discharged about 100 yards below.

The remainder of the distance, Smith's Mill to Springfield, was covered August 20 to 22, 1919. At this time the river had very recently returned to its banks after a spring of heavy rains and floods. Although the marginal willows were no longer inundated and sand bars were beginning to appear, low water conditions were not yet attained. No attempt was made to estimate the dilution of the sewage below Decatur; however, it was observed that a considerable stream of water was flowing over the dam. A comparison of determination of dissolved oxygen made at Frye Bridge, October 14, 1918, with the determination made above the dam at Smith's Mill (just a few miles below) August 20, 1919, also shows that the water was in a much worse condition at the former time. The only respect in which these two trips may be regarded as continuous is in the examination of bottom animals (clams, snails, worms, etc.). These, being unable to migrate either into or out of a given situation, as conditions become favorable or unfavorable, would occur in the same places in the summer of 1919, as they had in the fall of 1918. Thus at whatever time of year a study is made, animals of this type, by their presence or absence, furnish an approximate idea of the least favorable condition to which the locality is subject.

The data of the biological survey are given in Table 1.

TABLE 1—RESULTS OF A BIOLOGICAL SURVEY OF THE SANGAMON.

Date.	Oct. 4, 1918.	Oct. 5, 1918.	Oct. 6, 1918.	Oct. 7, 1918.	Oct. 8, 1918.
Location.	1 mile below Decatur.	6 miles below Decatur.	Scroggins Bridge south of Harristown.	South of Niantic.	Niantic Bridge.
Estimated distance below Decatur by river	1 mile	6 miles	20 miles	30 miles	.35 miles
Depth	6 feet	2½ feet	3 feet	3 feet	2 feet
T. C.	18°	18°	18°	16.5°	15°
D. O. ppm	Trace	0	0	0	Trace
per cent saturation	----------	0	0	0	
Alkalinity ppm.	300	260	348	286	286
pH	7	7	7.7	7.7	7.6
Appearance	Sewage	Inky	inky but opaque	dark slaty	dark slaty
Odor	Sewage	Putrid	Septic	Septic	Septic
Biota A: Of bottom		heavy festoons of whitish grey moulds	mouldy slimes on bottom Oscillaria along shore	moulds (unidentified) Sphaerotalis natans Tubificid worms (appearing)	moulds Sphaerotalis natans Tubificid worms

TABLE 1—Continued.

Date.	Oct. 8, 1918.	Oct. 11, 1918.	Oct. 12, 1918.	Oct. 13, 1918.
Location.	4 miles below Decatur.	Bridge south of Illiopolis.	3 miles below Illiopolis.	West of Mt. Auburn 1 mile below Mosquito Creek.
Estimated distance below Decatur by river	39 miles	50 miles	53 miles	60 miles
Depth	1 foot	1 foot	3 feet	3 feet
T. C	16.6°	15.7°	17°	16°
D. O. ppm	Trace	0.3	0.2	0
per cent saturation		3.0	2.0	0
Alkalinity ppm	320	300	310	300
pH	7.6	7.8	7.9	7.9
Appearance	dark slaty	milky	gray, turbid	gray, turbid
Odor	Septic	less pronounced	disagreeable	not pronounced
A: of bottom	Sphaerotalis natans Tubificid worms Oscillaria (along shore)	Tubificid worms Chironomid larvae	Tubificid worms Chironomid larvae 1 crayfish near shore	Tubificid worms Chironomid larvae Cambarus immunis (crayfish) 1 dead Buffalo fish 1 minnow apparently dying several small Bullheads gulping at surface probably washed in from the creek
B. Plankton	Nematode worms Rotifers Rotifer citrinus Rotifer neptunis Philodina Ciliates Oxytricha Eschaneustyla Carchesium Vorticella Colpidium Paramoecium putrium Flagellates Euglena Phacus Anthophysa vegetans Desmids Pleurotaenium Netrium Filamentous algae Stigeoclonium Oscillaria Moulds Unidentified Sphaerotalis natans	Nematode worms Rotifers Rotifer citrinus Philodina Ciliates Carchesium Vorticella Colpidium Epistylis Paramoecium putrium Flagellates Euglena Anthophysa vegetans Chlamydomonas Rhizopods Arcella Diatoms Navicula Desmids Netrium Closterium Filamentous algae Microthamnion Stigeoclonium Oscillaria Moulds Unidentified Sphaerotalis natans	Nematode worms Rotifers Rotifer citrinus Ciliates Vorticella Colpidium Flagellates Euglena Phacus Anthophysa Desmids Netrium Pleurotaenium Closterium Filamentous algae Microthamnion Stigeoclonium Oscillaria Moulds Unidentified Sphaerotalis natans	Rotifers Rotifer neptunis Rotifer citrinus Ciliates Carchesium Vorticella Flagellates Anthophysa Euglena Phacus Desmids Netrium Closterium Pheurotaenium Filamentous algae Oscillaria Moulds Unidentified Mould zygotes Sphaerotalis natans

TABLE 1—Continued.

Date.	Oct. 14, 1918.	July 20, 1919.	July 20, 1919.	July 20, 1919.
Location.	Frye bridge north of Bolivia.	Smith's Mill above dam.	Above Roby bridge ½ mile below dam.	3¼ miles below dam
Estimated distance below Decatur by river	70 miles	75 miles	75 miles	78 miles
Depth	6 feet	6 feet	1 foot	2¼ feet
T. C	16°	25°	25°	25°
D. O. ppm	0	4 1	7.8	9.7
per cent saturation	0	48.9	93	115
Alkalinity ppm	320		287	
pH	7.9	8		8
Appearance	greenish gray	green, slightly grayish	green	green
Odor	faint	noticeable	none	none
A: of Bottom	Tubificid worms Chironomid larvae	Tubificid worms Chironomid larvae Crayfishes Some carp said to be above dam yet	Crayfishes Cambarius propinquus Cambarius virilis Unionidae Quadrula undulata Quadrula lachramosa Lampsilis alata Lampsilis luteola Lampsilis anadontoides Unio gibbosus Anadonta grandis Tritigonia tuberculata Strophitus edentulus Alasmodonta costata Sphaerium Gastropods Pleurotera elevatum (a few) Campeloma subsolidum Insect nymphs Caddis fly Heptagenia } May Hexagenia } flies Chironomid larvae Tubificid worms in mud Fishing said to be fair for cat, carp and "some game fish" after the spring floods	Crayfishes Cambarus propinquus Insect larvae Chironomid larvae Heptagenia

TABLE 1—Continued.

Date.	Oct. 14, 1918.	July 20, 1919.	July 20, 1919.	July 20, 1919.
Location.	Fry Bridge north of Bolivia.	Smith's Mill above dam.	Above Roby Bridge ¼ mile below dam.	3½ miles below dam.
B. Plankton	Rotifers Rotifer citrinus Philodina Ciliates Vorticella Paramoecium caudatum Flagellates Euglena Phacus Anthophysa Desmids Netrium Closterium Pleurotaenium Filamentous algae Oscillaria Microthamnion Moulds Sphaerotalis natans Unidentified	Rotifers Rotifer citrinus Ciliates Vorticella Stentor Spirostomum Flagellates Euglena Phacus Eudonina Desmids Netrium Closterium Scenedesmus Filamentous algae Oscillaria Spyrogyra Moulds Sphaerotalis natans	Plankton sample not taken	Crustaceae 1 nauplius Rotifers Rotifer citrinus Notops Ciliates, several very small forms Flagellates Euglena Phacus Eudorina Desmids Netrium Closterium Scenedesmus Tetradesmus Diatoms Tetradesmus Diatoms Stauroneis Filamentous algae Oscillaria Spyrogyra Conferva

Date.	July 20, 1919.	July 21, 1919.	July 22, 1919.
Location.	Northwest of Buckhart about 2½ miles below Robey.	Riverton.	Springfield Water Works.
Estimated distance below Decatur by river	87 miles	105 miles	120 miles
Depth	7 feet	8 feet	15 feet
T. C.	25°	26.2°	27°
D. O. ppm	12.8	7.5	9.8
per cent saturation	152	91	109
Alkalinity ppm	--------	--------	--------
pH	--------	8	--------
Appearance	green	green	green
Odor	none	none	none
A: of Bottom	Uniondae Lampsilis luteola Lampsilis alta Quadrula pustulosa Quadrula undulata Tritigonia tuberculata Symphynota costata Fish Carp } seen Bullhead } Channel cat, reported by fishermen Insect larvae Caddis worm (a few; 1 Corydalus larva (helgomyte	Unionidae Lampsilis luteola Lampsilis alata Unio gibbosus Quadrula undulata Quadrula pustulosa Tritigonia tuberculata Anadonta grandis Sphaeriidae Sphaerium Musculium Gastropods Pleuvocera elevatum Campeloma subsolidum Insect larvae May fly nymphs (hexagenia) Chironomid larvae Fish Sunfish (small) observed Bullhead } Reported as common in spring Carp } Buffalo } Cat }	Bottom conditions abnormal because of dam

TABLE 1—Conciuded.

Date.	July 20, 1919.	July 21, 1919.	July 22, 1919.
Location.	Northwest of Buckhart about 4½ miles below Robey.	Riverton.	Springfield Wa:er Works.
B. Plankton			Rotifers Notops Philodina Ciliates A few small forms Paramoecium Flagellates Eüglena Phacus Eudorina Pandorina Glenodinium Rhizopods Arcella Desmids Netrium Closterium Scenedesmus Tedradesmus Diatoms Fragellaria Filamentous algae Oscillaria Conferva Unidentified fragments

There is a complete disappearance of bottom animals immediately below Decatur; not until Niantic is reached, about 30 miles below, do the first animals appear. These, the tubificid worms, are known to be capable of living in the complete absence of free oxygen and are typical sludge worms. The next form to enter, the chironomid larva or "blood worm" is found about 20 miles farther down stream. Like the tubificids, this larva is capable of anaerotic existence at least for long periods. Soon after, the first cray fishes appear, but no other bottom forms are found until we reach Roby, some 75 miles below Decatur. The fish observed west of Mt. Auburn had probably entered from Mosquito Creek, a short distance above, and were dying or showing signs of great distress at the time observed.

The dam at Smith's Mill is about 8 feet high, and as the water pours over, considerable mechanical aeration is accomplished. The effects of this aeration are shown by a comparison of the dissolved oxygen determinations made July 20; above the dam 48.9 per cent saturation, and one-fourth mile below the dam 93 per cent of saturation. Following this aeration we find a return of the normal inhabitants of the river bottom in the region immediately below the dam and opposite the village of Roby. These animals, however, undergo a secondary disappearance at a distance of from 3 to 3½ miles below the dam, and do not again occur for about seven miles, although at Buckhart, twelve miles below the dam, they are again found in normal abundance. At the time of this survey, July 20, 1919, a steady increase in, dissolved oxygen content of the water was found from the dam down stream for more than twelve miles. However, the secondary disappearance of bottom animals can only be interpreted as meaning, that in less favorable seasons there is sufficient putrescible material still in the water at Roby to absorb the oxygen mechanically introduced by the agitation of passing over the dam, and that a stable condition is not reached for about ten miles. Below Buckhart, the return of' the normal bottom fauna takes place very rapidly, although the more susceptible snail, pleurocera elevatum, was not found above the entrance of the South Fork below which point it occurred in abundance.

In the Plankton collections from Niantic to Smiths Mill, rotifers, especially E. cirtiums, occurred in such abundance that one might suppose himself to be looking at an infusion culture of them. There was a gradual decrease in the number of ciliates and increase in the number of desmids, especially of the netrium type, which were so abundant in the sample taken at Frye Bridge as to make it distinctly green in contrast to the grayish dirty look of earlier samples. Paramoecium putrium was gradually replaced by Paramoecium caudatum. Euglena was abundant throughout as were also moulds. The disappearance of nematode worms and most of the ciliates in the later samples show a marked improvement, although the organisms found at Frye Bridge were still sewage or highly tolerant forms.

The Plankton collections made in July, 1919, show nothing of special interest except the presence of sphaerotalis natans above the dam at Smith's Mill and its disappearance below. The other organisms found might occur in any river of the State.

Chemical analyses of water and mud from the bottom of the river were made at intervals during the winter of 1918-1919 and the summer of 1919. Water samples were collected 10 inches from the bottom. The early winter of 1918 was rainy and there was less than a week during the entire season when ice was formed across the river. Even at such times the riffles were not frozen over so air penetrated freely to all parts of the water. For this reason dissolved oxygen never disappeared from the water as is commonly the ease under ice, and the decomposition processes going on in the water were oxidations leading to the formation of nitrates rather than reductions leading to the formation of ammonia. Similarly the summer of 1919 was one of considerable rainfall and moderate temperatures, washing out the stream bed, affording greater dilution to the sewage, and allowing the processes of decomposition to proceed more slowly, so that the penetration of oxygen into the water kept pace with its absorption from the water by the sewage. It was **not** until September that low water conditions were really attained. **Conse-**

quently the chemical analyses of water and mud given in Tables 2 and 3 must be regarded as representing the condition of the Sangamon under the most favorable circumstances.

During the winter the water of the river at Harristown, Niantic, and Illiopolis, instead of appearing inky or of a dark slate color, as was the case in the fall, was of a murky pea soup color and full of floating masses of feathery grayish moulds, sometimes 6 or 8 inches in diameter, and so abundant that the sampling bottle and chain by means of which it was lowered came up literally festooned with them. These moulds were still found in the water at Smith's Mill, although less abundant and no longer in large masses.

The bottom of the river at Harristown is rocky and at Illiopolis sandy so no mud samples were taken at either of these points. Mud samples taken at Niantic were in every case of an inky blackness and strongly putrefactive odor. Except after the spring floods and especially during the winter the samples taken at Smith's Mill had a marked disagreeable odor. Samples from Springfield and Petersburg were without offensive odor.

An examination of Table 2 shows an abrupt drop in dissolved oxygen and rise in oxygen consumption. There is a rise in NH_3 and organic nitrogen immediately below Decatur followed by a gradual return to normal which at the time of this investigation was reached about Buckhart. At each point of sampling the dissolved oxygen increases during the winter, reaching a maximum about April after the heavy spring rains, from which point it decreases progressively throughout the summer and early fall. The minimum is reached sooner in the upper part of the river, Harristown to Illiopolis, than it is farther down, at Smith's Mill. Correspondingly the capacity of the water to consume oxygen decreases; the ammonia nitrogen content and organic nitrogen decrease to a minimum after the spring rains and then increase to a maximum in the fall or late summer, probably to the beginning of fall rains.

Except the sample taken opposite Buckhart, a disagreeable odor was detected in the water in each case where the dissolved oxygen fell below 60 per cent of saturation, or the ammonia or organic N. rose above 1 ppm. This became distinctly disagreeable where the dissolved oxygen fell below 50 per cent of saturation, or the ammonia rose above 2 ppm. Although the sample taken at Buckhart, September 2, showed 1.05 ppm. ammonia nitrogen, the dissolved oxygen was 128 per cent of saturation and the water was without odor. As the twelve miles between this station and Smith's Mill was a region of very rapid recovery from offensive conditions, this doubtless indicates that aeration and the return of a normal color are accomplished more rapidly than the escape of ammonia already formed, part of which is undoubtedly held in the form of carbonates.

TABLE 2—ANALYSIS OF WATER OF THE SANGAMON RIVER.

Location and date.	Depth feet.	T. C.	D. O. ppm.	D. O. Per cent saturation.	Oxygen consumed ppm.	Nitrates ppm.	NH_3 ppm.	Organic N. ppm.	Remarks.
Decatur (above dam)—									
December 23, 1918	5	8°	10.9	91.8	5.9	2.4	.056	.48	After heavy rain, flooded.
February 4, 1919	7	3.7	11.2	84.6	3.9	2.33	.16	0.7	Normal rainy winter.
April 7, 1919	7	15°	10.4	100	4.4	3.6	.096	.88	Early spring.
Harristown—									
September 1, 1919	1½	23°	0	0	62.6	0.4	16.0	4.32	Low water.
October 6, 1918	3	18°	0	0	----	----	----	----	
Niantic—									
November 25, 1918	2	4°	2.8	21.3	----	----	1.7	1.12	After fall floods.
February 5, 1919	5	1.9°	8.7	68.	10.5	7.52	1.0	2.2	Normal winter condition.
April 8, 1919	6	15.2°	8.9	70.4	8.2	3.0	1.36	0.96	After early spring rains.
July 20, 1919	4	25.2°	3.0	35.8	15.2	1.2	2.8	2.4	Early summer condition.
September 1, 1919	1½	23°	0	0	50.6	0.4	14.8	3.52	Normal fall or low.
October 8, 1918	2	15°	trace	----	----	----	----	----	Water condition.
Illiopolis—									
February 6, 1919	1½	2°	7.3	52.7	9.6	8.00	1.2	1.72	Normal winter condition.
September 1, 1919	¾	23°	0	0	40.8	.48	12.0	3.2	Normal fall or low water condition.
October 11, 1918	1	15.7°	0.3	3.0	----	----	----	----	
Smith's Mill (above dam)—									
December 21, 1918	7	7°	9.4	77.2	11.0	2.64	.28	.44	Flooded.
February 7, 1919	6.5	3°	9.7	72.	6.3	3.36	1.2	1.2	Normal winter condition.
April 10, 1919	6.	15.4	8.2	81.5	6.6	3.0	.136	0.8	After early spring rains.
July 20, 1919	6	25°	4.1	48.9	9.8	1.44	.64	2.0	Early summer.
September 2, 1919	5	22°	2.5	28.3	18.6	0.72	5.6	2.56	Normal fall or low.
October 14, 1918	6	16°	0	0	----	----	----	----	Water condition.
Buckhart—									
September 2, 1919	1½	22°	11.3	128	16.2	1.4	1.05	2.56	Normal fall or low water condition.
Springfield—									
November 24, 1918	16	4.2°	9.8	74	----	----	0.56	0.32	After fall floods.
December 20, 1918	13	7°	10.2	83.8	10.9	2.64	0.32	0.88	Normal winter condition.
February 8, 1919	18	1.7°	11.7	85.6	6.0	3.48	0.48	0.8	High but within banks.
April 11, 1919	10	15.4°	----	----	3.7	3.0	.104	0.8	After early spring rains.
July 22, 1919	15	27°	9.8	109	9.5	1.2	.28	2.0	Early summer after rains.
September 3, 1919	13	22°	5.3	60	10.3	1.0	.43	2.24	Normal fall or low water condition.
Petersburg—									
February 10, 1919	2	1.5	11.4	81	4.6	----	0.29	1.0	Winter condition; within banks.
April 9, 1919	3	15.3	10.2	100	2.3	3.0	.136	0.92	After early spring rains.
South Fork at Rochester—									
September 2, 1919	1½	22°	9.7	110	12.3	0.4	0.22	1.6	Normal fall or low water condition.

TABLE 3—ANALYSIS OF MUD FROM THE BOTTOM OF THE SANGAMON RIVER.

Location and date.	Weight of sample gms.		gms. Loss or incineration.	Per cent of moisture.	Weight in mgms.		Per cent of dry weight as—			Per cent of organic matter as—		Remarks.
	Fresh.	Dry.			NH_3.	*Total N.*	Organic matter.	NH_3.	N.	NH_3.	N.	
Decatur (above dam)—												
December 23, 1918	10	3.77	----------	62.3	0.3	----------	----------	.0077	----------	----------	----------	
February 7, 1919	10	3.6	----------	64.	0.4	7.92	----------	.0062	.22	----------	----------	
April 7, 1919	15	6.389	0.648	57.4	0.5	15.84	10.7	.0078	.247	.077	2.44	
Niantic—												
February 5, 1919	10	3.4	----------	66.	1.8	14.28	----------	.054	.42	----------	----------	
April 8, 1919	15	7.748	0.527	48.3	1.6	21.62	6.8	.0206	.28	.304	4.1	After heavy rains.
July 22, 1919	10	4.896	0.673	51.0	1.00	11.37	13.7	.0204	.232	.148	1.69	
September 1, 1919	10	3.515	0.545	65.	1.2	11.7	15.5	.034	.333	.220	2.15	
Smith's Mill—												
February 7, 1919	10	3.78	----------	62.	0.8	10.2	----------	.021	.27	----------	----------	
April 10, 1919	15	7.014	0.423	53.2	1.4	17.39	6.03	.02	.248	.331	4.1	
July 20, 1919	10	5.475	0.663	45.	0.8	9.86	12.1	.0146	.12	.18	1.48	
September 2, 1919	10	6.396	0.536	36.	0.72	7.4	8.38	.011	.115	.134	1.38	
Above Junction with S. Fork—												
July 21, 1919	10	6.523	0.555	34.7	0.68	6.06	8.5	.0104	.093	.12	1.09	
Springfield—												
February 8, 1919	10	3.095	----------	60.	0.35	6.93	----------	.0112	.224	----------	----------	
April 11, 1919	15	6.779	0.523	54.8	0.36	12.54	7.7	.0053	.184	.07	2.4	
July 22, 1919	10	4.686	0.728	53.1	0.72	9.82	15.5	.0154	.209	.099	1.34	
September 3, 1919	10	4.631	0.557	53.7	0.64	7.8	12.0	.014	.168	.115	1.40	
Petersburg—												
February 10, 1919	10	4.61	----------	54	0.18	5.07	----------	.004	.11	----------	----------	
April 9, 1919	15	9.43	0.519	37.1	0.48	8.82	5.5	.005	.094	.092	1.7	
Clear Creek—												
July 21, 1919	10	4.81	0.71	51.9	0.68	8.23	14.7	.0141	.17	.096	1.16	A northern tributary some 15 miles below Robey.
South Fork (100 yards above Junction)—												
July 22, 1919	10	6.171	0.452	37.8	0.4	5.83	7.3	.0065	.094	.088	1.29	
(at Rochester)—												
September 2, 1919	10	4.531	0.515	53.	0.64	7.8	11.36	.007	.145	.062	1.27	

In considering the low oxygen content of the water at Springfield on September 3, 1919—60 per cent of saturation—the greater depth of this sample must be taken into account. Samples taken at Westcart, about three miles above the Springfield Water Works on August 14, 1918, showed in 9 feet of water at the bottom, 47.4 per cent of saturation, 5 feet below the surface 52 per cent, and 1 foot below the surface 54.7 per cent of saturation. From this it would be expected that the samples taken at the Springfield Water Works in 10 to 16 feet of water, would appear low in oxygen as compared to samples taken in the shallow upper parts of the river. Moreover the low ammonia content of this sample indicates relative freedom from pollution.

The mud analyses (Table 2) were made to see whether the condition of the bottom might prove a more practical criterion in comparing the degree of pollution of two streams, than the analysis of the water, since it is less affected by fluctuations in water level. The total nitrogen of these samples shows little correlation with the degree of pollution of the river. This is rather to be expected since a bottom composed of algae, diatoms, and organic detritis deposited from the water, might contain as large a percent of nitrogen as a deposit of sewage sludge. On the other hand the ammonia, especially when expressed as the percent of dry weight of the sample, shows a marked correlation with the degree of pollution of the stream. In every case where the ammonia rises to or above 0.02 per cent of the dry weight of the sample, an offensive odor was noticeable which was lacking in the other samples. The ammonia rises abruptly below Decatur and falls off again, gradually reaching a normal condition near Springfield.

A comparison of Tables 2 and 3 shows that while the water reaches its least offensive condition during the winter and after the heavy April rains, the bottom attains to this condition much later; at Niantic it is reached in July, at Smith's Mill in September. This is undoubtedly due to the fact that so long as there is an abundance of free oxygen in the water, there will be little or no putrefaction at the bottom, which will therefore tend to improve. Bad conditions return at the bottom after free oxygen has largely disappeared from the water, which point is reached at Niantic before it is at Smith's Mill.

DISCUSSION OF RESULTS.

The Plankton of a stream affords a good criterion of the quality of the water at the time it is collected. Thus in Table 1 the Plankton collected during the fall of 1918 in water with little or no dissolved oxygen, is characterized by such forms as Sphaerotalis natans, nematode worms, ciliates, and the creeping rotifers, while the samples, taken in

July, 19.19, in water high in dissolved oxygen, are characterized by Phytoflagellates, desmids, and the swimming rotifers.

On the other hand the bottom animals, as has already been mentioned, afford a criterion of the worst conditions to which a locality is subject. A comparison of the bottom animals found (Table 1) with the quality of the water (Table 2) and the character of the bottom (Table 3), shows a close correlation in the region between Decatur and Smith's Mill, where water with little or no oxygen and a bottom high in ammonia support only moulds, tubificid worms, chironomid larvae, and a few cray fish. However, the disappearance of clams and snails between Roby and Buckhart is inexplicable on the basis of any chemical data collected and can only be accounted for on the supposition that previous conditions had been much worse than those observed during the winter and spring of 1918-1919.

The following account of former conditions was obtained by conversing with and questioning a considerable number of people who live, or have work, near the river. As all narratives agreed upon the following points, the description may be regarded as accurate. At Harristown. and Niantic the worst conditions are said to have occurred during the summer of 1916. This season, as has been mentioned, was exceedingly long, hot, and dry, so that from the middle of July to the last of September, practically the entire stream below Decatur was undiluted sewage. The high temperatures caused very rapid decomposition of this matter, hence the occurrence of the worst conditions in the regions immediately below Decatur. . The spring floods are said to have receded rapidly that year so that many fish failed to escape and were soon seen gulping at the surface and dead along the shore. Shortly after (it is reported at Illiopolis) the crawfishes left the water. At first they "backed out" along the shore, and later many of them were found dead. Conditions reached their worst during August and the early part of September. The people most affected were, of course, those living on farms adjacent to the river. To them the stench became "intolerable." They . "could neither get away from it nor get used to it." It "stuck to them" and they "noticed it all of the time" although it was worse in the evenings. The measures employed to relieve conditions were closing the houses to "keep out the stink" and then burning coffee which is believed to have "absorbed-some of the smell." It is even reported that on a still evening with a slight breeze from the south odors from the river were distinctly discernable in the villages of Harristown and Niantic (about three miles from the river). The author feels no inclination to question this report, since under less extreme conditions in August 1918, and again in September, 1919, she recognized unquestionably the odor of the river a mile away.

In the lower part of the river, Roby to Springfield, the worst conditions were attained during the long severe winter of 1917-1918. In summer high temperatures' lead to the rapid decomposition of the sewage so that a considerable degree of purification is accomplished in the first 25 or 30 miles, thus the lower part of the river is saved at the expense of the upper part. In a severe winter, however, the sewage is swept along under ice, which prevents its oxidation by excluding air, and is carried in cold storage, as it were, to accomplish its purification at a much greater distance below its source. Thus in winter the same degree of decomposition may be found at Roby, Buckhart, or even Springfield, that is found in summer at Illiopolis, or Niantic. So long as the ice is on, the presence of undecomposed sewage is not evident, but with the breaking up of the ice, and the rise of temperature in early spring, a rapid decomposition sets in which results in the development of offensive conditions.

In 1917 objectionable conditions were noticed at Roby in the early fall. At this time, it was said, the river at Illiopolis was of a chalky color "as though you had taken half a tumbler of skimmed milk and filled it up with water." At Roby it looked "like about one part of milk to three of water." (This homely simile describes admirably the condition observed by the author between Illiopolis and Mt. Auburn in October, 1918). The odor was so pronounced that the people of Roby, which is on the bank of the stream, had to keep their houses closed. With the onset of cold weather nuisance abated until about Christmas time when a brief thaw again produced objectionable conditions. The month of January, 1918, was cold throughout, but with the breaking up of ice in late February and March, the worst conditions developed. People resorted to burning coffee in the houses, and it is asserted that the odor from the river was so strong that such articles of food as butter and milk "took it up."

In Riverton, some 30 miles by river below Roby and below the junction of the South Pork, there is a power plant which draws its boiler water from the river. Early in February it was noticed by workmen in this plant, that the water, when heated, produced offensive odors. Conditions grew worse until the middle of March when the odors are asserted to have been "almost suffocating." At the time of the break up in March offensive odors from the river were noticeable "all over town."

At the plant of the Western Cartridge Company, near Springfield, river water is used both for boiler water and for the showers of the workmen. Conditions similar to those noted at Riverton were described here.

Early in February the water developed such an objectionable odor upon heating as to be unfit for bathing purposes. Conditions were at their worst from the middle to the latter part of March and then rapidly returned to normal.

At the Springfield Water Works a more detailed description of conditions was obtained. Springfield derives its water supply from deep wells but the boiler waters used at the pumping station are drawn from the river. Waste waters from the pumping plant are emptied into a sort of lagoon through which they pass into the river. As these waste waters have a relatively high temperature, an open space is maintained around the point of discharge when the lagoon and river are frozen over. Early in February large numbers of fish were seen crowding around this open space, a sign of the depletion of oxygen in the waters under the ice, and soon after they were found dead in large numbers. At the same time it was observed that the water had assumed a dark inky appearance (a similar appearance was observed by the author at Illiopolis, September 2, 1919) and developed a putrefactive odor upon heating.

By the midle of March the odors resulting from the heating of this water in boilers made working conditions in the plant very disagreeable. The men affirm that they "had to get out very often to get air." This condition persisted until the beginning of spring rains.

From these accounts we may readily believe that during the winter of 1917-1918 oxygen practically disappeared from the water and highly putrefactive conditions were found as far down as Springfield and that, had chemical tests been made, as high or nearly as high ammonia, oxygen demand and organic nitrogen would have been found at Smith's Mill in February as were found at Niantic in September, 1919. Not only is the secondary disappearance of mollusks between Roby and Buckhart accounted for, but the fact of their presence at all above the junction of the South Fork can only be explained on the basis of their exceedingly slow metabolism and relatively high resistence to unfavorable conditions at the lower temperatures.

SUMMARY.

The Sangamon River above Decatur is suitable for an abundance of our common game fish up to the limit of its capacity at low water. Among invertebrates the most characteristic are the clams, unionidae, snails, especially Pluerocera elevatum, and Ephemerid nymphs, both Hexagenia and Heptagenia.

These characteristic inhabitants of the unpolluted stream must be kept in mind in considering the changes wrought in the stream by the sewage of Decatur, and the distance traversed by the water before it accomplishes self purification or return to an approximately normal condition.

Results of biological and chemical survey of the Sangamon between Decatur and Springfield, made between August 8, 1918, and September 3, 1919, in order to determine the degree of pollution of the river show:

1. Plankton animals present varied greatly with season and water level. During the low waters of early fall only sewage and highly tolerant forms were found within 75 miles (by river)-of Decatur.

2. The normal bottom fauna disappeared entirely below Decatur. Only typical sludge worms (tubificids) were found in the first 40 miles. The highly tolerant midge larva appeared within the next ten miles. Seventy-five miles below the source of pollution several of the normal bottom animals reappeared and about 10 miles further down the normal bottom fauna was re-established.

3. Dissolved oxygen drops off, frequently to zero, below Decatur and at low water sufficient oxygen to support ordinary aquatic animals is not found again within 75 miles.

4. Oxygen consuming power of the water, organic nitrogen and ammonia rise rapidly immediately below Decatur and then gradually decrease to normal.

5. Dissolved oxygen, oxygen consumption, organic nitrogen and ammonia of the water fluctuate greatly with the temperature and volume of the stream.

6. Ammonia content of mud from the bottom of the river increases suddenly below Decatur and then decreases gradually to normal (about 80 miles below).

7. The ammonia content of the mud from any given location shows a seasonal variation due to temperature and oxygen content of the water. Slight temporary fluctuations in water level do not appreciably affect the ammonia content of the mud.

8. The worst conditions occur in the upper part of the river during hot dry summers, and in the lower part of the river, in the early spring following a severe winter.

9. Chemical analyses of the water and mud afford the best criterion for the degree of pollution of the water at the time the sample is taken. The animals of the bottom form the best criterion for judging the **worst** conditions to which the location is subject.

EXPERIMENTS WITH MILES ACID PROCESS OF TREATMENT FOR SEWAGE DISPOSAL.

By W. D. Hatfield.

Experiments with the Miles Acid Process[2] of Sewage Disposal were carried out during March, 1918, in concrete tanks of the fill-and-draw type located in the basement of the power house at the University of Illinois. These tanks were those used by F. W. Mohlman for experiments on sewage purification in the presence of activated sludge.[1]

Two of these tanks were refitted with sloping bottoms so that sludge could be drained off. As sewage was pumped into the two remodeled tanks sulfur dioxide (SO_2) was added to one of them by introducing it into the influent pipe with the sewage. After a sedimentation period of three hours the supernatant liquid from both tanks was drawn off and the tanks were refilled. The capacity of the tanks was 450 gallons and sewage was added 15 times, making a total of 6,750 gallons of sewage treated in each tank.

The average alkalinity of the sewage was 450 parts per million, (as calcium carbonate), and the average acidity of the effluent after treatment with sulfur dioxide was 75 parts per million, (as calcium carbonate). The average removal of suspended matter by plain sedimentation was 33 per cent and that by sulfur dioxide treatment was 70 per cent. By adding sewage in both tanks in such a way that the sludge at the bottom was thoroughly mixed with the sewage a period of three hours' sedimentation of the total sludge was always secured.

As the sludge built up, better clarification was secured by this process, an interesting phenomenon somewhat similar to what occurs in the activated sludge process.

The turbidity of the sedimentation effluent averaged about 200, and that of the sulfur dioxide treated effluent about 100. Results on the relative amount of sludge were not obtainable due to an accident to the sludge valve on the sulfur dioxide treatment tank. From the removal of the suspended matter the following results of total sludge were estimated :

Miles Acid Sludge............1035 pounds per million gallons
Sedimentation Sludge ......840 pounds per million gallons

Chemical analyses of the dried sludges showed the following results:

	Miles Acid Sludge.	Sedimentation Sludge.
Nitrogen per cent	2.4	2.3
Fat per cent	26.4	18.4

The nitrogen content of the sludge was not greater under the sulfur dioxide treatment than when the activated sludge process was employed. By the use of the Miles Acid Process the fat content was increased materially over that of the sedimentation sludge. Its extraction may be found profitable.

The cost of the SO_2 treatment on sewages with high alkalinity, characteristic of this section of the country, is prohibitive. The calculated cost of sulfuric acid at present prices necessary to treat this particular sewage by this process is $46 per million gallons. To treat with sulfur dioxide produced from sulfur would be even more expensive at present prices. The treatment would require about 500 parts per million of sulfuric acid per 1,000,000 gallons of sewage; basing the calculations upon a sewage having an alkalinity of 450 ppm., and allowing an excess of 50 ppm. of sulfuric acid.. For 1,000,000 gallons of sewage 4,200 pounds of 100 per cent sulfuric acid would be required or with chamber acid, 66°, worth $22 per ton, the cost of the acid would be $46.

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A WATERWORKS LABORATORY.*

The State Water Survey Division recommends chemical and bacteriological control and careful supervision over the sanitary quality of all water furnished. Water taken from deep wells need be examined only occasionally and a special laboratory is not essential. Water taken from shallow wells or from surface supplies such as rivers, lakes or reservoirs is subject to variation and should therefore be carefully watched. We are glad to report that there is a growing demand among the operators of the water purification plants for more careful control and for closer supervision of the quality of the water. At the suggestion of the State Water Survey Division small laboratories equipped for making the simple tests have already been established at several water works plants in the State.

Generally the physical and chemical tests made include turbidity, color, alkalinity, chlorides and chlorine. The bacteriological tests include the determination of the number of bacteria and the fermentation test. By means of these few tests and the proper interpretation of results obtained a water purification plant may be operated to much better advantage.

The following list of apparatus and chemicals is submitted with the hopes that it may prove of service to water works operators who wish to establish small laboratories. This list is a revision of the list published in the Bulletin No. 8, State Water Survey, (1910). The list is made less extensive than is the one in Bulletin No. 8 and it has been revised in such a manner that it specifies the apparatus needed to carry out the determinations as described in the 1917 edition of Standard Methods of Water Analysis, American Public Health Association. With the apparatus given in the list chemical determinations of turbidity, color, alkalinity, free carbon dioxide,. free chlorine and chlorides and bacteriological determinations of the total number of bacteria growing on agar at 37½ ° and the fermentation test to indicate the presence of the members of the B. coli group may be made.

In the preparation of the list it has been taken for granted that both electricity and gas are available. In every case, however, where apparatus using gas is specified there will be found immediately following that

*Revised from Bull. 8, 136, by R. E. Greenfield.

item specification for an alternate apparatus using kerosene or alcohol which may be substituted in case gas is not available. Likewise in every case where an apparatus using electricity is specified immediately following will be found one using gas and following that is one using kerosene, either one may be substituted for the electric apparatus.

In preparing the list a few cases were encountered where different pieces of apparatus could be used equally well. In these cases we have first given the type which we should prefer and immediately following is the other apparatus which would be equally efficient, and might be purchased in the place of the first.

All standard solutions should be purchased ready made. Media should either be purchased ready made or in the form of desicated media which has only to be added to water and sterilized before being used. If it is desired to make up all needed standard solutions and media a more extensive list of apparatus must be purchased. If the operator has had sufficient experience to make possible this additional work he will also be able to select his own apparatus. Such an additional list is therefore not given.

The above lists might be further increased by addition of apparatus and chemicals for the determinations of residue on evaporation, nitrates, nitrites, ammonia, and for microscopical examinations. We do not publish these lists at the present time as these tests will be attempted only by experts. The State Water Survey Division will be glad to consult and advise any one desiring to install apparatus for any of these additional tests.

Laboratory tables and furniture may be made to suit the needs of the operators. They are often included in the contract of the plant. Most firms selling chemical apparatus also sell ready made laboratory furniture.

FOR CONVENIENCE IN DESCRIBING AND IDENTIFYING APPARATUS NUMBERS FROM THE CATALOG OF SARGENT & COMPANY ARE GIVEN, BUT THE APPARATUS MAY BE PURCHASED FROM OTHER DEALERS.

APPARATUS.

NO.		CAT. NO.
1	Harvard trip scale	420
1	Box weights, metric, brass 1,000 gms. to 1 gms	500
1	Nest of beakers, 0 to 4 Griffin's lip form	582
12	Bottles, 4 oz	670
12	Bottles, ½ gal. glass stoppered	682
2	Bottles, 6 oz. glass stoppered	682
12	Bottles, 32 oz. glass stoppered	682
24	Bottles, 6 oz. salt mouth mushroom stopper	692
2	Bottles, dropping 2 oz	732
2	Burettes Geissler's 50 cc. graduated to 1/10 cc	892
1	Burette automatic, capacity of burette 50 cc. (complete)	916
1	Burner, adjustable for coal gas	994

NO.		CAT. NO.
or 1	Lamp, Barthel's for alcohol No. 1	2707
2	Casseroles, 95 mm. diam	1164
1	Calcium chloride tube with one bulb 5"	1226
1	Pinchcock, large	1274
1	Clamp Bunsen	1306
1	Clamp holder	1318
24	Nessler tubes, U. of I. style, 1 set for color; 1 set for av. Cl...	1348
or	(U. S. Geological Survey Turbidity outfit, Arthur H. Thomas Cat No. 48704).	
2	Cylinder, double graduated 100 cc	1560
100	Filter papers, 15 cm. diam	1828
3	Flasks, Erlenmeyer, 175 cc	1890
1	Lens, Engravers lens No. 146 (Bausch & Lomb Optical Co. Cat.	
or 1	Reading Glass, 2½" diameter.	
2	Funnel, 1½" diameter	1992
1	Funnel, 8" diameter	1992
1	Funnel, 4" diameter	1992
1	lb. glass tubing assorted to 10 mm. diam	2338
6	Pencils for writing on glass	3108
24	Pipettes, volumetric, graduated 10 cc	3138
2	Pipettes, 50 cc	3138
2	Pipettes, 25 cc	3138
2	Pipettes, 5 cc.	
24	Pipettes, 1 cc. Mohr's graduated to 1/10 cc	3146
2	Pipette boxes copper for pipettes	3161a
1'	Tubing, rubber pure gum ½" diam	3454
6'	Tubing, rubber white, inside diam.. 5/16"	3462
1	Support, large and 3 rings	3700
1	Burette stand Chaddocks	3720
2	Thermometers, 1 reading to 250° C; 1 reading to 110° C	3818
1	Tripod iron diam. 5"	3976
1	Tripod iron diam. largest ring 12"	3978
1	Turbidity rod, aluminium (not needed if U. S. G. S. Turbidity outfit is ordered)	4046
2	Wire gauze, 6 x 6 inches	4174
1	Autoclave	6016
or	No. 633 Arnold Sterilizer	6404
36	Petri dishes 100 mm. diam. x 16 mm. deep	6052
2	Boxes for petri dishes. .•	6058
1	Incubator (Chicago Surgical & Electric Co. No. 11)	6189
or 1	Incubator, Bact, small size for use with gas	6187
or 1	Sartorious incubator for use with kerosene	6188
300	Heavy glass 50 x 7 mm	6410
100	Heavy glass 75 x 10 mm	6410
	Tubes for bacteriological work without flare heavy glass	6410
400	heavy glass 130 x 12 mm	6410
100	heavy glass 160 x 31 mm	6410
or 100	3 oz. wide mouth Flint glass bottles	674
4	Baskets, wire 5 x 5 x 4	6414
1	Basket, wire 6" diam. x 6" high	6416
3"	Platinum wire about No. 28 size	6416
or 6"	Nichrome wire about No. 28 size	6416
1	Book, ruled for bacteriological results.	
1	Book, ruled for chemical results.	
1	Diary.	
1	Standard Methods of Water Analysis, from American Public Health Association, Boston, Mass.	

APPARATUS TO BE PURCHASED LOCALLY.

1 gas plate, 2 burner.
or 1 Kerosene or gasoline stove, 2 burner.

1 Oven for Kerosene stove, or gas plate, 1 or 2 burners, not less than 15" x 12 x 12".
or 1 Electric oven, suitable size.
1 Double Oatmeal boiler, 2 qt. aluminium.
1 Cup, 1 qt. capacity, aluminium with handle.
1 Large aluminium spoon.
6 Tumblers, heavy clear glass.
2 Blocks with holes to hold 12 Nessler tubes.

SUPPLIES.

1 lb. Phenolphthalein solution.
1 lb. Methyl Orange solution.
1 liter N/50 H_2SO_4. '
1. liter N/22 Na_2CO_3.
1 liter Silver Nitrate solution 1 cc. = .0005 gr. of Ci.
½ oz. Merks Azolitmin.
1 oz. Erythrosine.
1 lb. Soda Lime.
1/4. Potassium chromate, C. P.
1 oz. O-Tolidin (purified by alcohol).
1 liter Hydrochloric Acid, C. P.
1 lb. Sodium Hydroxide.
1 lb. Lactose crystallized highest purity (Merks).
1 Liter 1½ agar in tubes.
or 1 lb. desicated agar medium Difco.
2 liters Lactose broth.
or 1 lb. desicated Lactose broth media Difco.
½ liter 2½% Lactose agar.
or 1 lb. desicated Litmus Lactose Agar, or Endo media, Difco.
3 oz. Saturated alcoholic solution basic Fuchsin.
1 lb. Sodium Sulfite, anhydr. c. p.
1 liter Turbidity standard 1 cc. = 1000 ppm.
1/4 liter Platinum-cobalt standard color solution color of 500. (Not needed if U. S. G. S. Turbidity set is purchased).

SUPPLIES TO BE PURCHASED LOCALLY.

1 gal. Denatured alcohol.
6 Towels.
5 lbs. Cotton, non-absorbent.
½ pt. Alcohol, ethyl.
1 lb. Cotton, absorbent.
1 lb. Chloroform for anesthesia.
1 box Labels.
1 Distilled water.

FIRST AID OUTFIT.

1 lb. Baking Soda.
2 oz. Carbolated vaseline.
3 oz. Tincture of Iodine.
1 Scissors 6" long.
1 pair good tweezers.
1 Eye glass.
1/4 lb. Absorbent cotton (sterilized).
15 yds. Adhesive tape 1" wide (sterilized).
1 yd. Gauze dressing (sterilized).
10 yds. Bandage 2" wide (sterilized).
1 lb. Lysol solution.
1 lb. Boric acid solution.
½ lb. Carron oil.

DEPARTURES FROM STANDARD METHODS FOR THE DETERMINATION OF THE BACILLUS COLON IN WATER.

By Esther A. Wagner and W. F. Monfort.

The studies following are attempts to demonstrate the optimum concentration of lactose in broth, including the concentration after dilution by addition of the sample, the quantity of beef extract, and of peptone, and the practical value of gentian violet in the preparation and use of sugar broth in routine water analysis.

Five series of 100 cc. each were inoculated with water from a local well which contained B. coli, B. aerogenes and spore-forming bacteria. In all, 500 samples were tested: i. e. 100 portions of 10 cc. each inoculated into 40 cc. Standard Methods broth; 100 portions of 10 cc. each inoculated into 10 cc. Standard Methods broth; 100 portions 10 cc. each into 10 cc. Standard Methods broth containing 1:20,000 gentian violet; 100 portions of 10 cc. each into 10 cc. 2 per cent lactose broth; 100 poritons of 10 cc. each into 10 cc. 2 per cent lactose broth containing 1:20,000 gentian violet. Only colonies which appeared to be typical B. coli, methyl-red positive organisms, were transferred from Endo plates which had been streaked from the positive tubes since B. aerogenes was found by Kligler[6] be more resistant to dyes. The results are given in Table 1. Series A shows no improvement over series B; Standard Methods procedure gives essentially the same number of recognizable methyl-red positive colonies as when only 10 cc. of broth are used with 10 cc. of sample. But almost double the number of methyl-red positive colonies were detected in series C wherein gentian violet was added, and as a result the abundant "spreaders" were inhibited. The same result was obtained in series E with a diminished lactose content equivalent to 1 per cent in the inoculated broth. Small numbers of confirmations in series D are probably due to the large number of overgrowths.

In order to find out whether or not B. Coli and coli-like organisms are inhibited by high concentrations of lactose a series of concentrations from 0.5 per cent to 50 per cent lactose in Standard Methods broth was inoculated with fresh cultures from agar slants.

In almost every ease 0.5 per cent showed the highest gas formation. However there seems to be no distinct gas ratio between the various concentrations.

TABLE 1.

Series.	Gas in 48 hours.		Characteristic Endo colonies.		Confirmatory tests.			
					Gas in lactose.		Methyl-red reaction.	
A 40 cc. broth;* 10 cc. sample	89+	11—	28+	61—	23+	5—	23+	5—
B 10 cc. broth; 10 cc. sample	90+	10—	25+	65—	19+	6—	20+	5—
C 10 cc. broth; 10 cc. sample 1:20,000 gentian violet	86+	14—	48+	38—	47+	1—	48+	--------
D 10 cc. .2 per cent lactose broth; 10 cc. sample	85+	15—	16+	69—	14+	2—	14+	2—
E 10 cc. .2 per cent lactose broth; 10 cc. sample 1:20,000 gentian violet	79+	21—	47+	32—	47+	--------	47+	--------

* Standard methods procedure.

In this connection six cultures were inoculated into fermentation tubes containing ten various concentrations of lactose solution. No gas formed even after 48 hours incubation as was to be expected due to the acidity produced. As soon as peptone, 1 cc. of 1 per cent solution was added vigorous gas formation took place in concentrations of 0.5 to 10 per cent lactose, showing the ability of peptone to act as a buffer substance.

To determine the minimum concentration of gentian violet in lactose broth which would give desired results eight bottles were prepared, each of which contained 100 cc. of peptone-lactose broth and various concentrations of gentian violet; (1) 1:10,000,000; (2) 1:5,000,000; (3) 1:1,000,000; (4) 1:500,000; (5) 1:400,000; (6) 1:300,000; (7) 1:200,000; (8) 1:100,000. These were pasteurized for 15 minutes at 70°-80°C. They were then sealed with paraffin and kept at room temperature. After four days, distinct growth and bubbles on the surface could be seen in the first three bottles. After a week, the fourth bottle showed bacterial growth and soon after, the fifth became cloudy. A concentration of one part of gentian violet in 300,000 parts of water seemed to inhibit enough so that autoclaving of sugar media could be dispensed with, and only pasteurization was necessary. This seems of special importance in view of the common occurrence of spore-forming bacteria in dry sugars. In higher dilutions, which were insufficient, the color was taken up by some of the organisms and the growth later observed in the bottle was a white heavy development such as was mentioned by Gorham[4] and others.

Using 10 cc. portions of Standard Methods broth to 10 cc. of sample, and gentian violet broth consisting of *.2* per cent lactose, peptone, 1:100,000 gentian violet omitting the prescribed beef extract, some comparative results are obtained with the Standard Methods broth used in water analysis. Table *2* shows some representative results.

TABLE 2.

No.	Source.	10 cc. broth to 10 cc. sample. Gas formed. 24 hours.	10 cc. broth to 10 cc. sample. Gas formed. 48 hours.	Endo.	Lactose.	M. .5.	Broth 2 per cent peptone; .2 per cent lactose; 1 part 100,000 G. V. (10:10 cc.). Gas in lactose. 24 hours.	Gas in lactose. 48 hours.	Endo.	Lactose.	M. 5.
1*	Bloomington 75 foot drilled well	—	+	+	+	+	—	+	+	+	+
		—	+	+	+	+	—	+	+	+	+
		—	+	—	—	—	—	+	+	+	+
2*	Mt. Morris 50 foot drilled well	+	+	+	+	+	—	+	+	+	+
		+	+	—	—	—	—	—	----	----	----
		—	+	—	—	—	—	—	----	----	----
3*	Women's swimming pool	+	+	+	+	+	+	+	+	+	+
		+	+	+	+	+	+	+	+	+	+
		+	+	+	+	+	—	+	+	+	+
4*	Moweaqua well	+	+	+	+	+	—	—	----	----	----
		+	+	+	+	+	—	—	----	----	----
		+	+	+	+	+	—	—	----	----	----
5*	Elliott well 108 foot drilled	—	+	+	+	+	—	+	+	+	+
		—	+	+	+	+	—	+	+	+	+
		+	+	—	—	—	+	+	—	—	—
6*	Frankfort 25 foot dug well	+	+	+	+	+	+	+	+	+	+
		+	+	+	+	+	+	+	+	+	—
		+	+	—	—	—	+	+	+	+	+
7*	Women's pool	+	+	+	+	+	+	+	+	—	—
		—	+	+	+	+	+	+	+	+	+
		—	+	—	—	—	—	+	+	+	+
8*	Men's pool	—	+	+	—	+	—	+	+	+	+
		—	+	+	+	+	—	+	+	+	+
		—	+	—	—	—	—	—	—	—	—
9*	Waukegan 175 foot drilled well	—	+?	—	—	—	—	—	----	----	----
		—	+?	—	—	—	—	—	----	----	----
		—	+	+	+	+	—	—	----	----	----
10*	Long Point 30 foot dug well	+	+	+	+	—	—	+?	+	+	+
		+	+	+	—	—	+?	+	+	+	+
		+	+	+	+	+	+?	+	+	+	+
11*	Buffalo 60 foot drilled well	—	+	+	—	+	—	+	+	+	+
		—	+?	—	—	—	—	+?	+	+	+
		—	—	----	----	----	—	—	----	----	----

1* Standard routine analysis confirmed 3 out of 5.
2* Standard routine analysis confirmed 2 out of 2.
3* Standard routine analysis confirmed 1 out of 2.
4* Standard routine analysis confirmed 1 out of 2.
5* Standard routine analysis confirmed 2 out of 2.
6* Standard routine analysis confirmed 2 out of 2.
7* Standard routine analysis confirmed 1 out of 2.
8* Standard routine analysis confirmed 1 out of 2.
9* Standard routine analysis confirmed 0 out of 2.
10* Standard routine analysis confirmed 1 out of 2.
11* Standard routine analysis confirmed 1 out of 2.

So far no exception has been encountered in which the new broth does not at least equal that prescribed by Standard Methods. In several cases one tube of the Standard Methods broth contained gas where the gentian violet failed to do so but after being streaked on Endo no B. coli colonies were obtained. Gas formed twice in gentian violet broth which did not give B. coli on Endo plates.

A culture of B. coli communis (Parke-Davis) failed repeatedly to ferment lactose and dulcite in standard 1 per cent sugar broth oven after it had been through peptone solution and other enrichment media. At the same time it gave vigorous fermentation of 0.2 per cent lactose in 2 per cent peptone media with concentrations of gentian violet varying from 1:10,000,000 to 1:100,000. Salter[8] (1919) noted that crystal violet decreases the growth of B. coli communis in dilutions as great as 1:1,000,000. In view of the data above it is suggested that the decrease in growth might be due to the concentration of lactose rather than to the presence of the crystal violet.

Correlation of results of various investigators with prescribed Standard Methods suggests certain desirable changes. Standard Methods prescribes a volume of broth equal to at least four times the sample. The concentration of lactose in a tube containing 40 cc. of standard broth to 1 cc. of sample is 0.8 per cent; in a tube containing 10 cc. of broth to 1 cc. sample 0.9 per cent; both of these are in excess of Burling and Levine's[2] recommendation (0.5 per cent) as well as of Smith's[9] 0.1 per cent essential concentration. Berman's[1] findings seem to justify no more than 0.2 per cent. A quantity must be present sufficient for reaction during a two-day period of incubation. The amount seems to lie between 0.1 and 0.5 per cent in the broth after inoculation. If this be true the Standard Methods procedure of using 1 per cent lactose is in error.

If the function of peptone and beef extract is primarily and almost wholly that of buffer action, (Berman 1917) the necessary quantity of nitrogenous matter with phosphates may be provided without the use of beef extract, which is to be regarded as a convenient accessory rather than an indispensable component of culture broth for B. coli. The essentials are sufficient sugar, and a buffer with a hydrogen ion concentration of 6.6 —7.4. The variable acidity of beef extract complicates the adjustment of the final reaction.

The efficiency of the broth is increased by gentian violet; the desired quantity seems to be 1:200,000; transfers to Endo's medium from broth containing this concentration of gentian violet give a larger per cent of recognizable colonies which prove to be methyl-red positive. There is no interference with the development of B. aerogenes. (Kligler 1918[6]). The prolongation of heat in sterilization of sugar media leads to hydrolysis. Spore-forming bacteria including various laboratory infections occur frequently in dry sugars. (Elser and Huntoon 1909 ;[3] Hiss 1905;[5] Norris and Pappenheimer 1905;[7] Gorham 1909[4]). These make the sterilization of lactose broth difficult and give results "which cannot be relied upon. The addition of gentian violet to broth (1:200,-000) appears to insure inhibition of gram positive spore-forming bac-' teria. A single heating to the thermal death point of B. coli (70-80° C.) for 15 to 20 minutes prepares the broth for use.

B. coli shows no inhibition in concentrations of gentian violet up to 1:100,000. Even an old authentic culture which failed to form gas in 1 per cent lactose broth vigorously fermented .2 per cent lactose in varying concentrations of gentian violet 1:10,000,000 to 1:100,000.

CONCLUSIONS.

1. The volume of broth as prescribed by Standard Methods is four times the needed amount.
2. One per cent lactose inhibits B. coli and one-tenth of 1 per cent gives optimum results.
3. Gentian violet when added to liquid media at a concentration of 1:250,000 eliminates false presumptive tests, gives clean Endo plates and helps in giving early knowledge of the presence of B. coli.
4. Peptone serves as a buffer in lactose broth. Beef extract may be used but need not be considered an indispensible component of culture broth.
5. Broth made as follows seems to give optimum results:

   2 per cent peptone.
   0.2 per cent lactose.
   1:100,000 gentian violet.

The peptone will regulate the pH value but adjustment of media is necessary when beef extract is used.

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SWIMMING POOLS AT THE UNIVERSITY OF ILLINOIS.

Compiled by Margaret C. Perry.

Within the last few years the condition of water in swimming pools has been the subject of considerable investigation by bacteriologists.

The purity of the water in the pools is of great importance, because pools have been installed in Y. M. C. A. buildings, athletic clubs and in public recreation buildings in the large cities and in gymnasiums of colleges and universities. These pools are used daily by large numbers of people and if the water becomes contaminated it constitutes a source of infection to everyone entering the pool.

It is difficult to set a standard for the allowable amount of contamination of a swimming pool water. The same standard cannot be applied with fairness to drinking water and to swimming pool water. If the same standard were applied most of the pools would be condemned. Attempts have been made to formulate standards, but none have been generally accepted. According to Atkins, [1] "chemical tests are of little value in determining the pollution of swimming pool water and the number of B. coli cannot be regarded as directly indicative of pollution; it remains, therefore, for the total number of bacteria present to give the best indication of pollution." Whittaker[5] in writing of the swimming pool at the men's armory and gymnasium of St. Paul, Minnesota advocates the most stringent requirements found; the bacterial count must not exceed 100 per cubic centimeter and organisms of the B. coli group must be absent in 10 cc. amounts; Renesselaer Polytechnic Institute[4] allows a count of 250; California has the most liberal standard; they attempt to keep the total count below 1,000 per cc. and allow one Bacillus colon communis per cubic centimeter.

It has been suggested that the eyes and nose of the bather be used as the correct indicators of the fitness of the water for bathing purposes. This test may have some practical value, but it can hardly be regarded as a method for scientific control.

We have formulated no standard of purity for the swimming pool water at the University of Illinois; however, an effort has been made to conform as closely as possible to the Treasury Department Standard for water used on interstate carriers. Repeated tests of samples of water from the women's pool showing no gas formers in 10 cc. portions have shown very high bacterial count, and we conclude that the total count cannot be considered a true index of pollution, as will be explained later. Even though the initial number of bacteria in the supply used to fill the swimming tank be small a rapid increase in the total number of bacteria takes place during the first few days, followed by a marked decrease in numbers, until a point is reached where there seems to be an equilibrium established and further use of the pool causes comparatively little change.

The increase in the number of bacteria may be regarded as due to the multiplication of the bacteria originally present in the supply and to the addition and multiplication of organisms from the bodies of those using the pool. If a comparatively pure water were used to fill the tank, the initial number of bacteria would be low and the multiplication of these harmless organisms would not be serious. However, the addition and multiplication of bacteria, which may or may not be pathogenic, from the bodies of bathers may be a real source of danger to all who enter the pool.

If it were possible to fill the tanks daily with good pure water the danger from the use of the pool would be very small. Owing to the scarcity and cost of water, cost of heat and labor, daily refilling of the pool is impracticable and it becomes necessary to resort to some means of purification to render the water safe for use without refilling.

Various methods for the purification of swimming pool water have been suggested and used. Filtration removes suspended matter and, to a certain extent bacteria, but does not give a sufficiently pure water unless supplemented by some other means.[2] Bleaching powder, $CaOCl_2$; liquid chlorine, Cl; copper sulphate, $CuSO_4$; and ultra violet rays have been suggested and all are in use to a certain extent. Manheimer,[3] in comparing various methods for the purification of swimming pool water, reaches the following conclusions: bleaching powder is very efficient, may be obtained at a low cost, and does not require much care in handling; liquid chlorine is also very efficient, rather cheap, and at the present time various types of apparatus are on the market which make liquid chlorine an agent easy to control; ultra violet ray machines are efficient but cost about ten times as much as bleaching powder; $CuSO_4$ is not efficient, stains the titles, causes a marked reduction in the transparency of the water, the cost is comparatively high, but it is easily handled.

The method of use, whether a slow continuous addition or a single daily dosage depends entirely upon the sterilizing agent used. $CuSO_4$

gives better results when added gradually and continuously while $CaOCl_2$ is more efficient when added in single daily doses.

The data given in this article is based on observations made on both swimming pools in the men's and women's gymnasiums at the University of Illinois.

Men's Pool'. The tank is 75 feet long by 23 feet wide and is finished in white tile; the water is 8 feet deep at one end and 3½ feet at the other end giving a total capacity of 75,000 gallons.

In 1909, Mr. George Huff, director of physical training at the University of Illinois requested that we give some chemical and bacteriological supervision to the swimming pool in the men's gymnasium. At that time the water was changed weekly and it was found on examination that the number of bacteria increased rapidly during the early part of the week and decreased about as rapidly during the latter part of • the week. It was recommended that one to one and one-half pounds of bleaching powder be added to the water in the pool. By this means the number of bacteria was decreased. In 1916 owing to the precipitation of iron in the water which comes originally from deep wells and contains 2 parts per million of iron a pressure filter was installed through which the water could be circulated. At first the use of bleaching powder was continued followed by treatment with liquid chlorine for about two months. In 1917 an ultra violet ray apparatus was installed and continued in operation most of the time since.

For circulation the water is pumped from the bottom of the deep end of the pool and with the make up water, after treatment with alum passes through a Jewel filter to the surface of the shallow end of the pool. This serves to remove the suspended matter. The filter is washed daily. After leaving the filter the water is heated by passage through steam coils and the temperature raised to 76° F., 74° for swimming meets. Students are supposed to have a soap and water bath before entering the pool, and no suits are worn. The water is in continuous circulation and the pool is refilled about four times a year.

Analyses have been made at irregular intervals since 1909. At times series of tests would be made daily for several weeks. We are giving below the results obtained during daily examinations which have extended over a period of one week each.

The first series of tests recorded in Table 1 show the results for one week when the water was being filtered and bleaching powder added in such quantities and at such times as the attendant saw fit.

The method of procedure of which the analyses in Table 1 are a test was not satisfactory.

TABLE 1—WATER IN POOL TREATED WITH BLEACHING POWDER.

Date.	B. coli 10cc.	B. coli 1.0cc.	B. coli 0.1cc.	Gelatine No. per cc.	Agar No. per cc.
1917					
April 16	1+	2—	2—	4,500	200
April 17	1+	2+	2—	36,000	12.000
April 18	1+	2+	1+, 1—	30,000	150
April 19	1+	2—	2—	7,800	7,000
April 20	1+	2—	2—	15,000	50

The second series recorded in Table 2 shows the results of analyses for one week when liquid chlorine was being added to the pool. There is a marked reduction in the number of organisms per cubic centimeter and B. coli was found in only one of the samples analysed.

TABLE 2—WATER IN POOL TREATED WITH LIQUID CHLORINE.

Date.	B. coli 10cc.	B. coli 1.0cc.	B. coli 0.1cc.	Gelatine No. per cc.	Agar No. per cc.
1917					
June 12	1—	2—	2—	250	17
June 13	1—	2—	2—	1	10
June 14	1—	2—	2—	1	1
June 15	1—	2—	2—	260	250
June 16	1+	2—	2—	1	7

The results are not as uniform nor as good as could be obtained if the plant had been carefully supervised. The use of liquid chlorine was only temporary, while the ultra violet ray machine was being installed. There was fear, probably without sufficient proof, that the chlorine was affecting the throats and eyes of the bathers.

For the last two years the water for the men's pool has been purified by the use of an ultra violet ray machine. A two-lamp machine is in use and the water is treated with alum and filtered, passing from the filter through the heater, the ultra violet ray machine and then to the pool; the water enters the pool at the shallow end through a perforated pipe placed about 6 inches above the surface of the water and falls as a spray into the water.

The odor noticed when liquid chlorine was used was probably due to the spraying of the water almost immediately after the addition of the chlorine.

A vaccuum cleaner is used about once a week to remove the solid material which settles to the bottom of the pool. The results obtained are fairly uniform and the investigation of occasional apparent failures usually disclosed the fact that either the lamps needed replacing or the machine needed cleaning. The following results of the analyses for one week may be considered representative.

TABLE 3—WATER IN POOL TREATED BY ULTRA VIOLET RAYS.

Date.	B. coli confirmed.		Gelatine No. per cc.	Agar No. per cc.
	10cc.	1.0cc.		
1919				
October 13	2—	2—	5	80
October 14	1+, 1—	2—	3	11
October 15	1+, 1—	2—	5	110
October 16	2—	2—	31	22
October 17	2+	1+, 1—	25	230

Women's Pool. The tank is 36 feet long, 15 feet wide and is finished in white tile, the water is 6 feet deep at one end and 3 feet at the other giving a total capacity of 18,000 gallons. The water is circulated by means of a centrifugal pump. Suspended matter is removed by coagulation with alum and filtration, the water is heated, 76° to 78°F., by passage through a steam coil on the way from the filters to the pool. The water enters the pool at the shallow end, the inlet pipe is about one foot below the surface of the water; the outlet is at the deep end of the pool and is placed near the bottom. Bleaching powder is added daily by drawing the required amount in a cloth bag around the edge of the pool until it is dissolved. No one is allowed to enter the pool without having a soap and water bath, no stockings are worn and only cotton suits are allowed, these suits are subjected to a steam treatment each time they are worn.

During the University session, analyses have been made five times a week.

TABLE 4—WATER IN POOL TREATED WITH A POOR QUALITY OF BLEACHING POWDER.

Date.	B. coli confirmed.		Gelatine No. per cc.	Agar No. per cc.
	10cc.	1cc.		
1919				
May 26	2—	2—	1	650
May 27	2+	2—	5	too many
May 28	2+	2—	6	too many
May 29	2+	1+, 1—	6	26000
May 30	1+, 1—	2—	8	32500

The first series of analyses, recorded in Table 4, show the results when a poor quality of bleaching powder, 1½ pounds -containing only 11 per cent available chlorine, was being used. A large number of organisms growing on agar at 37° C. were found, B. coli was present in most of the 10 cc. portions and in one of the 1 cc. portion.

The addition of a similar amount of a good quality of bleaching powder, one containing 25 per cent available chlorine, showed a marked reduction in the number of organisms present and B. coli was found only once during a period of three months. The amount of bleaching powder added, 2/3 parts per million of available chlorine, is in excess of the quantity in general use; but after thorough mixing, there is no odor noticeable and the excess is available for use against fresh pollution.

TABLE 5—WATER IN POOL TREATED WITH A GOOD QUALITY OF BLEACHING POWDER.

Date.	B. coli confirmed.		Gelatine No. per cc.	Agar No. per cc.
	10cc.	1cc.		
1919				
June 2	2—	2—	2	25
June 3	2—	2—	1	1
June 4	2—	2—	10	4
June 5	2—	2—	11	12
June 6	2—	2—	2	25

Samples of water taken from the women's pool before the addition of the bleaching powder usually showed a heavy growth of pin-point colonies while samples taken after the addition of bleaching powder were free from such growth. Colonies of this type are occassionally found: in water supplies treated either with liquid chlorine or bleaching powder To determine whether bleaching powder destroyed the organisms or merely inhibited their growth, plates were made from the treated water immediately after collection, and after the sample had been allowed to standi at room temperature for three, six, and twenty-four hour periods. The plates from samples made immediately after collection and at the end of three hours were free from the minute colonies; plates poured after the sample had been allowed to stand for six hours showed a slight growth and plates poured at the end of twenty-four hours were thickly seeded with typical pin-point colonies. This would indicate that the bleaching powder had an inhibitory action but was not fatal to organisms of this type. Since this marked increase in bacterial count took place under conditions which eliminate the possibility of increased pollution the total bacterial count cannot be considered as a fair index of pollution.

The results obtained from the treatment used for the women's pool were decidedly better than the results obtained from the treatment in use at the men's pool. The number of organisms per cubic centimeter for the women's pool, 150 samples, averages less than 250 with practically no B. coli in even the ten cubic centimeter portions; the average number of organisms per cubic centimeter, 150 samples, for the men's pool is nearly five hundred with B. coli present in half of the ten cubic centimeter portions examined and very often in the one cubic centimeter portions as well. Treatment with bleaching powder, liquid chlorine or the ultra violet rays will give satisfactory results if properly supervised.

It is suggested that in addition to the treatment of the pools more satisfactory results might be obtained if an educational campaign were started to teach people something of the care and use of public swimming pooools.

REFERENCES.

1. Atkins, Kenneth, Bacteriology of the swimming pool, Ill. "Water Supply Ass'n. 1911, 72-86.
2. Hinman, J. J. Jr., Swimming pool operation, J. Am. W. W. Assoc. 4, 86-103 (1917).
:3. Manheimer, Wallace, Comparison of methods for disinfecting swimming pools, J. Inf. Dis. 20, 1-9 (1917).
4. Mason, William P., Swimming pool management, Can. Eng. 37, 459-60.
5. Whittaker, H. A., Investigations on swimming pools at the University of Minnesota, J. Am. Med. Assoc. 70, 1901-5.

ASSOCIATIONS AND COMMISSIONS.

Certain phases of Illinois water problems are of interest to several state, interstate, national and international associations and commissions. In order to place before the citizens interested in the water supplies of the State information concerning the activity of these associations, it is customary to publish the names of the organizations with titles of articles pertaining to the water supplies of Illinois. The organizations are noted below.

STATE OF ILLINOIS, DEPARTMENT OF REGISTRATION AND EDUCATION.

F. W. Shepardson, Springfield, director. One of the departments of State Government created according to provisions of the Civil Administrative Code on July 1, 1917. The Code provides for a board of Natural Resources and Conservation Advisors in this department. This department has power to "investigate and study the natural resources of the State and to prepare plans for the conservation and development of the natural resources * * *." At a meeting of the board of advisors the State Natural History Survey Division, the State Geological Survey Division, and the State Water Survey Division were organized.

The State Natural History Survey Division. S. A. Forbes, Urbana, chief. This division is interested in the character of streams of the State with respect to their effect on aquatic life. A special study has been made to determine the effect of Chicago sewage on the plankton and food fishes in Illinois rivers, the chemical work of which has been done under the direction of the State Water Survey Division. Bulletins are published at irregular intervals. Volume XI, Article VIII of the Bulletin contains a study of "The Reactions and Resistance of Fishes' to Carbon Dioxide and Carbon Monoxide," by Morris M. Wells. In Volume XIII, Article II, by Victor E. Shelford, is entitled "Ways and Means of Measuring the Dangers of Pollution to Fisheries;" in the same volume, Article VI is by Stephen A. Forbes and Robert Earle Richardson on "Some Recent Changes in Illinois River Biology." An address by Stephen A. Forbes, "Forest and Stream in Illinois" was published as a separate.

The State Geological Survey Division. F. W. DeWolf, Urbana, chief. This division has records of well borings and information in regard to horizons from which water may be obtained. During 1918 and 1919 abstract of Bulletin 38, and Bulletin 39 were published. Bulletin 39, page 30, "The environment of Camp Grant" by Rollin D. Salisbury and Harlan H. Barrows, includes a description of the water supply of the camp.

STATE OF ILLINOIS, DEPARTMENT OF PUBLIC HEALTH.

C. St. Clair Drake, M. D., director. The powers of the department include the power "to act in advisory capacity relative to public water supplies, water purification works, sewerage system, and sewage treatment works, and to exercise supervision over nuisances growing out of the operation of such water and sewage works, and to make, promulgate and enforce rules and regulations relating to such nuisances." A monthly bulletin, "Health News," is published by the department. During 1918 and 1919 Volumes 4 and 5 were published. Volume 5, 1919, contained the following papers in regard to Illinois water supplies:

Matte, Hubert P., Contamination of Well Water, No. 5, p. 131.

Danger from Polluted Water Supplies, No. 10, p. 221.

Hansen, Paul, Water Supply and Sewerage, No. 11, p. 235.

STATE OF ILLINOIS, DEPARTMENT OF PUBLIC WORKS AND BUILDINGS.

F. I. Bennett, Springfield, director. This department has power "to exercise the rights, powers and duties vested by law in the Rivers and Lakes Commission of Illinois, its officers and employees, * * *." It is the duty of the department to have general supervision of every body of water within the State wherein the State or the people of the State have any rights or interests. A Division of Waterways has been created.

Division of Waterways. W. L. Sackett, Springfield, superintendent. Among the duties of this division is to see that all of the streams and lakes of the State of Illinois wherein the State of Illinois or any of its citizens has any right or interest, are not polluted nor defiled by the deposit or addition of any injurious substances.

PUBLIC UTILITIES COMMISSION OF ILLINOIS.

Established January 1, 1914. Thomas E. Dempcy, Springfield, chairman. The commission, as an administrative body, has jurisdiction over all private corporations and individuals who own or operate water or power plants as public utilities. Its powers do not extend to municipally owned plants. It has extensive authority over reports, accounts, capitalization, mergers, intercorporate contracts, rates, services, and facilities. A certificate of convenience and necessity from the commission is necessary to authorize a new enterprise as a public utility, and the operation of the undertaking is brought under its active control and regulation. Under the present law a public utility must be incorporated by the Secretary of State, before receiving a certificate of convenience and necessity from the Utilities Commission. No fees are charged by the commission in any action, except authorization of security issues. Much of the commission's work consists of the regulation of rates and the adjudication of complaints concerning the practices of public utilities.

UNITED STATES PUBLIC HEALTH SERVICE,

Dr. Rupert Blue, Washington, D. C., Surgeon-General. The Public Health Service publishes bulletins and a weekly journal entitled "Public Health Reports," containing current information regarding the prevalanee of disease, the occurrence of epidemics, sanitary legislation and related subjects. Volumes 33 and 34 were published during 1918 and 1919.

UNITED STATES GEOLOGICAL SURVEY.

George Otis Smith, Washington, D. C, director. The Survey has charge of stream measurements and other investigations of water resources of the country. Water-Supply Papers are issued at frequent intervals. About 485 of these papers have been published down to the end of the year 1919. Of particular interest to Illinois men of recent publication, is No. 435 on "Hudson Bay and Upper Mississippi River Basins."

INTERNATIONAL JOINT COMMISSION.

For the United States, Obadiah Gardner, chairman; Whitehead Kluttz, Southern Building, Washington, D. C, secretary. For Canada, Charles A. Magrath, chairman; Lawrence J. Burpee, secretary. Problems involving the sanitary condition of the boundary waters between Canada and the United States are referred to this commission. The final report of the commission was published in 1918.

AMERICAN PUBLIC HEALTH ASSOCIATION.

Established in 1872. Dr. Lee K. Frankel, New York City, president 1918-1919; Dr. W. S. Rankin, Raleigh, N. C, president 1919-1920;

A. W. Hedrich, Boston, Mass., secretary 1918-1920; annual meeting for 1918 was held in Chicago, Ill., annual meeting 1919 was held in New-Orleans, La. "Standard Methods of Water Analysis" is published by the association. The official publication is The American Journal of Public Health. Volume 8 was published in 1918 and Volume 9 in 1919. Volume 8 includes the following articles of interest to Illinois Water Works men:

Pearse, Langdon, Activated Sludge and the Treatment of Packing-house Waste, p. 47. ,

Ericson, John, Chlorination of Chicago's Water Supply, p. 772.

AMERICAN WATER WORKS ASSOCIATION.

Established in 1880. Charles E. Henderson, Davenport, Ia., president 1918-1919; Carlton E. Davis, Philadelphia, Pa., president 1919-1920; John M. Diven, Troy, N. Y., secretary 1918-1920, present address 153 West Seventy-first Street, New York City, N. Y. The annual meeting for 1918 was held in St. Louis, Mo., and in 1919 it was held at Buffalo, N. Y. "The object of this association shall be the advancement of knowledge of the design, construction, operation and management of water works, and the encouragement, by social intercourse among its members, of the friendly exchange of information and experience." Volume 5 of the quarterly journal was published for the year 1918 and Volume 6 for the year 1919. The following articles, read before the Illinois Section of the association are published in Volume 5:

Matte, H. P. T., Water Waste Elimination, Methods and Results at Oak Park, Illinois, p. 263.

Shelford, Victor E., Water Pollution and Fish Life, p. 434.

Parr, S. W., The Property of Certain Waters with Reference to Their Action on Metals, p. 451.

Volue 6 contains:

Amsbary, F. C, Treatment of Water to Prevent the Growth of Crenothrix, p. 194.

Monfort, W. F., and Barnes, O. A., Chloramine and Crenothrix, p. 196.

Stein, Milton F., Water Softening for Municipalities, p. 202.

Sperry, W. A., The Lime-Softening of Water and the Use of Sludges as an aid Thereto, p. 215.

Sjoblom, M. C, Typhoid Fever at Moline, Illinois, p. 230.

Anderson, A. E., The Operation of the Moline Filtration Plant, p. 238.

Judson, Everett, Differentia of B. Coli, p. 243.

McClenahan, W. T., and Rankin, R. S., Water Testing Stations, p. 248.

Habermeyer, G. C, Cost of Pumping Through Pipe Lines, p. 258.

Enger, M. L., New Well of Large Capacity at the University of Illinois, p. 263.

Howson, L. R., Unusual Ground Water Supply Conditions at Baton Rouge, Louisiana, p. 271.

Postel, F. J., The Water Supply Problem of Our State Institutions, p. 276.

Matte, H. P. T., Problems of the State Department of Public Health During the War, p. 285.

Jewell, Minna E., Quality of Water in Illinois Streams, p. 290.

ILLINOIS SECTION—AMERICAN WATER WORKS ASSOCIATION.

Established as Illinois Water Supply Association in 1909 and became a section of the American Water Works Association in 1915. W. W. DeBerard, Chicago, chairman 1918-1919; W. E. Lautz, chairman, Pekin, Ill., 1919-1920. George C. Habermeyer, State Water Survey Division, Urbana, Ill., secretary 1918-1920. This section is composed of persons interested in the water works and water supplies in Illinois. Papers dealing with topics of interest to water works men are read at the annual meetings, which are held at the University of Illinois. Many of these articles are published in "Journal of the American Water Works Association." (See list given above).

WESTERN SOCIETY OF ENGINEERS.

Established in 1895. C. B. Burdick, 1417 Hartford Building, Chicago, president 1918; A. S. Baldwin, Illinois Central Station, president 1919; Edgar S. Nethercut, 1735 Monadnock Building, Chicago, secretary 1918-1920. The annual meeting is held in Chicago. The official publication is a monthly journal; Volumes 23 and 24 were published for years 1918 and 1919.

ILLINOIS SOCIETY OF ENGINEERS.

Established in 1885. J. G. Melluish, Bloomington, president 1918; J. W. Dappert, Taylorville, 1919; E. E. E. Tratman, Wheaton, secretary 1918-1920. Water supply and sewage disposal problems form an important part of the work of the members of this organization. The official publication for 1918 and 1919. The thirty-third and thirty-fourth annual reports, include the following articles: The thirty-third contained :

Beitman, A. H., Drainage Work near Quincy, Illinois, p. 75.

Habermeyer, G. C, The State Water Survey Division, p. 112.

Report on Sewerage and Sewage Disposal, p. 120.

Report on Construction of Sewerage Works, p. 121.

Barnes, W. T., Operation and Maintenance of Sewerage Works, p. 128.

The thirty-fourth annual report, 1919, contained:

Sjoblom, M. C, Operation of Sewage Disposal Works, p. 27.

Williams, C. C, The Bloomington Water Works, p. 45.

Hill, C. D., Sewage Disposal Problem of Chicago, p. 46.

Newell, F. H., Water Resources of Illinois, p. 60.

ILLINOIS ACADEMY OF SCIENCE.

Established in 1907. E. D. Salisbury, Chicago, president 1918-1919; H. B. Ward, president, Urbana, 1919-1920; J. L. Pricer, Normal, secretary 1918-1920. The functions of the academy are the promotion of scientific research, the diffusion of scientific knowledge, and the unification of the scientific interests of the State. All residents of the State who are interested in scientific work are eligible to membership. Transactions are published annually. Volume 9 for 1916 and volume 10 for 1917 were published during the period covered by this report. Of interest to water works men. was an article by Edward Bartow on "Purification of Sewage by Aeration in the Presence of Activated Sludge" in Volume 9; in Volume 10 an article by Paul Hansen on "Relation of Public Water Supplies and Sewerage to Public Health."

SANITARY DISTRICT OF CHICAGO.

Charles H. Sergei, of Chicago, is president and George M. Wisner, of 910 South Michigan Avenue, Chicago, is chief engineer. Under provision of an act of the Legislature the Sanitary District of Chicago was organized in 1889. The primary purpose of the work of the district has been sanitation, and due to its activity sanitary conditions have been greatly improved. During 1918 and 1919 investigation of the methods of treating sewage and of its disposal have been continued. Two articles of special interest are noted. (See list under American Public Health Association).

NORTH SHORE SANITARY DISTRICT.

W. J. Allen of Waukegan is president. In addition to the president the following are members of the Board of Trustees: J. T, Hayes, Homer Cooke, John Oliver, James Anderson, Jr. The members of the Board of Engineers are: John W. Alvord, Chicago; Harrison P. Eddy, Boston and Chicago; George W. Puller, New York. In April, 1914, the North Shore Sanitary District was created in accordance with "An Act to create sanitary districts, and to provide for sewage disposal." The duties of the Board of Trustees are, chiefly, to provide for the disposal of sewage and to preserve the water supplied to the inhabitants from contamination. The district has acquired 30 acres of land for the location of a purification plant, has investigated methods of sewage treatment, and has raised money which is available for construction.

DECATUR SANITARY DISTRICT.

W. C. Field of Decatur, president, and Porter Milliken, W. M. Wood, and Wm. C. Field are members of the Board of Trustees. Preston T. Hicks is chief engineer. In August, 1917, in accordance with an act passed the same year the Decatur Sanitary District was organized. Money has been raised by taxation, engineers employed to prepare plans for intercepting sewers, and some contracts let for their construction. It is expected that money will be available for a purification plant.

BLOOMINGTON-NORMAL SANITARY DISTRICT.

John W. Harber, president, John J. Condon, treasurer, and Fred D. Barber, clerk, are members of the Board of Trustees. Richard Dunn is attorney and Elmer Fulsom and Milo C. Taylor are the engineers. In November, 1919, the Bloomington and Normal Sanitary District was organized under the provisions of the act of 1917. The area included in this district is about 8 square miles. Surveys are being made for an intercepting sewer. In consultation with the State Water Survey, preliminary investigations of the methods of sewage disposal have been made.

EL PASO SANITARY DISTRICT.

Arthur Henning is president, and in addition to the president, John W. McKinney and John Scofield are members of the Board of Trustees. Miller, Holbrook, and Warren are the engineers. The district was organized early in 1919. It takes in the full city but nothing outside.

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