DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 254

E UNDERGROUND WATERS OF NORTH-CENTRAL INDIANA

BY

STEPHEN R. CAPPS

WITH A CHAPTER ON

'HE CHEMICAL CHARACTER OF THE WATERS

BY

R. B. DOLE

WASHINGTON
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ILLUSTRATIONS.

UNDERGROUND WATERS OF NORTH-CENTRAL INDIANA.

By Stephen R. Capps.

INTRODUCTION.

NEED OF INVESTIGATIONS.

The region discussed in this report includes an area of 7,611 square miles in north-central Indiana, between 85° 27′ and 86° 44′ west longitude and 39° 36′ and 41° 46′ north latitude. The counties included are Hendricks, Marion, Hancock, Boone, Hamilton, Madison, Clinton, Tipton, Carroll, Howard, Grant, Cass, Miami, Wabash, Fulton, Marshall, Kosciusko, St. Joseph, and Elkhart. (See fig. 1.)

The work was undertaken during the season of 1907 as a part of the underground-water investigations of the United States Geological Survey. The object of these investigations is to supply to communities, municipalities, and water users generally definite information as to the quantity, quality, distribution, accessibility, and proper safeguarding of the ground-water supplies, which, with the increasing pollution of surface waters by industrial wastes and a growing population, are becoming more and more important. North-central Indiana includes not only many closely settled farming and manufacturing centers, but a region in which there has been extensive development of the oil and gas industries, and hence there is particular need for reliable information upon which to base a proper practice in water-supply development. In such development in the future ground waters will share as they have in the past. They are utilized for domestic supplies, for manufacturing enterprises of various sorts, and by railroads and other users of steam power. In some places large sums have been wasted in unwise attempts at development, as, for example, in deep drilling at points where a careful study of conditions proves that suitable supplies are to be found at shallow depths or not at all.

PREVIOUS WORK.

In 1899 a paper on the wells of northern Indiana, by Frank Leverett,[a] was issued by the Geological Survey. Although Mr. Leverett collected the material for this paper during his investigations of the

[a] Wells of northern Indiana: Water-Supply Paper U. S. Geol. Survey No. 21, 1899.

glacial geology of the State and was not directing his attention particularly to the conditions of water supply, his results were found to be of such value that the edition of his paper was soon exhausted.

W. S. Blatchley,[a] of the Indiana Geological Survey, has published an excellent paper on the mineral waters of Indiana. This paper,

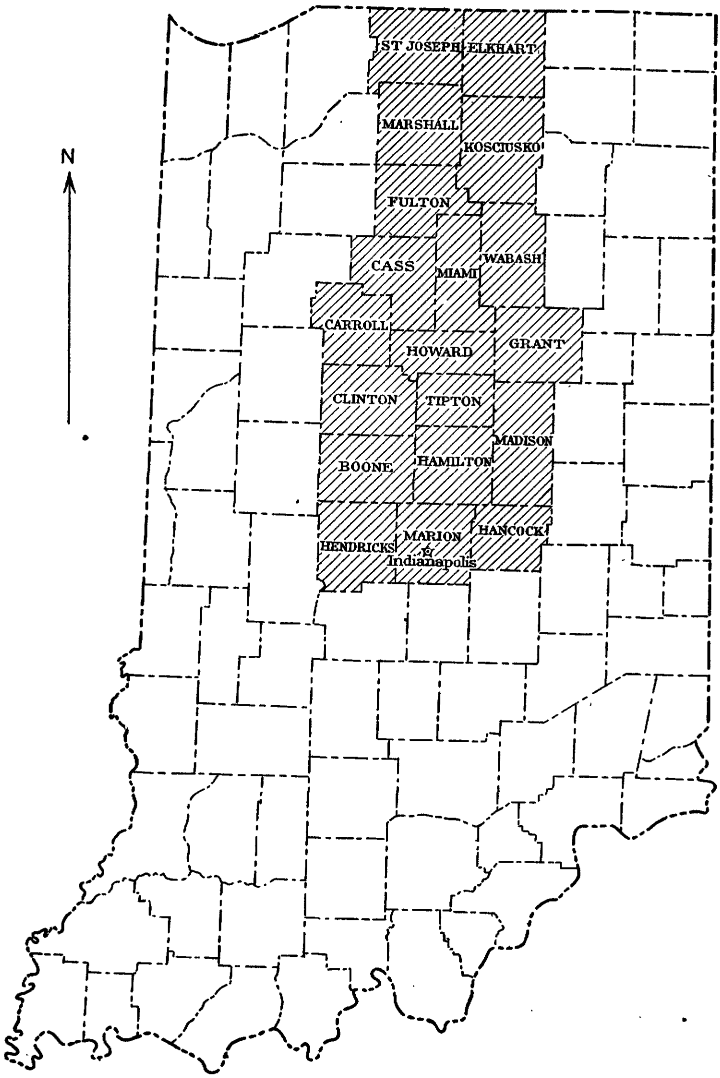

FIGURE 1.—Index map showing area covered by this report.

as its title indicates, deals only with a special phase of the general problem. In the sixteenth report of the state geologist of Indiana, the records of many deep wells are given, and a number of these records are used in the present paper.

[a] Blatchley, W. S., Mineral waters of Indiana: Twenty-sixth Ann. Rept. Indiana Dept. Geology and Nat. Res., 1901.

The report of the Indiana state board of health for 1906 includes a description of the public water systems of the State. This paper, by H. E. Barnard, although brief, contains valuable data. Other scattered references to underground-water conditions occur in the various reports of the Indiana Geological Survey, but these reports are not complete for any considerable areas.

In this report many valuable data have been taken from the various reports of Frank Leverett, especially in regard to the glacial geology of the area. The map of the glacial geology (Pl. I) is compiled from his earlier maps and from an unpublished map which will appear more fully under his name in a report of this Survey which is now in the hands of the printer. The geologic map in this report follows the geologic map of Indiana, by T. C. Hopkins,[a] and the geologic section is compiled from sections published by W. S. Blatchley and George H. Ashley,[b] and by Frank Leverett.[c]

CONDITIONS UNDER WHICH WORK WAS DONE.

The field work upon which this report is based was begun July 1, 1907, under the direction of F. G. Clapp. Mr. Clapp remained in the field until September 10, and the writer until November 9, of the same year. After Mr. Clapp withdrew from the field to undertake investigations elsewhere, the northern four counties were investigated wholly by the writer, by whom the report on the whole area was prepared.

The field study of the geology of this region was necessarily confined for the most part to the Pleistocene deposits, since the underlying rocks outcrop at the surface at widely separated localities, because of the thick mantle of glacial deposits overlying them. But wherever rock outcrops could be found they were studied carefully, especial attention being paid to joints, bedding planes, and other openings with reference to their capacity for holding or affording passage for underground waters.

Every township and every community of 25 people or more was visited and an examination made of the conditions of the local water supply. It was not possible to visit each well, but when such visits were impracticable correspondence with the owners yielded much information.

GENERAL SUMMARY OF RESULTS.

In the area under discussion a great variety of conditions are met in endeavoring to obtain supplies of underground water. About two-thirds of the area is covered with drift to a depth of over 100 feet, and in such places by far the greater number of the wells obtain

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[a] Hopkins, T. C., Geological map of Indiana; Indiana Geol. Surv., 1901–1903.

[b] Rept. Indiana State Geologist, 1897.

[c] Water-Supply Paper U. S. Geol. Survey No. 114, pp. 258–263.

their water from the drift. In the areas where the drift is less than 100 feet thick the conditions also vary greatly. Where rock lies at a depth of 30 feet or less the greater number of wells reach or penetrate the rock. Where the drift is more than 30 feet thick less than half the wells reach the rock. This 30-foot dividing line is only approximate, however, and the conditions vary in different localities. As driven and drilled wells become more common the number of them that reach the rock increases.

There are few places in the area where enough water for domestic purposes can not be obtained at moderate depths. Difficulties are often met, however, in obtaining wells of sufficient yield for public supplies or for manufacturing purposes where large quantities of water are needed.

In order that the sources of the most abundant and accessible water supplies in this area might be reported upon definitely, the conditions in 378 cities, towns, and villages were investigated, and a considerable amount of work was done in the country districts between these communities.

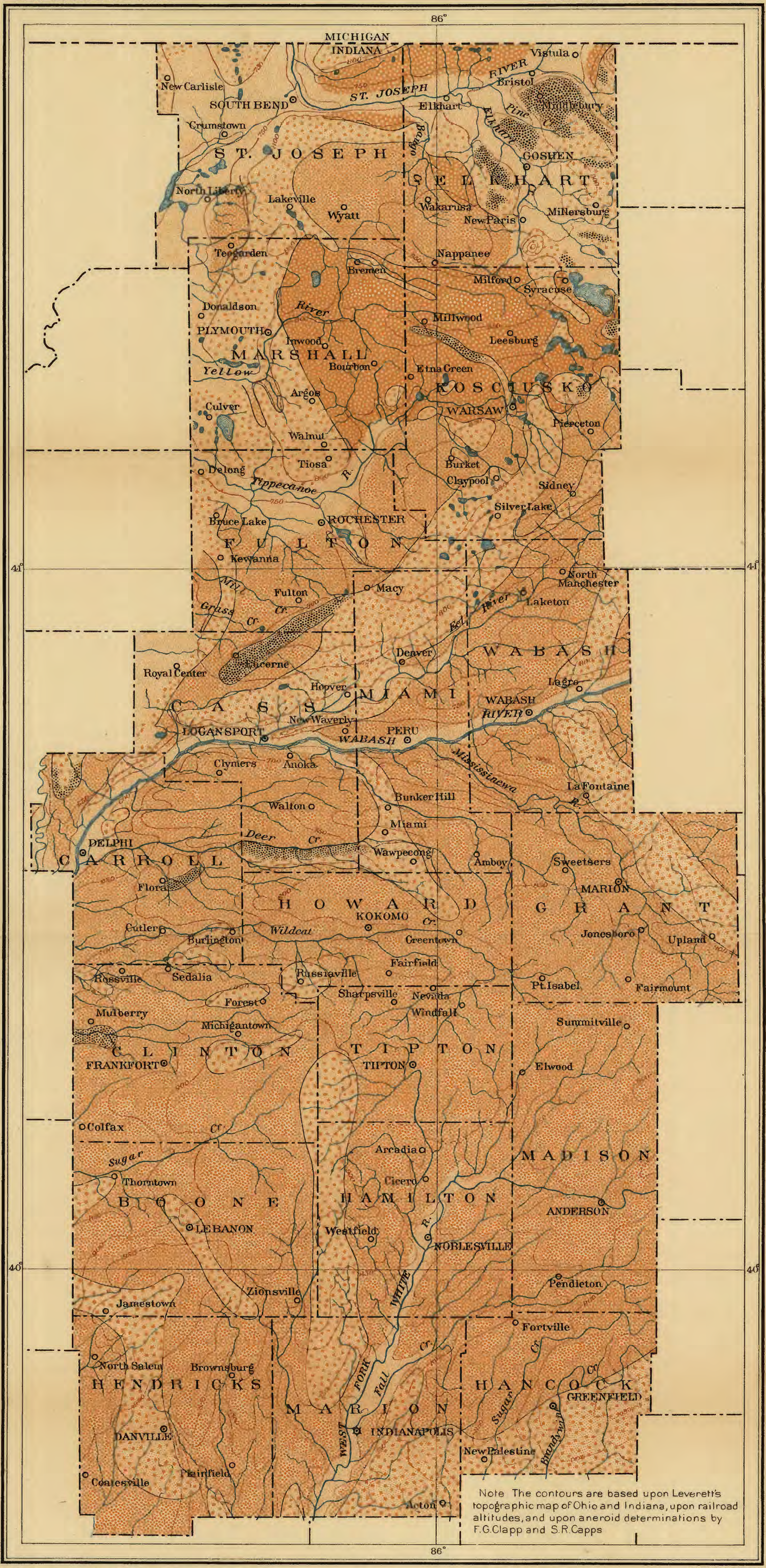
Especial attention was paid to the water conditions in communities having public supplies. Recommendations are herein made as to possible improvements where such supplies are inadequate or show bad sanitary conditions.

More or less complete records of about 1,200 wells were procured. The more significant of these in each county, as well as the analyses of the various waters, are tabulated at the end of each county description.

In all, 83 areas in which flowing wells occur were visited and their outlines mapped. These areas are discussed in the county descriptions, and suggestions are made as to the possibility of obtaining flowing wells.

ACKNOWLEDGMENTS.

From the nature of the work it was necessary that information should be obtained from a very large number of persons, of whom it is impossible to make individual mention but to all of whom thanks are due for courtesies rendered. To Dr. J. N. Hurty, secretary of the state board of health, and to Dr. H. E. Barnard, chemist of the state board of health, the thanks of the author are particularly due for courtesies in analyzing water samples and for other assistance. In each congressional district the Representative gave valuable information and aid. The officials of the various railroads in the area have been uniformly courteous in furnishing information concerning the waters along their lines. A large number of chemical analyses and well records were obtained from the files of the Pittsburg, Cincinnati, Chicago and St. Louis Railway, the Lake Erie and Western Railroad, the Cleveland, Cincinnati, Chicago and St. Louis Railway, the Lake



Compiled from published and unpublished maps by Frank Leverett of the Pleistocene deposits of Indiana.

A. HOEN & CO. BALTIMORE.

MAP OF NORTH-CENTRAL INDIANA
SHOWING THE SURFACE DEPOSITS

BY STEPHEN R. CAPPS

Scale $\frac{1}{625,000}$

10 0 10 20 Miles

Contour interval 50 feet

1909

LEGEND

Alluvium | Moraines | Till plains | Outwash aprons and sandy till plains | Bowlder belts

Shore and Michigan Southern Railway, and the Erie Railroad. Records of a great number of oil and gas wells were obtained from Mr. L. A. Von Behren, of the Marion Gas Company; Mr. Charles Dale, of the Cicero Gas Company; Mr. Sherman, of the Noblesville Gas and Improvement Company, and many others. Material assistance was rendered by the majority of the superintendents and chief engineers of the city waterworks of the region, among whom Mr. H. McK. Landon, of the Indianapolis Water Company, and Mr. E. E. Hully, of the Marion Water Works Company, furnished especially valuable data. Of the many well drillers who were seen, the following made some sacrifice of time to give information: Messrs. John E. Weigel, of Marion; Charles Million, of Lake Cicott; the firm of Linton & Graf and Mr. Wm. H. Hayworth, of Logansport; Messrs. D. M. Kimmerling, of Anderson; S. Mason, of Fisher's Switch; Patrick O'Shea, of South Bend; and T. F. Hersey, of Lebanon. In addition to the foregoing a number of other citizens have taken interest in the work and given exceptional assistance in various ways. Among these are: The Hon. C. B. Landis, of Delphi; Mr. T. E. Cartwright, of Summitville; Dr. C. W. Burket, of Warsaw; Mr. Cicero Simms, of Frankfort; and Mr. S. T. Mark, of Alexandria.

GEOGRAPHY.

DRAINAGE AND RELIEF.

General relations.—Except Elkhart County and parts of St. Joseph and Kosciusko counties, which drain by St. Joseph River into Lake Michigan, and a considerable portion of St. Joseph and Marshall counties, which drain by Kankakee River into Illinois River, the area under discussion lies in the Ohio River basin. It is a plateau from 700 to slightly more than 1,000 feet above sea level. Only the deeper river valleys fall below the lower limit, White River at the south edge of the area having an elevation of less than 700 feet, while Wabash River, at the west-central edge, has incised its valley considerably below the 600-foot level. The total range in elevation is about 450 feet. (See Pl. I.)

Wabash River system.—The largest and most important drainage basin of this region is that of Wabash River. This stream flows somewhat south of west across Wabash, Miami, Cass, and Carroll counties. It has a deep, well-developed valley, which is cut 100 to 150 feet below the level of the bordering uplands. The flood plain of the stream varies in width from one-fourth mile to 2 or 3 miles, and is generally limited by bluffs of Niagara limestone, into which the valley has been cut. Wabash River and its tributaries drain about 4,050 square miles of the region under discussion, considerably more than one-half the whole area.

The most important tributaries of the Wabash are (1) Mississinewa River in Miami, Wabash, and Grant counties; (2) Eel River in Kosciusko, Wabash, Miami, and Cass counties; (3) Tippecanoe River in Carroll, Kosciusko, and Fulton counties; (4) Pipe Creek in Cass, Miami, and Grant counties; (5) Wild Cat Creek in Carroll and Howard counties; (6) Eel River in Cass, Miami, and Wabash counties.

White River system.—Next in importance to the Wabash basin in respect to the area drainage is the basin of West Fork of White River, with an area in this district of about 1,900 square miles. The stream flows west and south across Madison, Hamilton, and Marion counties and furnishes water for a number of the larger cities along its banks. The only important tributary within this area is Fall Creek, which flows through the same counties as White River but lies farther south and east.

Most of Hancock County and small areas in eastern Marion and southern Madison counties drain through Sugar and Brandywine creeks and their tributaries into East Fork of White River. Neither of these creeks is notable for its size or for the development of its valley.

Kankakee River system.—The northern two-thirds of Marshall County and the south and west parts of St. Joseph County are drained by Kankakee River and its tributaries. The river flows southwestward through the Kankakee marsh and joins Desplaines River below Joliet, Ill., to form Illinois River.

St. Joseph River system.—In the northeast corner of the region there is an area of about 700 square miles, including Elkhart and parts of St. Joseph and Kosciusko counties, which is tributary to St. Joseph River. This river flows into Lake Michigan and belongs to the great St. Lawrence drainage basin. It makes a loop southward from Michigan into Elkhart County and flows west-southwest to South Bend, at which city it turns sharply northward and reenters Michigan. Elkhart River, its only important tributary in Indiana, traverses Elkhart County from south to north and receives the drainage from a part of northern Kosciusko County.

Lakes.—Scattered throughout the morainic portions of this region are many small lakes and ponds. Almost without exception these lakes occupy basins left in the irregular surface of the glacial moraine deposits. Kosciusko County alone has over 60 such lakes, and they are numerous in St. Joseph, Elkhart, Marshall, and other counties. In spite of the abundance of these bodies of water there is none of great size. Wawasee and Syracuse lakes in northeast Kosciusko County are connected and form the largest lake in the area. They are together 6 miles long and have an area of a little more than 5 square miles. Some of these lakes, including Maxinkuckee, Wawasee, and Winona lakes, have become popular as summer watering places.

Marshes.—Much the same agencies that produced the lakes of this region have caused the extensive marshy areas that have existed, especially in the northern counties. Considerable areas in Fulton, Marshall, Kosciusko, and St. Joseph counties were formerly so marshy that cultivation was out of the question. Much has been done in the last generation to reclaim these wet lands, and networks of drainage ditches have so reduced the water level in some of the marshes that they are now annually plowed without great inconvenience from the moisture. The ditching is still in progress and the area of the waste lands is being rapidly reduced. Ditching projects have been especially successful in Cass, Kosciusko, and Marshall counties, and in these and in St. Joseph County are the largest of the areas still to be drained.

CLIMATE.

Northern Indiana is a region of temperate climate and moderate rainfall. The following tables show the temperature and precipitation for some stations within the area from 1900 to 1906, and by months for 1907. It will be seen that the highest temperature recorded in this period was 106° F., at Indianapolis in the summer of 1901, and the lowest was −24° F., at Delphi in the winter of 1905. These were both exceptional seasons, the average range of temperature for these cities being less than 110°.

Temperature at seven Indiana cities, 1900–1906.

[Degrees Fahrenheit.]

	1900.			1901.			1902.		
	Maximum.	Minimum.	Mean.	Maximum.	Minimum.	Mean.	Maximum.	Minimum.	Mean.
Anderson	94	−7	....	104	−11	51.2	93	−7	51.8
Delphi	97	−7	51.6	104	−12	49.9	95	−12	49.9
Indianapolis	94	−7	54.0	106	−10	52.0	93	−5	52.4
Kokomo	93	−6	52.7	102	−9	....	94	−7	51.4
Logansport	95	0	52.1	105	−12	50.2	96	−11	50.7
Marion	98	−9	52.7	105	−12	50.9	97	−10	51.2
South Bend	93	−9	50.9	103	−15	49.1	91	−11	49.5

	1903.			1904.			1905.			1906.		
	Maximum.	Minimum.	Mean.	Maximum.	Minimum.	Mean.	Maximum.	Minimum.	Mean.	Maximum.	Minimum.	Mean.
Anderson	96	−8	51.1	92	−13	49.1	90	−17	50.9	93	−10	......
Delphi	100	−12	49.4	95	−20	47.6	95	−24	49.3	96	−13	......
Indianapolis	94	−9	51.9	91	−7	50.3	92	−16	51.8	92	−2	......
Kokomo	97	−10	50.7	......	−12	......	94	−20	50.3	96	−19	......
Logansport	97	−10	......	95	−15	47.8	96	−19	49.2	98	−9	......
Marion	97	−12	50.6	94	−18	48.2	95	−20	50.3	95	−14	......
South Bend	93	−10	48.1	94	−11	45.7	......	......	......	95	−6	......

Precipitation at seven Indiana cities, 1900–1907.

[Inches.]

	1900.	1901.	1902.	1903.	1904.	1905.	1906.	1907.
Anderson	....	28.68	39.20	34.68	40.61	45.33	32.85	43.33
Delphi	40.69	30.92	42.51	33.48	40.23	40.87	39.27	44.91
Indianapolis	38.45	30.33	37.70	32.46	45.42	33.27	36.47	38.56
Kokomo	40.65	31.37	40.86	31.50	....	....	35.97	38.54
Logansport	30.96	29.52	39.96	38.38	32.43	38.14	41.70	44.62
Marion	37.94	32.35	40.63	39.81	41.88	39.64	43.54	43.70
South Bend	34.55	30.93	41.53	42.32	31.47	39.27	35.53	43.58

Temperature at eight Indiana cities, by months, 1907.

[Degrees Fahrenheit.]

	January.			February.			March.			April.		
	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.
Anderson	66	−1	33.0	59	3	28.7	82	20	48.0	75	22	42.3
Delphi	66	−2	29.8	58	0	26.4	85	17	44.8	80	19	41.4
Indianapolis	69	2	......	63	6	......	82	24	......	75	27	......
Kokomo	67	−3	32.8	59	−0	28.4	84	17	48.0	77	20	41.9
Logansport	65	−1	30.2	61	−0	27.2	86	18	46.6	78	20	42.4
Marion	65	−3	31.8	58	2	27.6	85	18	46.6	79	19	43.2
Rochester	60	−2	30.6	50	−1	26.5	75	20	44.6	69	21	41.4
South Bend	65	−4	26.7	53	−3	24.4	82	15	41.6	70	17	39.0

	May.			June.			July.			August.		
	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.
Anderson	83	32	56.2	88	40	66.7	90	52	73.4	89	49	70.2
Delphi	84	28	54.8	92	42	66.8	93	45	73.6	94	45	70.0
Indianapolis	83	34	......	88	45	......	93	52	......	90	54	......
Kokomo	82	29	54.5	92	40	66.5	90	45	72.7	93	45	69.8
Logansport	85	30	55.8	94	44	68.2	93	46	75.2	95	46	71.2
Marion	84	28	55.2	93	38	67.2	91	48	74.2	92	45	70.5
Rochester	80	30	55.0	88	42	67.9	88	50	74.2	87	48	70.1
South Bend	80	26	51.9	90	45	65.6	87	47	71.0	90	45	69.0

	September.			October.			November.			December.		
	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.
Anderson	86	37	64.9	82	20	51	61	18	39.3	60	10	33.4
Delphi	92	33	63.7	86	23	48.8	60	15	37	60	9	30.8
Indianapolis	87	40	......	83	31	......	58	20	......	60	18	......
Kokomo	90	33	63.4	85	25	49.4	58	15	39.1	60	11	34.6
Logansport	95	35	65	89	26	50.2	59	17	39	61	10	32
Marion	88	33	64.2	84	55	49.8	56	17	38.2	60	9	32.4
Rochester	85	37	63.2	72	27	49.3	55	19	38.1	55	10	31.8
South Bend	91	35	63	83	27	48.4	56	26	37.9	55	14	29.8

Precipitation at eight Indiana cities, by months, 1907.

[Inches.]

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Anderson	6.40	0.15	4.69	2.76	2.85	4.88	6.93	4.85	2.27	1.89	2.18	3.48	43.33
Delphi	7.00	.32	3.93	1.91	2.87	5.50	6.43	3.86	3.94	1.31	2.31	5.53	44.91
Indianapolis	7.68	.18	4.07	2.07	2.85	4.68	4.41	2.33	2.31	2.23	2.52	3.23	38.56
Kokomo	5.59	.04	3.80	2.08	3.15	4.45	4.88	4.05	2.51	2.42	1.74	3.83	38.54
Logansport	4.60	.35	3.92	1.71	4.07	6.38	5.79	6.13	2.71	1.70	2.42	4.84	44.62
Marion	7.01	.15	4.62	2.64	2.35	7.46	3.97	3.82	2.66	2.35	2.00	4.70	43.73
Rochester	4.80	.15	5.31	2.32	4.20	6.46	4.61	2.99	4.73	1.60	2.57	4.40	44.14
South Bend	3.42	.42	3.91	3.76	4.13	4.83	5.10	3.48	4.82	2.43	2.36	4.92	43.58

The annual precipitation, which is rather evenly distributed, varies from about 30 inches in very dry seasons to over 40 inches in wet seasons, but even in the driest seasons there is usually enough rain to insure crops.

As the ground is frozen for about four months each year, and the precipitation then is of course in the form of snow, very little of it can enter the ground during that period. During the remaining eight months the soil is in condition to absorb large amounts of the rainfall, and this goes to swell the ground-water supply. The direct influence of the rainfall on shallow wells is noticeable wherever such wells are in use. During the spring, when the rainfall is heaviest, and when, in addition, the snows that have accumulated on the surface during the winter melt, the ground-water level often rises notably, sometimes filling wells nearly to the top and flooding cellars which are not tightly walled and floored. Later, in the dry summer months, the water table is lowered by evaporation from the surface, by leakage from springs and seeps along the lowlands, and by the drain upon the waters by vegetation and by wells. In seasons of exceptional drought the water table may be so lowered below the bottom of the shallower wells that they fail. Often if such wells are deepened a few feet the water table is again encountered, and the wells once more become productive.

The influence of climatic or seasonal conditions on the deeper wells is much less evident. In most deep-lying formations the movements of the water are very slow, and a change in the supply caused by seasonal conditions might be observable, if at all, not until long after the cause for the change had passed.

The waters in many deep water-bearing rocks are under hydrostatic pressure from a head at some distant point, and are separated from the surface by impervious beds. Under such conditions, changes in season or in rainfall in the area about the well would have no effect whatever upon the supply of the well, unless they also were effective in the region from which the water-bearing beds derived their supply.

NATIVE VEGETATION.

The greater part of northern Indiana was originally heavily timbered, and the timber lands still produce a considerable amount of saw logs. The white, red, and burr oak logs are much sought, and the best bring high prices from the manufacturers of furniture and veneer. Beech is the timber of next importance; hickory, elm, ash, and maple are also abundant.

The timber lands are now nowhere extensive, and have been reduced to small areas which are surrounded by cultivated fields. Carelessness and waste are still exhibited in the management of the timber lands and the cutting of timber, and a little study and care would greatly increase the future production of the forests, which become more and more valuable with the rapidly advancing price of lumber.

Undisturbed timber lands are admirable agents in the conservation of underground water. The thick loamy soil of woodlands, formed of decaying matted leaves and roots, is well adapted to retain moisture, and the shade of the forest greatly retards evaporation. By retaining the water that falls upon them the forest soils reduce the run-off and increase the quantity that sinks into the ground. Thus the forest lands act as reservoirs and assist in equalizing the ground-water supply. In the areas where all forests have been cut away and the fields put under cultivation it has been noticed that the water table has fallen, and wells which formerly furnished abundant water are now dry for part of the year.

SOILS AND CROPS.

The soils of northern Indiana, though varied, are for the most part rich, as are most of the soils in the Mississippi Valley which have been deposited by glacial agencies. Most of the farm lands have a soil composed of a mixture of oxidized glacial clay and organic material. The glacial till is a mixture of ingredients gathered from the country to the north, and the efficiency of this mixture has long been known from the large production of most of the areas which were fortunately coated with it. As far down as it reaches this till is fertile, and as the average thickness over northern Indiana is more than 100 feet, there is at least no immediate danger that the soils will be removed from this region by erosion. The glacial drift, originally bluish, has commonly been oxidized to yellow for a few feet below the surface.

In many areas which are or have been low and marshy there is a layer a foot or two thick of light, black soil largely composed of decomposed vegetable matter. This soil is locally called muck, and in certain sections it produces large crops of onions and potatoes. The vegetable matter has in some places accumulated in sufficient amount and purity to form a considerable layer of peat.

Along the bottom lands of both large and small streams are found the alluvial soils. The extent of these alluvial areas varies with the width of the valley bottoms, but wherever found they furnish most desirable farming land, unless the high waters from the streams flood them too frequently.

In the northern counties there are broad flat areas mapped by Leverett as sandy till plains (Pl. I), in which are various combinations of till-plain and outwash materials. As a whole the soils in these areas contain more sand and gravel than the soils of the typical till plains, as in much of western Kosciusko and eastern Marshall counties.

Along the west edge of Marshall, Fulton, St. Joseph, and Cass counties are areas where the surface materials consist for the most part of impure sands. These sandy areas are on the eastern edge of what was in glacial times a broad shallow lake, which has been named Lake Kankakee. The sands were deposited along the shores of the lake and winds have spread them over much country that never lay beneath the lake itself. The sandy soils are cultivated in many places, but will not support as heavy crops as the clayey soils.

Northern Indiana falls within the "corn belt," and a greater acreage is devoted to this cereal than to any other crop. Over much of the country wheat is a close rival at present, the high price of wheat in the past few years having caused much land which had previously been used for corn culture to be planted in wheat. Oats and other cereals are also important crops, while in some places onions and potatoes are cultivated almost to the exclusion of the grains.

SPECIAL FACTORS IN DEVELOPMENT.

Oil and gas.—Within the last twenty-five years rich strikes of petroleum and natural gas have been made in various parts of the area, and, as usual, many people have been attracted to the oil and gas fields. The oil was piped or hauled to various centers outside of the producing fields to be refined, but the gas drew to the fields a multitude of manufacturers who, seeing increased profits from the use of this cheap and abundant fuel, located their plants wherever the gas was to be had. A list of the various users of gas for manufacturing purposes in the year 1888 is given in one of the reports of the Department of Geology and Natural History of Indiana.[a] Since that report was published, however, the supply has diminished greatly and numerous wells have been abandoned. Some districts have "played out" entirely. Many factories found it impossible to operate successfully, and their vacant buildings are a common sight in the old gas fields.

Transportation.—The situation of the area gives it uncommon transportation facilities. All the railroads between Chicago and the East take courses south or southeast around the south end of Lake Michigan, and most of these roads cross the area considered in this report. In addition, a network of railroads crosses in other directions, and these roads, with the increasing number of electric interurban lines, afford exceptional opportunities for marketing crops and for easy communication between towns. The rapid development of the country is in large measure due to these conditions.

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[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., pp. 280-301.

INHABITANTS.

The nineteen counties covered by this report have an aggregate area of 7,611 square miles. As shown by the census of 1900, the population was then 781,690, an average of 102 inhabitants to the square mile. The actual distribution of the population, however, is rather irregular. In Fulton County settlement is least dense, there being but 45 people to the square mile, while in Marion County the average is 493 to the square mile. This high average is due, of course, to the location in Marion County of Indianapolis, which is much the largest city in the State.

South Bend, the second city in size in the area, had, in 1900, a population of 35,999. There were at that time no other cities larger than 30,000.

Aside from the cities, the population throughout the nineteen counties is rather evenly distributed, and the larger counties have, in general, a proportionately large population.

GEOLOGY.

OUTLINE OF GEOLOGIC HISTORY.

Briefly, the geologic history of this area is as follows: For a very long period, during Cambrian, Ordovician, Silurian, Devonian, and Carboniferous times, the seas over this region varied in depth from time to time, giving the conditions necessary for the successive formation of sandstones, shales, and limestones to a thickness of several thousand feet. Between the deposition of the Cambrian and the Carboniferous sediments there were certainly a few and probably many periods when land emerged from the seas and was worn away by the streams, waves, and winds. After and probably during Carboniferous time there was a general emergence of this land from the water, and perhaps the area has never since been covered by the sea. At different times during the slow processes of sedimentation and of changes in the relations of land and sea stresses were set up in the rocks of the earth's surface at certain places and the beds were locally folded and distorted, as we can now see by the notable departure of the beds from the horizontal, as at Delphi. During this long period of emergence the land was subjected to the erosion of streams and other agencies and was doubtless notably reduced. The land surface was cut into ridges and valleys and the streams established well-developed drainage lines. This was the condition at the beginning of the glacial period.

The glacial period began when a great glacier slowly advanced from the north, covering the land with ice many hundreds and perhaps many thousands of feet thick. The more prominent irregularities of the rock surface were worn away and the topography was fundamentally changed. In the course of time, from changes in climatic conditions, the glacier melted back far to the north, leaving behind it great quantities of detrital material. Later there came again at least one and perhaps more than one ice invasion, reducing still further the rock surfaces or overriding the former deposits and adding to the already enormous deposits of glacial débris.

With the final withdrawal of the ice the Recent period was begun. Since the beginning of this period the streams and other erosional agencies have been constantly at work, reestablishing drainage lines to replace those which the glaciers disturbed and placing under stream control the irregular surfaces of the glacial deposits. Much work still remains to be done by the streams before the marshes and lakes are all drained, but this work is being forwarded in a notable way by the artificial construction of drainage ditches.

RELATIONS OF GROUND WATER TO GEOLOGY.

A very intimate relation exists between the geology of a region and its underground water supply. With the temperate climate and abundant rainfall with which the area here under discussion is favored, the abundance of the ground water, the ease with which it can be obtained, and the character of the water depend in great measure upon the structure, texture, and composition of the materials which compose the upper portion of the earth's crust. The underground waters occupy the openings of various kinds which exist in the materials below the surface. With favorable conditions of topography, the underground waters will be easily available if such openings are numerous, large, and continuous, and will be difficult to obtain if the openings are few, small, and discontinuous. The chemical character of the water, too, is determined by the chemical composition of the materials through which it passes, by the solubility of the constituents, by the length of time the water remains in contact with the soluble elements, and by conditions of pressure, temperature, etc. A fuller discussion of the relation of the different types of materials to the underground waters will be given in the following pages. As the relation of the underground waters to the formations in which they occur is a definite one, it is possible, if the character, composition, and depth of the underlying formations are known, to predict with a considerable degree of accuracy the amount, character, and depth of the water which may be obtained by wells in a given place. A careful study of the geology and of the succession of geologic formations is therefore necessary for a proper interpretation of the facts collected in an investigation of this kind.

EFFECT OF GLACIATION ON TOPOGRAPHY.

MOVEMENTS OF THE ICE.

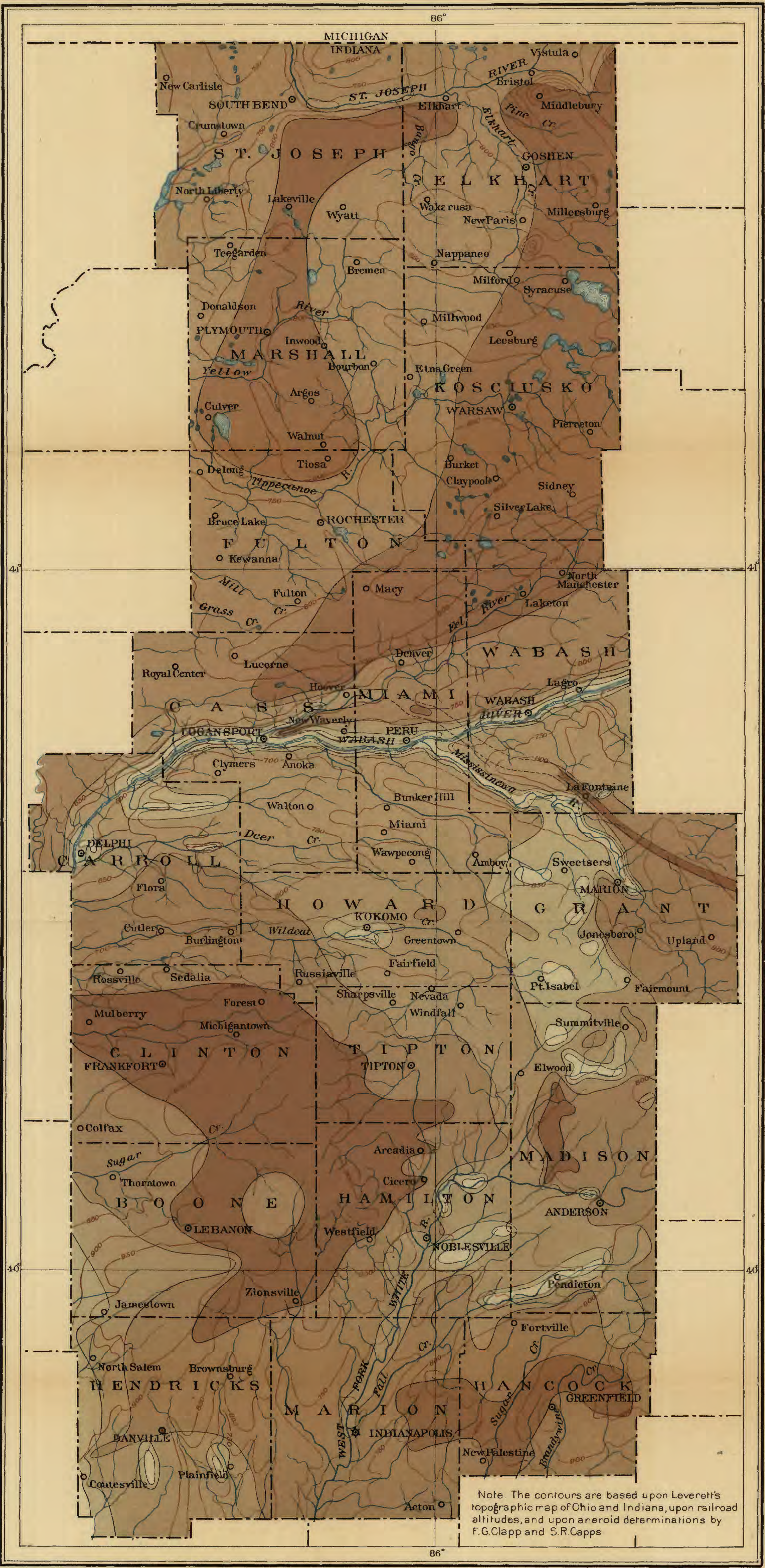
Before the great ice invasions of the glacial epoch the topography of this region was very different from that of the present. At that time the great sheet of bowlder clay, now covering the region, was absent, and the then-existing surface forms were the result of erosion by preglacial streams in the rocks which at present underlie the mantle of glacial deposits. Most of these earlier stream valleys had courses very different from those followed by the present streams, and the surface of the country was much steeper and more rugged than it is now. Upon the advance of the great glacier from the north all this was changed. The ice, moving slowly south, first removed all the soil and loose materials, and then, with its base shod with fragments of rock frozen into the ice, gradually wore down the hills and smoothed off the most prominent irregularities. Great quantities of rock débris were picked up and carried by this ice sheet. Much of this material was collected from areas far to the north, from which the ice came, and many bowlders of crystalline rock are scattered over the surface and incorporated with the bowlder clay. As there are no crystalline rocks in place for a long distance north of the present position of some of these bowlders, it is certain that they must have been carried far before they were dropped by the ice.

The materials which the ice gathered in its southward journey were deposited toward the south or melting edge of the glacier. Much was deposited beneath the thinning glacier edge as till, filling depressions and grading over the worn rock surfaces. Many of those stream valleys which had not been erased by the grinding action of the glacier were filled full and leveled over by the deposits of glacier-brought débris. Some such filled-in valleys can be recognized by collecting the records of well drillings, some of which show a great depth to rock, while others near by reach rock at much shallower depths. Such an old preglacial valley is that described by J. A. Bownocker,[a] which runs from the Ohio River Valley near Cincinnati north along the present Little Miami Valley, and then northwest and west through Grant and into Wabash County. This buried canyon certainly continues still farther north and west, but the data at present available are insufficient to determine its entire course. There is some evidence that it follows the course indicated in Plate II, across Wabash and Miami counties.

It has been shown[b] that this region has been subjected to more than one glacial invasion, but it was the last ice advance that had the greatest influence in molding the present surface, for the last

[a] Ohio State Acad. Sci., Special Paper No. 3.

[b] Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 4, 1898, p. 434.



Compiled from well records. The outlines of the different areas can be considered only approximate.

MAP OF NORTH-CENTRAL INDIANA
SHOWING THE THICKNESS OF SURFACE DEPOSITS

BY STEPHEN R. CAPPS

Scale $\frac{1}{625,000}$

10 0 10 20 Miles

Contour interval 50 feet

1909

LEGEND

- Rock at 0 to 20 feet below the surface
- Rock at 20 to 50 feet below the surface
- Rock at 50 to 100 feet below the surface
- Rock at 100 to 200 feet below the surface
- Rock at more than 200 feet below the surface

glacier rehandled and rearranged the materials which it found in its course and effaced the irregularities of the drift as left by its predecessor, while its own moraines are unmodified by destructive agencies except the slow ones of weathering and stream erosion since the withdrawal of ice.

MORAINES.

At the edge of the ice, as it covered this region, was deposited much of the material that it had picked up and carried with it. Many of these deposits form huge irregular ridges, which the ice left as it retreated, forming successive moraines farther and farther north. As the edge of the ice sheet was irregular in outline, and as the general retreat of the glacier was irregular and interrupted by short advances, the moraine deposits are most unsystematic. The ice at each advance would modify or destroy all the previously formed moraines over which it passed. These conditions account for the irregular and patchy distribution of the morainic areas, as shown on the map (Pl. I).

OUTWASH PLAINS.

At the base of many of the morainic deposits are plains of fine gravels, sands, and silts which slope at a low angle away from the morainic ridges. These plains were deposited at the time the glaciers were building the moraines. The abundant waters from the melting ice flowed away from the ice edges and carried with them large quantities of the finer débris. This material was deposited beyond the moraines and built up the gentle slopes there. It is in such deposits or in the irregular gravel beds of the moraines themselves that most of the gravel pits throughout the area are located.

TILL PLAINS.

Perhaps the most notable topographic feature of this area is the great extent of the plains formed of pebbly clay or till. These plains were built below the body of the glacier which was advancing over them, and the present level or slightly rolling surface of much of the country, especially south of Wabash River, is due to these deposits of till or ground moraine. The till is discussed more fully in the following pages.

SURFACE DEPOSITS.

GLACIAL TILL.

DESCRIPTION.

The term till has been applied to those clayey phases of glacial débris which were laid down by the great ice sheets that covered this area in Pleistocene times. It consists of a compact clayey matrix, through which are scattered pebbles, bowlders, and angular pieces of rock ranging from microscopic dimensions to a diameter of several feet. The rock fragments in this particular region are derived generally from the local limestones. There are many representatives, however, of the crystalline rocks of Canada that were brought hundreds of miles by the ice to their present resting place. The large bowlders in the till are usually of these more resistant crystalline rocks. At some places the till contains thin beds of rudely stratified gravels or sands, but these form only a small percentage of the total thickness.

DISTRIBUTION.

Originally the till sheet seems to have been continuous over the whole area. Postglacial erosion has now removed it from a few narrow strips along the valleys of the more important streams, but otherwise the till sheet is practically unbroken. It does not, however, outcrop everywhere at the surface. Plate I shows the present distribution of the till plains. Although much of the surface is now occupied by morainal deposits, outwash plains, and alluvium, the moraines and outwash deposits generally and the alluvium in most places are underlain by this great till sheet. The till varies in thickness in different parts of the area from a thin layer to more than 400 feet, and probably averages more than 100 feet thick throughout north-central Indiana (Pl. II).

TOPOGRAPHY.

The till, where not overlain by morainal deposits, has characteristically a very mild topography. Over entire townships there is often a range of only a few feet in elevation, with even the stream valleys less than a dozen feet below the level of the plain. The dead level of a perfect plain is usually broken by slight undulations or swells of 4 or 5 feet from trough to crest. This extensive till sheet forms the broad plateau of the whole region here discussed. The plateau surface ranges from a little below 700 feet to about 900 feet above sea level, and is broken by the valleys of the larger streams and by the more or less ridgelike, superimposed terminal-moraine deposits.

GROUND WATER IN THE TILL.

Source.—As it occupies the plateau tops and the crests of the stream divides, the till must receive most of its water from the rainfall. The flatness and imperfect drainage of much of its surface results in the absorption of a large proportion of the rainfall. In those areas where the till is overlain by gravelly morainic drift these more porous materials receive the rainfall and feed it to the underlying till. In places, too, there are deep preglacial valleys in the rock surface which have been filled with till, and here it doubtless receives some water from the rock. For the most part, however, the waters are absorbed directly from the rainfall.

Distribution and circulation.—By far the greater part of the till is composed of a fine-grained clay, which has a rather large proportion of pore space, but in which the individual pores are small. In the flat areas the water table approaches close to the surface, and most of the body of this material is saturated with water contained in these pores. The thin beds of gravel or sand, or of gravelly or sandy clay, also have a large amount of pore space, with larger individual pores. In some of these beds, if they happen to be higher at one end than at the other, waters under artesian pressure are found, the more impervious clayey beds above and below being effective in preventing the dissipation of the head which the slope of the bed gives to the water.

Even in the close-textured portion of the till there is some circulation of the waters, but the movement is very sluggish. On the other hand, in coarse gravel beds in the till the circulation may be very rapid. There may be all gradations in rapidity of movement between these two extremes, the rate varying with variations in the texture of the material.

Types of wells.—In most till areas the amount of available water for well supply is small. The most common wells are open or dug, and these will generally supply sufficient water for domestic use. They have been locally called seep wells, from the slow way in which the water seeps out of the till, and definite water channels are rarely encountered in this material. Dug wells, while furnishing sufficient water for ordinary domestic use during most of the year, are apt to fail in exceptionally dry seasons when the water table has become lower than usual. Furthermore, the open shallow wells are always in danger of pollution from cesspools and barnyards, the drainage from which enters the ground and becomes part of the ground-water supply. Tubular wells that case off the surface waters are much safer and can more easily be put down to such depths that they will not be affected by drought. If tubular wells will not supply sufficient water, deep dug wells, open only near the bottom, and with tightly cemented walls and tops, are recommended.

MORAINAL DRIFT.

DESCRIPTION.

The terminal-moraine deposits in this region are formed largely of the same sort of materials as those which make up the till. They consist of a heterogeneous mixture of glacial débris, composed of great bowlders, pebbles, and blocks of rock mixed indiscriminately with sands and clays. The common matrix of this unstratified mass is a blue clay. The bowlders and bits of rock included in the drift are derived both from the native rocks of the area and from the crystalline rocks of the upper course of the glacier in Canada. Interbedded with the unassorted drift are numerous lenses or pockets of stratified sands and gravels, some lying flat and some much disturbed. The morainal drift differs from the till in that it has never been subjected to the great pressure of an overriding ice body, and has not had the glacial kneading and squeezing which has given the till its tough, compact character.

DISTRIBUTION.

The morainic tracts, of irregular shapes and distribution, were deposited at the ice edge during the retreat of the glacier. Doubtless many moraines that do not now exist were built while the ice was advancing or during temporary halts in the general period of advance. Such moraines, however, were overridden and obliterated by the southward-moving ice edge. Only those survived which were built on territory which the ice never again invaded. In an area in which the moraine material is thin or absent we may infer that the final ice retreat was continuous and rapid. The presence of a well-defined moraine ridge indicates that the ice edge was approximately stationary at this point for some time.

The distribution of the different morainic areas is shown on Plate I. It will be seen that, while scattered irregularly over the entire area, they are more prominent topographically and more continuous north of Wabash River than south of it.

The Maxinkuckee moraine extends, in this area, from Tippecanoe River in Fulton County north through Marshall into St. Joseph, and thence eastward through Elkhart County. Another, deposited between two lobes of the great glacier, extends from a point a few miles north of Delphi northeastward through Carroll, Cass, Miami, Wabash, and Kosciusko counties. The other moraines are smaller, more patchy in distribution, and of less vigorous development.

TOPOGRAPHY.

Since terminal moraines are deposited along the front of a glacier it is natural to expect them to be more or less ridgelike in form. This is true of the great belt which crosses parts of Cass, Miami, Fulton, Wabash, and Kosciusko counties from northeast to southwest, and of portions of the Maxinkuckee moraine. The smaller patches are ridgelike only in their general relations to the surrounding till plateau. The surface commonly consists of an irregular succession of sharp hills and basin-like depressions. Many of the depressions contain lakes or have been silted up to form marshes. In many parts the moraine surface is thickly strewn with bowlders, most of them of the resistant crystalline rocks.

GROUND WATER IN THE MORAINAL DRIFT.

Sources and distribution.—All the moraines lie on top of the till plateau and stand up somewhat above their surroundings. Because of their elevated position the only source for the underground water of these deposits is the rainfall, a large part of which is absorbed by the porous drift. Some of it issues from the drift as springs or seeps near the base of the moraine, and some is fed to the underlying till.

In the moraines much of the water is held in the fine pores and gravelly portions of the unstratified clays. The clays give up their waters slowly, and wells in the bowlder clay, though commonly yielding enough water for household use, do not generally strike abundant supplies. Those wells which penetrate bodies of gravel or coarse sand, on the contrary, commonly yield largely, and it is from such open beds that most of the wells in the moraines obtain their water. The coarse gravel and sand beds are much more common in morainal drift than in the till plains, and as a result wells are more easily obtained and the water supplies are more abundant in the drift than in the till.

Types of wells.—Almost anywhere in the morainic areas tubular wells may be successful if they are continued downward to a bed of open material. Bowlders are encountered by many wells in the drift, causing difficulty, but most wells that avoid them are successful. Artesian wells are in some places obtained in the drift gravels and sands.

OUTWASH DEPOSITS.

DESCRIPTION.

Beyond the edge of a terminal moraine the till plain is in many places covered by an outwash plain formed while the moraine was being built. The abundant waters from the melting ice, heavily charged with débris from the glacier, built out alluvial fans of low slope from the base of the terminal moraine. In places the fans coalesced to form a continuous outwash plain or apron. Outwash plains are composed of imperfectly assorted gravel, sand, and silt. The individual particles of the beds are of the same materials which make up the moraines, but the assorting action of the waters has separated and arranged them, the coarser materials lying nearest the moraine and the finer farther away.

DISTRIBUTION.

While all the outwash plains are in close relation to the moraines next to which they were formed, such plains are not present beyond every moraine, but only where the slopes caused the glacial waters to flow out over a flat plain, as in northwest Kosciusko and eastern Marshall County (Pl. I). Where the waters drained into deep valleys and left their deposits in them, the chances were favorable for the postglacial removal of the outwash gravels.

GROUND WATER IN THE OUTWASH DEPOSITS.

The outwash plains receive much of their water directly from the rainfall, and the porous materials of which they are composed readily absorb the water precipitated upon them. The moraines at their upper edge also supply them with water by seepage and by direct communication between the gravels.

In the open gravel and sand beds of an outwash plain the lateral movements of the water are free and may be very rapid. If a single bed is continuous from the upper to the lower edge of the plain and has an outlet for the water below, the movement of the water may be free enough to keep the gravel bed drained. If, on the other hand, such a bed were included between impervious beds and had no free outlet below, a considerable artesian head would develop toward the lower edge of the inclined plain. Such conditions are not uncommon, and in certain areas many flowing wells are supplied in this way.

The outwash materials have, as a rule, remained uncemented. The ground waters, therefore, are contained in the minute pore spaces of the fine materials and in the larger openings of the coarser sands and gravels. In the coarser deposits which compose most of the outwash plains a great portion of the contained water is available for well supplies, and the most common type of well is the driven well, usually only 12 to 15 feet deep. Driven wells may furnish an unfailing supply of water but are not safe from the pollution of privies, manured fields, etc. To be perfectly safe they should be driven to a water-bearing bed below an impervious clayey layer.

VALLEY ALLUVIUM.

CHARACTER AND DISTRIBUTION.

All the larger streams of the areas here discussed have broadened their valleys and built up flood plains along at least a part of their courses. Many of the smaller streams have patches of alluvial bottom lands along their valleys, but alluvial deposits reach especially notable size in the valleys of St. Joseph, Wabash, and White rivers. The deposits are composed of the roughly assorted detrital materials which the stream has carried and left in favorable localities. The materials are gravels, sands, and silts, derived from the glacial deposits and from any material over which the stream has traveled, and contain the native limestones and decomposed shales, as well as the glacier-borne erratic materials.

It is uncommon for one of the large streams of this area to occupy the whole of its valley bottom, and it does so only in flood season or where the stream flows over a rock ledge. The remainder of the valley floor is alluvial material. Generally this floor is below high-water level, and is overflowed in flood seasons. Above this at some places there are remnants of older, higher flood plains which now stand as terraces above the present river flat. The alluvial bottoms vary in width, the widest measuring 3 or 4 miles, and appear on an areal map as long, narrow areas following the courses of the larger streams.

GROUND WATER IN THE ALLUVIUM.

The valley alluvium, like the materials of the outwash plain, consists of uncemented, imperfectly stratified gravels, sands, and muds. In all these materials the waters are in the openings between the particles. As the amount of available water in muds and fine sands is small, it is necessary to reach coarse sands or gravels for successful wells. Few wells 8 to 15 feet in depth fail to enter such gravel beds, and abundant water is everywhere obtainable at little expense. Valley alluvium, from its nature, occurs in valley bottoms where the water table approaches the surface, and water is obtained with such ease that people often neglect to go a few feet deeper than the water table, though by so doing they might obtain a much safer and more palatable water supply.

Much of the water in alluvial deposits is directly absorbed from the rainfall, for the porous beds will readily receive large amounts of water. Perhaps still more important is the water received by seepage or springs from the materials which form the uplands. The valley sides may be composed either of till, as they are in most places, or of limestone or shale, or of morainic deposits. A common but erroneous idea is that the bottom-land waters are supplied by the streams that flow through them. The movement of the underground waters is from the uplands toward the streams; and instead of the stream supplying water to its banks, the banks are constantly augmenting the stream by the escape of their stored waters. Chemical analyses of the stream waters and of the ground waters of the bottom lands in this area show a great difference, the stream waters containing much less lime than the ground waters. Only at times when the streams rise more rapidly than the water table of their banks do the streams furnish any addition to the ground-water supply, and then only for a short time. (See fig. 4.)

In the open and more porous beds of valley alluvium the movement of the ground waters may be rapid. The water table of the uplands is higher than that of the valleys, and this causes the waters to move streamward. There is also some movement of the waters down valley. (See fig. 4.) Under favorable conditions artesian pressure may develop in alluvial deposits, the head being furnished by the higher water table of the uplands. (See figs. 8 and 9.)

SAND.

DESCRIPTION AND DISTRIBUTION.

St. Joseph, Marshall, Fulton, and Cass counties, along their western edges, border on an area which, during the retreat of the last glacier, was occupied by a large lake, which has been called Lake Kankakee.[a] The basin which it occupied is now a sandy plain, and wind-blown sand tops the glacial clays for some distance east of the borders of the lake flat. The water-laid sands are in many places coarse or even gravelly, and were derived from the glacial deposits along the shores and shallows of the lake and from the débris dumped directly into the lake by the glacier. East of the shore of this extinct lake the sands, being wind sorted, are fine and contain little or no gravel.

Only a very small area of the region under discussion lies within the old lake basin, which is remarkably flat and featureless. Formerly the lake bed was an almost impassable marsh, but by systematic ditching much of it has been reclaimed. East of the lake basin the wind-blown sand has spread and emphasized the topography of the underlying drift. In some places small but distinct dunes occur.

GROUND WATER IN THE SANDS.

As the wind-blown sand lies altogether on the surface of the area in which it occurs, it is evident that its water is derived almost wholly from the rainfall. The lake-bed deposits, also, are largely dependent upon the rainfall for their water, although the bordering shores of glacial drift and dune sand supply some water to the sand beds.

The sandy deposits are unconsolidated and not subject to joints, so the contained water all occurs in the pore spaces between the rock particles. The pore space in sand is very large, ranging up to 35 or 40 per cent of the whole volume, and wells driven into the lake beds always get abundant waters close to the surface. In the wind-blown sands the pore space is large, but the particles are small and of uniform size, so that the sands have a habit of packing very closely. Drillers often have great trouble in finding a bed of material coarse enough so that it will not crowd into the strainer at the well bottom and clog it up. The sand also packs so closely around the pipes that wells are driven in and pulled with difficulty. The wind-blown sands are usually not deep, and even where blown into dunes of considerable size they are usually so well drained as to be of little value as water producers.

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[a] Leverett, Frank, Mon. U. S. Geol. Survey, vol. 38, 1899, pp. 334-338.

ROCK FORMATIONS.

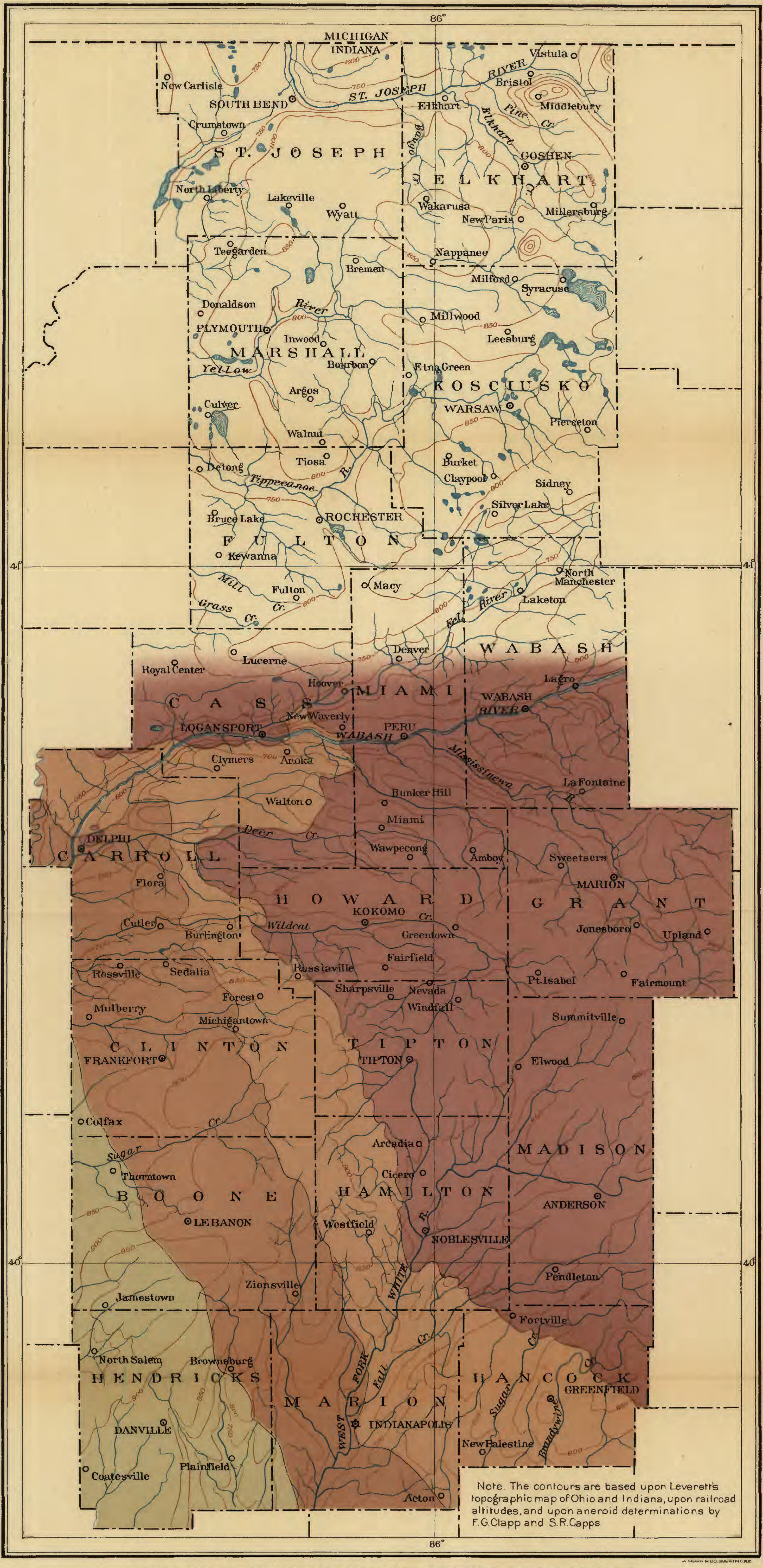
GENERAL GEOLOGIC SECTION.

Many wells penetrating deep into the earth pass through rock formations which do not come to the surface in the region. By a careful examination of the records of well borings, and by a comparison of these with the geologic succession in other areas where the deep-lying beds of northern Indiana outcrop at the surface, geologists have been able to determine in some detail the series of rocks which lie below the surface to great depths. Only those formations which have an influence upon the water supply of the region are of interest in this discussion, and only those will be discussed which have been penetrated by the drill. The following table shows in a general way the geologic formations represented, their thickness, general constitution, and value as water carriers:

Generalized section of the rock formations of northern Indiana.

System.	Series.	Group or formation.	Thickness.	Character.	Water supply.
			Feet.		
Quaternary			0-500	Alluvium, loess, drift, etc.	
Carboniferous	Mississippian	"Knobstone" group	600	Shales with some sandstone and limestone.	Produce little water.
Devonian		New Albany shale	50-100	Shales locally bituminous	Very poor water bearers.
		Sellersburg limestone [a] Jeffersonville limestone [a] Pendleton sandstone	100-350	Bedded limestones, with heavy bedded soft white sandstone (Pendleton sandstone) in certain areas.	Bear considerable waters in areas where they are near the surface.
Silurian		Kokomo limestone ("water lime") [b]		Bedded and jointed limestones	Furnish good supplies of water.
		Niagara formation: [b] Upper division	100-500	Compact, massive, or bedded limestone, in many parts somewhat crystalline, ranging in color from buff to bluish or greenish shades. Immediately below glacial drift in many places in the north and west parts of the area treated.	In many places carries considerable amounts of potable water in joints, bedding planes, and solution passages.
		Lower division ("Clinton")	±50	Brownish or reddish limestone	Poor water bearers.
Ordovician	Cincinnatian	Richmond formation "Lorraine" formation Utica shale	260-1,000	Blue-green shale and blue limestone above and fine-grained brown or black shale below. Does not outcrop in area treated.	Carries very little water. Nowhere known to furnish sufficient for well supply.
		"Trenton" limestone	±500	Massive limestone, in many places dolomitic. Does not outcrop in area treated.	Yields large quantities of salt water.
		Shale (formation undetermined)	25-80		
		St. Peter sandstone	150-250	Porous sandstone. Does not outcrop in area treated.	Carries abundant waters, highly mineralized with salt, sulphur, iron, etc.
		"Lower Magnesian" limestone	±400	Gray sandy dolomitic sandstone. Does not outcrop in area treated.	

[a] The Sellersburg and Jeffersonville limestones together are the "Corniferous" of well drillers.
[b] The name "Niagara," as commonly used by well drillers, includes the Kokomo limestone ("waterlime") and the Niagara formation.



GEOLOGIC MAP OF NORTH-CENTRAL INDIANA

The outlines of the various formations were taken from T. C. Hopkins's geologic map of Indiana, Indiana Geological Survey, 1901-1903. On account of the generally heavy mantle of surface deposits these outlines can be considered only approximate.

Scale $\frac{1}{625,000}$

10 0 10 20 Miles

Contour interval 50 feet

1909

LEGEND

QUATERNARY	CARBONIFEROUS	DEVONIAN		SILURIAN
Pleistocene (No outcrops)	Mississippian ("Knobstone" group)	New Albany shale	Sellersburg and Jeffersonville limestones	Kokomo limestone and Niagara formation

Except the Pleistocene deposits, which for the most part are unconsolidated materials, all the rocks of this region are sedimentary down to the bottom of the deepest well borings. In this area we have three great types of sedimentary deposits with which to deal: (1) Sandstones, which were deposited under water in the zone where wave action was important. In north-central Indiana sandstones are seldom encountered in the sinking of wells, and except in a small area in Hendricks and Boone counties are important as a source of supply only in borings of very great depth. (2) Shales, which were laid down under water; some of them in a zone farther from the shore and in deeper water than the sandstones, and some of them close to shore along low marshy coasts, in protected lagoons or near mouths of streams which carry fine sediments. Shales are encountered by wells in northern Indiana immediately below the glacial deposits, although they are nowhere close to the surface. In the southwest portion of the area, especially in Hendricks, Marion, Boone, Clinton, and Carroll counties, the shales are at many points entered immediately below the till, and at a few places outcrop at the surface along stream cuts. In the remainder of this area, shale is invariably encountered by wells that are sufficiently deep to go through the glacial deposits and the underlying limestone. It is seldom that these shales yield satisfactory supplies of water, and a knowledge of their distribution and characteristics is important to all drillers in order that they may avoid these unproductive deposits. (3) Limestones form the third type of sedimentary rocks. The idea formerly prevailed that the limestones were laid down in very deep waters, far from the shore. Of recent years, however, it has been generally conceded that they were deposited in water less than 100 fathoms deep. This is beyond the shale-forming zone, but is far shallower than the depths formerly believed necessary for the formation of limestone. Indeed, coral limestones are now known to be forming close to the shore. The chief essentials of a limestone-forming area are abundant lime-secreting organisms, comparatively shallow water, and an absence of clastic sediments. No deposits occur in north-central Indiana of such character as to prove beyond doubt that this area was ever covered by deep seas.

ORDOVICIAN SYSTEM.

ST. PETER SANDSTONE.

Description and distribution.—The St. Peter sandstone is known to underlie the "Trenton" limestone, although it has been penetrated but a few times in the northern part of Indiana, in which it nowhere comes to the surface. In areas where it does outcrop, and according to the records of drillings in this and other regions, the formation consists of a massive, porous sandstone, composed of rather firmly cemented siliceous sand. Where penetrated by the drill it has been found to be 150 to 224 feet thick. It is underlain by the "Lower Magnesian" limestone.

Doubtless this sandstone underlies the whole of the State, for over a great range of territory it has always been found when the bottom of the "Trenton" has been reached. The "Trenton" is known to lie continuously below this area.

Source and movements of water.—The nearest outcrop of the St. Peter sandstone is in Wisconsin, some two hundred miles from the nearest point in this area. From this outcrop it slopes gently southward. Above the St. Peter there are, in Indiana, thick deposits of impervious shale, which prevent the entrance into the sandstone of any surface waters. Where encountered by borings, the waters of the formation are found to be under considerable artesian pressure, and it is probable that they have traveled slowly through the porous rock from its outcrop in Wisconsin and that the artesian head is transmitted from the same place. The water is included in the pores of the rock as well as in any joints or bedding planes that may exist. The rock is massive, however, and it is not likely that the joints are large or continuous for any great distances, as joints probably develop more freely near the surface than in these formations, which are deeply buried. The movements of the waters, therefore, are doubtless very slow, and the period of time during which the waters have been confined in the rock must have been very long.

Character of the water.—The water from the St. Peter sandstone has not been put to use in the region under discussion. Something is known of its character, however, for at Cincinnati, Ohio, 100 miles southeast of Indianapolis, many wells have penetrated this sandstone, and it is probable that the chemical contents of the water are similar in the two areas. At Cincinnati the water is heavily charged with salt and iron and contains also a noticeable amount of hydrogen sulphide.

"TRENTON" LIMESTONE.

Description and distribution.—The deepest rock formation of this district that has been frequently reached by the drill is called the "Trenton" limestone. Because of the great development of the petroleum and natural-gas industries in northern Indiana many hundreds of wells have been drilled into the "Trenton," in which all the important strikes in oil and gas have been made. The formation is a massive limestone about 500 feet thick. Its actual thickness is seldom recorded, for oil and gas, where found at all, are near the top of the formation, and hence few wells penetrate deeply into it. The top of the "Trenton" lies 850 to 900 feet below the surface in the southeastern counties of this area, the depth gradually increasing to the north and west. The "Trenton" underlies the whole of the area covered by this report.

Source, occurrence, and movements of water.—The nearest outcrop of the "Trenton" limestone is in the river valleys in Kentucky, south of Cincinnati. There its top is between 500 and 600 feet above sea level, while in Hancock County, Ind., it is below sea level. This gives the formation a dip to the northwest of 5 or 6 feet per mile. Above it there is a thick series of impervious shales which prevent the entrance of any surface waters. The source, then, of the water found in the "Trenton" is probably the crest of the Cincinnati arch, as the low broad anticline is called which runs south from Ohio and Indiana into Kentucky and which gives the westward dip to the beds on its flank. It may, however, be in the area in northern Illinois and southern Wisconsin, in which these beds come to the surface.

The "Trenton" limestone equivalent which outcrops in Kentucky is a rather solid close-grained rock of small pore space. It is probable that in oil and gas areas the pore space is much greater. It is traversed, however, by extensive systems of joints and by well-defined bedding planes. Both of these sets of openings have in places been enlarged by solution, so that the rock now has certain well-marked circulation channels. The bedding planes, especially, provide open continuous passages for the water, and wells in the "Trenton" rarely fail to strike such channels. It is not surprising, therefore, that the "Trenton" waters, where encountered in north-central Indiana, have lost little of their head and rise in the wells far above the level at which they are reached.

Character of water.—The "Trenton" waters are all highly mineralized and are especially heavy in sodium chloride, some of them being almost saturated with salt. The salt waters are commonly associated with the oil and gas of the "Trenton," and often flood the wells in such quantities that they can not be pumped for oil profitably. As in many other marine formations, the salt was probably derived originally from the evaporation of sea water. In pumping the petroleum the oily salt waters are pumped from the wells and allowed to run over the land and gradually find their way to the streams. In this way the streams, and to a considerable extent the ground waters, have been polluted. Isaiah Bowman[a] has suggested that by direct ditching and by piping these waters to the streams the pollution of the ground waters could be largely avoided. The pollution of the streams seems inevitable as long as the oil and gas wells are producing. When these fail, the streams will have an opportunity to return to their normal state.

[a] Sackett, R. L., and Bowman, Isaiah, The disposal of strawboard and oil-well waste: Water-Supply Paper U. S. Geol. Survey No. 113, 1905.

Dangers from "Trenton" water.—As stated above, the salt waters of the "Trenton" limestone are often under considerable artesian pressure and in some places will rise in the wells as high as or higher than in the Niagara formation. While oil or gas wells are in use they are cased below the Niagara to keep the water from this and overlying formations out of the well. In this way the "Trenton" and Niagara waters are prevented from mixing. On the failure or exhaustion of deep wells the pipe is often pulled out. A state law has been passed requiring that all "pulled" wells should be tightly plugged below the Niagara. This is to prevent the fresh water from above from getting into the oil or gas bearing rocks, as well as to keep the salty "Trenton" waters out of the Niagara, if the "Trenton" waters are under sufficient pressure to rise to this level. Unfortunately the laws have been evaded and many wells are not properly plugged, so that the salty "Trenton" waters have in places forced their way into the Niagara formation in sufficient quantities to give the Niagara waters a decidedly salty taste. The whole supply of rock waters in certain regions has been imperiled in this way. It is impossible to undo the harm that has already been done, but an appreciation of the serious consequences of a ruined rock water supply should do much to bring about in the future a stringent enforcement of the laws for the proper plugging of all pulled wells.

CINCINNATIAN SERIES.

Description.—Above the "Trenton" there occur three great groups of shales and limestones—the Utica shale below and the "Lorraine" and Richmond formations above. The Utica consists of persistent, close-grained brown or black shales from 50 to 400 feet in thickness, while the "Lorraine" and Richmond formations consist principally of greenish or bluish shales with thin interbedded layers of limestone. The three formations together have ordinarily a thickness between 500 and 700 feet.

Source, occurrence, and movements of water.—The shales which compose the great proportion of these beds are so close-grained as to be practically impervious. The water they contain is included in the microscopic openings between the tiny particles and is held with great tenacity by the shales. Capillary attraction and adhesion to the walls of the pores make these waters almost stationary. It seems probable that some of the water has been in the shales since they were first deposited. Well borings that pass through 500 or 600 feet of these formations get very little water, and what they do get comes largely from the limestone layers.

Character of water.—Few wells in this area find their supply in the shale formations, and there was no opportunity to take samples of unmixed shale waters. In southwestern Ohio and southeastern

Indiana, where these beds come to the surface, the waters are found to be heavily charged with minerals, containing much more than any of the waters of the surface deposits. This large mineral content results from the lack of free circulation through the shales, the consequent long time during which the contained water remains in contact with them, and the comminuted condition of the particles, a condition that aids in the solution of the minerals. These shales do not outcrop in north-central Indiana, and are not to be considered as a possible source for well supplies there.

SILURIAN SYSTEM.

NIAGARA LIMESTONE.

Definition.—The term "Niagara group" is sometimes used in Indiana to include all rocks of Silurian age. More commonly it is made to include the massive limestones which lie immediately below the drift in much of the northeast part of Indiana. (See Pl. III.) In all the more important oil fields of this area the Niagara is the first rock reached and its thickness is an important consideration with oil and gas well drillers, as it is necessary to case the wells through the limestone to keep out the water. The formation ranges from a thin bed to more than 500 feet thick, varying with the amount of erosion which the surface has suffered. As stated above, the records of well borings often include the Kokomo limestone ("water lime") under the term "Niagara."

Lower division.—The lower part of the Niagara is a series of limestones and shales 50 to 100 feet thick which has been called "Clinton." This lower division nowhere outcrops in north-central Indiana, but nearer the crest of the Cincinnati anticline, in southeastern Indiana and southwestern Ohio, the beds come to the surface. Like the underlying rocks, these beds lie on the flank of the Cincinnati arch and dip to the west and north 5 or 6 feet per mile.

This lower division of the Niagara is inclosed above and below by dense impervious shales, so that there is little opportunity for the beds to receive waters from the adjoining formations. It seems probable from the slope of the beds and the exposed outcrops to the southeast that the waters contained in these rocks have come from the surface outcrops. In the shale beds the waters are held in fine pores, and little movement takes place, as open continuous passages are lacking. The limestones are compact and dense and the joints and bedding planes offer the only channels for circulation. In oil and gas wells the casing is usually continued through the lower division (so-called "Clinton"). The uncased wells which go to these beds receive most of their water from the upper division of the Niagara, and no opportunity was afforded to obtain samples of unmixed waters from the lower division. In this area these beds are not important as water producers.

No information was obtained in regard to the character of the waters from the lower division of the Niagara. In southwestern Ohio[a] the waters from this horizon are as soft as any of the ground waters. In that area these rocks are near the surface, and the waters are in continuous circulation and probably do not remain in the rock long enough to dissolve much mineral matter. In north-central Indiana, however, the beds lie much deeper, the water circulation is slower, and the waters are doubtless much more heavily charged with minerals than those in the southwestern Ohio region.

Upper division.—The limestones of the upper division of the Niagara formation are thick and massive, normally 100 to 500 feet thick. They are the oldest rocks which outcrop in the area discussed. They are in many places somewhat crystalline and bluish or buff. Thin beds of shale or "breaks" occur far apart in the limestone, and at its base borings pass through 2 to 40 feet of fine-grained greenish shale.

KOKOMO LIMESTONE ("WATER LIME").

The Kokomo is also a thick, heavy limestone, but is not so massive or so dense in texture as the Niagara and does not show any crystalline structure. Like that of the Niagara its surface is ordinarily covered by a thick coating of till, and the outcrops are limited for the most part to the sides of the deeper valleys. It is well exposed at Kokomo, hence its name.

This limestone is rather flat-lying in the eastern part of north-central Indiana, having a low, uniform dip to the west. It has been greatly disturbed along a northwest-southeast axis, along which the beds are often steeply uptilted and much fractured. This disturbance has been called the Wabash arch.[b] In the north and southwest portions of the area the Kokomo is overlain by later sedimentary beds.

SILURIAN WATER.

Source.—In the areas where the limestones lie immediately below the glacial deposits the limestone waters are largely derived from the till. The actual surface outcrops of the rocks are of small extent and are almost all in the deeper valleys where the waters move outward from the rocks. The main source of the rock waters is therefore in the overlying surface deposits. In the southwest quarter of this area and in its northern portion these limestones dip below

[a] Fuller, M. L., and Clapp, F. G., Underground waters of southwestern Ohio: Water-Supply Paper U. S. Geol. Survey No. 259 (in preparation).

[b] Thompson, Maurice, The Wabash arch: Thirteenth Rept. State Geologist Indiana, 1888, pp. 41–53.

the later rocks, which contain impervious beds of clay and shale. Under such conditions the limestone waters come from the higher areas, where they are in contact with the permeable water-bearing beds or where the rocks outcrop at the surface and can absorb the rainfall directly.

Occurrence and movements.—The texture of the limestones is dense, and all waters included in the body of the rock are in such fine openings that they are not readily yielded up. The available waters are those which occupy the systems of joints and the bedding planes of the rocks. Such openings are in places widened by solution to form channels several inches or even a few feet in diameter. (See Pl. V, *B*.) The bedding planes especially are utilized by the circulating waters. This is well shown in many stone quarries, where a thin sheet of water constantly flows out from certain bedding planes (Pl. VI, *A*). To have a freely circulating water supply a rock formation must have continuous openings and an outlet for the water at some point lower than the head. With these conditions in a limestone, those openings which are largest and have the most direct course between the source and the outlet have the advantage and receive the most water. With more rapid circulation comes increased solution along the favored channels. In this way complex drainage systems are occasionally developed below the surface. An abandoned channel of this sort is shown in the quarry face in Plate V, *B*. Wells which go through the surface deposits usually find good supplies of water within a few feet of the top of the limestone in the joints and cracks of the rock. Where the limestones are interrupted by shale beds abundant water is usually found just above the impervious shales. Occasionally a drill will break into a solution channel in the rock and drop to the bottom, and most wells which encounter openings of this kind prove to be inexhaustible.

Before the glacial period the surface of the limestones was much broken up and was deeply decayed by weathering. The advancing ice removed much of this broken and loose material, and left many hard, fresh surfaces of rock. In some places, however, the erosion was less severe, or post-glacial weathering has been especially effective, for beneath the till there is a zone of broken and weathered limestone. Into this weathered zone the water penetrates readily, and wells driven through the till into the broken limestone commonly find abundant waters.

Character.—As is to be expected, the limestone waters are invariably hard. The content of lime and magnesium is high and notable amounts of sulphates and chlorides are found in many samples analyzed.

DEVONIAN SYSTEM.

Description.—The Devonian beds underlie the southwest quarter of this area, but have few outcrops and are not very well known. (See Pl. III.) They are divided into the Pendleton sandstone, the Jeffersonville limestone, the Sellersburg limestone, and the black New Albany shale. The limestones range in thickness from a thin edge at their eastern border to 200 or 300 feet where they have suffered no erosion. The outcrops are usually covered with a heavy deposit of glacial till. The sandstone, the type locality of which is in Madison County, varies in thickness up to 20 feet.

The New Albany shale is a close-grained black or bluish shale about 100 feet thick, which outcrops in a narrow strip between the Devonian limestones and the Mississippian shales. (See Pl. III.) It is covered by a thick till sheet and few wells go into it.

The Devonian beds occur also in the northern portion of the area but are so deeply covered by surface deposits that their distribution is not known.

Source, occurrence, and movements of water.—The limestones have few surface outcrops and must receive their waters at their contact with the overlying till. No water could enter them from above in their deeper portions, where they are covered by the impervious New Albany shale.

The New Albany shale is so close grained that it contains little water and retains what it has. Very little additional water is needed to keep up the supply. The water is nearly stationary.

The limestones contain some water in minute pores, but their available supply is in the joints, bedding planes, and solution passages. At Indianapolis many wells are supplied by this limestone, and in a number of them the drill has broken into well-defined channels. Many of the wells give a large yield, but the demand upon the rock waters in this city is greater than the supply and the head has been gradually becoming lower for a number of years.

CARBONIFEROUS SYSTEM (MISSISSIPPIAN SERIES).

"KNOBSTONE" GROUP.

Description.—In the extreme southwest corner of the area covered by this report the rock formation nearest the surface is the "Knobstone" group, which lies immediately below the glacial deposits in parts of Marion, Hendricks, Boone, and Clinton counties. (See Pl. III.)

The "Knobstone" group consists of an alternating series of sandstones and shales, the sandstones gaining in relative importance toward the top of the group. The "Knobstone" at its greatest development has a thickness of about 600 feet. The beds are little disturbed and dip to the southwest as an inclined plane of low slope.

Source, occurrence, and movements of water.—The outcrops of the "Knobstone" everywhere in this area are drift covered, though they are the youngest rocks of north-central Indiana. The numerous shale beds which are distributed through the group effectively prevent the vertical circulation of waters. The rock waters therefore must be derived from the drift at the point of contact with the porous beds of the underlying formations. The shale beds are so close grained that the circulation of water in them is inconsiderable. In the sandstones the circulation is more free but is confined by the shales to single beds.

In the area of the "Knobstone" outcrops most of the wells are supplied by waters from the overlying surface deposits. The few wells which enter the rock find fair supplies in the sandstones, but no water in the shales. In the sandstone the waters are commonly found in crevices in the rock and in the pores.

GROUND WATER.

SOURCES.

PREVAILING IDEAS.

An idea which seems to have found rather wide credence in States bordering the Great Lakes is that the flowing wells are in some way connected with these lakes and that the head of the wells is maintained by them. Of the area here discussed only a narrow strip along the Wabash River in the neighborhood of Delphi has a lower elevation than 581 feet, the level of Lake Michigan, and Lake Erie is still lower. Delphi is about 75 miles from Lake Michigan. A large surface stream from Lake Michigan to Delphi would flow sluggishly, while the friction of underground waters in even the most porous of rocks would so reduce this head in 75 miles that a flow would be out of the question. Furthermore, the mouths of nearly all the flowing wells in the area are far above the level of Lake Michigan.

As for the shallower wells which do not enter rock at all, the source of head is as a rule local and is generally not more than a few miles from the well and commonly only a few hundred feet. This will be readily understood from the fact that most of these wells end in beds of gravel interbedded with glacial clays. These gravel beds are commonly of slight extent and vary greatly in thickness even in short distances. The source of head in such gravel beds must be within the limits of the open bed, which is usually only a few square miles in area.

Another common expression is that the drill penetrated a "lake" of water. Most such "lakes" of water are beds of porous gravel through which the water can enter the well as rapidly as it is pumped out. Actual cavities filled with water are locally found in limestones, but are not generally encountered in the areas which were glaciated. The erosive action of the ice wore away the upper portion of the limestone below the zone in which such caverns are likely to occur, and the period of time since the glacial epoch has been too short for the formation of very extensive solution channels.

Another common and perfectly natural idea is that the wells in the lowlands near rivers or lakes are supplied by these bodies of water. In some instances this is actually so, but the water supplied to most wells is drawn from the store of ground water and not from the surface waters. This will be understood by reference to figure 2; *W* is a well situated along a river flat; *G–G′* is the surface of the water table. The normal movements of the underground water are in the direction of the arrows. As long as the amount of water pumped from well *W* is not greater than can be supplied from the ground water without lowering it below the level of the river bank, or the stream does not rise more suddenly than the water table of its banks, the well will receive little water from the river. This has been definitely determined by the analyses of the waters from both sources. If the well is pumped enough to lower the water level the water from the river will flow into the well, which will yield a mixture of ground water and river water. The same conditions obtain if the well is located near a lake or a marsh.

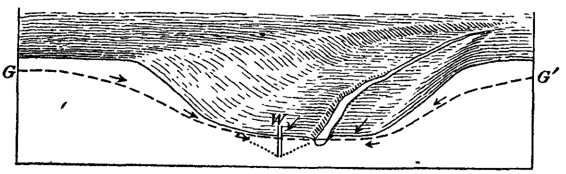


FIGURE 2.—Relations of flood-plain wells to the neighboring stream.

ACTUAL CONDITIONS.

Ground water is a term which has been applied to water, from whatever source, which is below the earth's surface. With little exception this water has all been precipitated upon the surface of the earth and absorbed through the various kinds of pores, cracks, and open spaces. As shown by the preceding paragraph, it is evident that the ground-water supply receives slight contributions or none from the established surface streams or lakes. On the contrary, the streams owe their permanence to a perpetual supply which they receive from the body of ground water. Without this ground-water supply most of the shorter streams would speedily drain their basins after each shower and would then remain dry until the next rain. As it is, numberless streams having very small drainage basins flow all or almost all of the year and fail, if at all, only when the ground-water level has been lowered below their beds by a season of great evaporation with little rainfall.

For the source of the great body of ground water we must therefore look to the precipitation which is absorbed by the earth and which percolates below the surface into the openings of the underlying materials. The total precipitation in any region can be divided into three parts: (1) That which is evaporated directly; (2) that which runs off the surface at once; (3) that which is absorbed and becomes ground water. The proportions of these three divisions vary greatly under different conditions of topography, soils, climate, and precipitation. With given conditions of precipitation, climate, and soil, however, the great factor in determining the proportions of the above three classes, is the topography, or configuration of the earth's surface. It is clear that in areas of steep slopes and well-established drainage the proportion of run-off will be large at the expense both of absorption and evaporation. In regions of slight relief and of few and sluggish streams the proportion of run-off will diminish and that of absorption and evaporation increase. As stated above, these proportions are vitally influenced by the character of the soil and the climate and the rate and character of the precipitation. As the area under consideration is for the most part a nearly level plateau of moderate elevation, without many deep valleys, the absorption is relatively large and all of this absorbed water goes to swell the body of ground water on which the wells depend.

MOVEMENTS.

IN THE SURFACE ZONE.

The manner in which the water is absorbed and stored in the earth varies greatly with the materials. In the unconsolidated surface materials which cover almost the entire area there is a nearly complete absence of well-defined continuous openings or passages. In these materials the water is absorbed into the pores between the particles by gravity and by capillary action and gradually moves downward to the water table, where it is stored in similar openings. In loose material the amount of water which can be held and the rapidity of movement possible for the waters are determined by the character of the materials and the size and continuity of the openings. In fine-grained clays the amount of water which can be stored may be large, but the movements of the water are necessarily extremely slow. In coarse, uniform gravel, on the contrary, the storage capacity for water is great and the movements of water may be rapid.

The waters near the surface of the water table move much more rapidly than those more deeply situated. The surface of the water table fluctuates somewhat with the seasons, but these movements decrease rapidly downward except in rocks with well-defined and continuous water channels. Toward the surface of the water table the movements of the underground waters have commonly a close relation to the movements of the surface waters. This is especially true in this region, where the water table is ordinarily in the unconsolidated, structureless glacial till. This relation is shown by the arrows in figure 2. Figure 3 shows a different set of conditions. If the rock surface *R–R'* is considered to represent the surface of the earth the movements of the ground waters would be along the

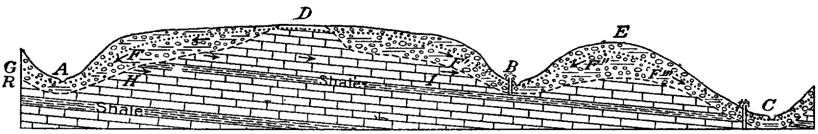


FIGURE 3.—Influence of surface slopes and of structure on movements of underground waters. Dotted line *G–G'* is the water table. Broken line *R–R'* is the rock surface. The water movements in this rock are along the bedding planes. The material above the rock is a rather impervious pebbly clay. The arrows indicate the direction of the underground water movements. *D* is a plateau with equal slopes toward *A* and *B*. On the slope toward *B* both the clay and rock waters move toward *B*. Only the clay waters move toward *A*, the rock waters moving in the opposite direction. The waters at *H* and *I*, independent of the surface topography, move past valley *B* to valley *C*. The conditions are favorable for artesian flows from rock wells at *B* and *C* if the surface deposits are impervious.

bedding planes in disregard of the surface slopes. If, however, the rock surface is covered to some depth with glacial drift, the upper ground waters will move in the same direction as the surface drainage, but the movements of deeper waters will be controlled by the structure of the rock.

IN THE DEEPER ZONES.

The movements of the deeper underground waters are determined by an entirely different set of factors from those which regulate the movements near the surface. The most important of these factors are the character and the structure of the saturated materials and the opportunity for escape of the waters. In very deep waters changes of temperature may be the controlling influence in the circulation, but such deep waters are reached by few wells and are therefore outside the province of this paper.

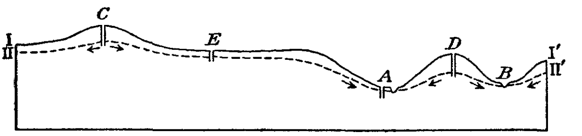
The older consolidated rocks which lie under the surface deposits contain water in their openings down to the bottom of the deepest borings. These rocks all contain a considerable amount of pore space, usually less than the unconsolidated materials. These pores contain some water, but the movements of the water in the pores is usually too slow to furnish wells with suitable supplies. Parallel to the beds of many rocks there are sheetlike openings called bedding planes. Many of the rocks, though they may be very dense in texture, have continuous openings or cracks which cross the bedding planes. Such cracks are called joints. From the open and continuous nature of the joints and bedding planes they form the most natural and convenient channels for the movements of underground waters and for their storage. In many places abundant supplies of water are found in deep-lying limestones or sandstones, which are separated from the surface of the earth by beds of impervious shales. In such places we must look to some distant point for the source of the waters—to a place where the water-bearing formation comes to the surface or where at least the overlying impervious formation is lacking. This point may be scores or even hundreds of miles from the point where the water is reached by the wells, and the water has traveled the whole distance through the joints, bedding planes, and pores of the rock. This is true of a few wells which have found their water supply in the porous St. Peter sandstone or the underlying sandstones. The nearest point of outcrop of these formations is far up in Wisconsin and the waters must have come at least that distance.

Although we have certain rock waters whose source is distant, it does not necessarily follow that the source of all rock waters is far from the point at which they are reached by wells. On the contrary, many rock waters are supplied by the precipitation in the immediate neighborhood of the wells from which the water is drawn. This may be true even though the rock does not outcrop at the surface. If the rock is overlain by porous gravel or gravelly clay the water may penetrate through this into the rock and move downward into still deeper rocks if there is no intervening impervious bed. There can be no question that in this area much of the rock water is in this way supplied by the overlying drift to the rock. The "Niagara" limestone, which lies immediately below the drift in much of the east and central parts of this area (see Pl. III), yields abundant waters to a large number of wells, though it actually outcrops at the surface over a very small area. The waters are fed to the limestone by the drift above, and many flowing wells along the bottom lands have tapped this source of supply. It is impossible to estimate accurately the time which may have been required by certain deep waters to move from their sources to the point where the water now issues from the wells. We know only that even with the most favorable conditions—an open, porous, or much fractured and jointed rock, with a strong head of water and a free outlet below—the length of time the water must have required to travel, say, 100 miles is necessarily great. With the actual conditions in the St. Peter sandstone—a rather porous but not much fractured rock, with considerable head but no adequate outlet below—the period of time the water has been in the rock is without doubt enormous. It even seems reasonable to suppose that in some of the deep-lying, impervious shales a part of the water now found may possibly have been there since the sediments were first laid down.

OCCURRENCE.

RELATION TO TOPOGRAPHY.

Below the earth's surface a level may always be reached at which the materials are saturated with water. This saturation may extend downward indefinitely, or only to some impervious layer. In either case the upper surface of the saturated zone is known as the water table. There is an intimate relation between this water table and the surface topography, and while the water table usually follows, in a general way, the slopes of the surface, it is much less irregular and of milder relief. Thus, on hilltops there is a ready drainage on all sides, and the waters falling on the surface flow off rapidly as surface waters, or entering the soil become ground waters and escape more slowly by percolation. The level of the water table is, therefore, farther from the surface on the hilltops than in the lowlands, where there is a less ready escape for the ground water and where the surface slopes are less conducive to rapid run-off. Figure 4 indicates the relation of the ground-water table to the surface slopes. These relations are important only in their influence on the waters near the surface of the water table. The deeper waters are affected by the variations of the water table only as these variations either increase or decrease the hydrostatic pressure in their own areas.



IGURE 4.—Diagram showing relation of the water table, II-II′ to the surface topography I-I′. The most favorable locations for wells are at *E*, *A*, and *B* It should be noted that well *C*, though on much higher ground than *D*, finds water nearer the surface. The arrows indicate the direction of the underground water movements.

RELATION TO STRUCTURE.

Rock waters have certain characteristic methods of occurrence and the manner of occurrence in each type of rock is more or less constant. In general, rock waters are contained in three varieties of openings—(1) pores, (2) bedding planes, and (3) joints. Any one or all of these classes of openings may become enlarged by solution to form continuous channels of considerable extent.

Pores.—Pores are the minute openings between the imperfectly fitting particles of which a rock is composed. In many rocks the total amount of water contained in the pores is greater than that contained in all the other openings. The pore spaces, however, have a remarkable capacity for holding their water and do not commonly yield much to wells.

Bedding planes.—Bedding planes are the sheet-like partings between beds of rock that are different in texture or arrangement of materials. Bedding planes may be very inconspicuous in fresh rocks, but become prominent as soon as the rock is attacked by solution or weathering. As a result of the slow percolation of the water along the bedding planes the openings may be enlarged by solution until passages of considerable size are formed, especially in limestones and in calcareous shales. In many sedimentary rocks the bedding planes offer the readiest means of circulation to the rock waters and therefore furnish the best supplies to wells that penetrate them.

Joints.—All hard, brittle rocks are traversed by sets of cracks formed to relieve stresses which have at some time been set up in the rocks. In sedimentary rocks some of these planes of fracture coincide with the bedding planes and can not be distinguished from them. Other sets of cracks may intersect the bedding planes, and these, which in this area are usually nearly vertical, are called joints. In many rocks the joints offer the easiest means of passage for underground waters, and some of them are dissolved out to form well-defined underground stream courses. Such solution passages have a tendency to form at the intersection of a joint with a bedding plane. It is a common occurrence with drillers for the drill to "drop" several inches, or even a foot or two, into one of these solution cavities. An abundant supply of water is generally found in these openings.

RELATION TO TYPE OF MATERIAL.

UNCONSOLIDATED DEPOSITS.

Since the unconsolidated materials contain no definite partings corresponding with the joints and bedding planes of the hard rocks, the waters are all contained in the pores. The pores range in size from the large openings in coarse gravels to the capillary and subcapillary openings in the dense clayey till. As the amount of water available for wells depends for the most part upon the size and continuity of the pores, the texture of the material determines to a large degree the value of any bed as a water producer. The characteristic features of the various types of unconsolidated materials and their capacity to furnish wells with water have already been discussed.

CONSOLIDATED DEPOSITS.

Sandstones.—Most sandstones yield considerable water from their pores as well as from their joints and bedding planes, and where sandstones are found within a reasonable distance of the surface they generally offer a good source for well supplies. In north-central Indiana, however, the only notable sandstone deposit is the St. Peter, which is a good water producer where accessible but which in this region lies so deep that it has been reached by the drill only a few times. Some wells in western Boone and Hendricks counties are supplied by waters from sandstones of the "Knobstone" group.

Shales.—The shales of this area are fine-grained rocks which are not much indurated. On account of their softness they are rather plastic, and the stresses which have fractured the harder limestones and sandstones have not had this effect on the shales. The impervious character of these shales is unfavorable to the circulation of underground waters, and not many solution channels are developed in them. Although the pores occupy relatively great space, they are too fine to permit the water to escape readily. Hence few wells find satisfactory supplies in the shale beds.

Limestones.—Although limestones contain a relatively small amount of pore space, they afford the best source of rock-water supply in this region because of their solubility and the consequent fact that the percolating waters have so widened and enlarged the joints and bedding planes as to convert them into open channels, through which the water circulates freely when once it has penetrated them. Thousands of wells have been drilled into the Silurian limestones ("Niagara" of well drillers), and very few of them have failed to find sufficient water for domestic use. In many places large quantities of water are obtained from this limestone for manufacturing purposes and for city supplies.

VOLUME.

As already stated, the volume of underground water depends in a measure upon the surface configuration of the region. No matter how great the precipitation or how great a proportion of this water enters the ground, the volume of ground water will not be large unless the topography of the region and the character of the materials are favorable for holding it. If there is a ready opportunity for the waters to escape to the surface again, the water table will be lowered as fast as it is augmented from above. For this reason the water table in a region of deep valleys and narrow divides will, on the average, be much farther from the surface than in another area of similar climate and materials where the general level is little dissected by valleys. The greater part of northern Indiana consists of till plains of slight relief, and over most of this area the water table stands near the surface.

By available water is meant that water in a formation which is free to enter a well sunk near it. This definition excludes a large part of the water in very fine-grained materials, such as shales and clays, in which the pores are so small that their capillary attraction and their lack of continuity prevent the escape of water. In the coarser sands and gravels the pores and openings are large and relatively more continuous, and nearly all of the water in such coarser deposits is available. The amount of available water, therefore, depends more upon the texture of the material than on the total amount of pore space. A clay may contain 25 to 35 per cent of pore space, but may yield very little water to wells; a coarser sand, with perhaps less pore space, may yield the greater part of its water to wells. Sandstones, if porous, will give up much of their content of water. In limestones the only water available is that which lies in the well-defined joints, bedding planes, and solution channels. The water contained in the body of the limestone is not available.

MINERAL MATTER IN SOLUTION.

The amount and character of the mineral matter which underground waters carry depend upon a complex set of conditions. Two factors, however, deserve particular discussion because of their relative importance. The amount of mineral matter which a ground water carries depends (1) on the solubility of the materials through which the waters have passed and (2) on the length of time during which the water has remained in contact with these materials. The solubility of the materials encountered is, perhaps, the most important single factor. Waters passing through salt beds, for example, might in a short time become very saline, even to the point of saturation. Other waters might remain in pure siliceous sandstones or quartzites for ages without acquiring much silica. With regard to lime, magnesium, and similar substances with which waters are rarely saturated, it is largely the time during which the waters are in contact with these substances that determines the amounts dissolved, though temperature, pressure, and the chemical action of the substances in solution upon those encountered are important factors. The relations between the character of the rock formations and the quality of the waters from them are discussed in the chapter on the chemical character of the waters by R. B. Dole (pp. 230–267).

SPRINGS.

DRIFT SPRINGS.

As a result of the coating of glacial deposits which almost completely mantles this region, most of the springs that occur throughout the area necessarily emerge from the glacial drift. All springs that come from these glacial deposits are classified as drift springs. It is possible that in some springs the waters are supplied from channels in the rock below, but when this could not be determined, the waters were classed as coming from the materials out of which they emerge.

For the occurrence of well-defined springs it is necessary that the water table should come to the surface and that the surrounding water-bearing materials should allow a ready circulation of the waters. If the materials are close grained and the circulation is sluggish, the water will emerge as "seeps" and not as well-defined springs. In the drift favorable conditions most commonly occur in the morainic areas where there is considerable surface relief, and where there are many beds of gravel interbedded with clayey drift. Figure 5 shows two conditions in a moraine which would give springs. Spring No. 1 comes from a gravel lens in the bowlder clay. This lens has no surface outcrop above, but receives its water slowly from the overlying drift. As the water can escape most readily by following the open gravel bed to its outcrop, spring No. 1 is formed. Spring No. 2 emerges from the contact of the gravel capping on a hilltop with the underlying more impervious bowlder clay. The water absorbed at the surface passes down through the gravel to the clay and follows the contact to its outcrop on the hillside, where spring No. 2 is formed.

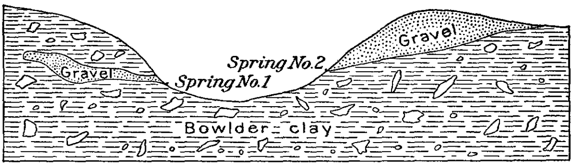


FIGURE 5.—Conditions producing springs in glacial drift.

ROCK SPRINGS.

The rock outcrops in this area are almost all located along the sides of the deeper valleys, and it is along these valley-side outcrops that most of the rock springs are found. The springs issue from just above some impervious bed in the limestone, or from some solution channel or prominent bedding plane. In some places, especially in fresh quarry exposures, there are flows of water from all the more conspicuous bedding planes. (See Pl. VI, *A*.) Figure 6 illustrates the conditions favorable for rock springs along the valleys. Bed No. 1 is till; No. 2 is a fractured and somewhat weathered limestone overlying an impervious shale, No. 3. Springs will issue at *A* and *A′*. Beds Nos. 4, 5, and 6 are limestone. Between beds 4 and 5 there is the opening of a large solution passage, and a large spring discharges at *B′*.

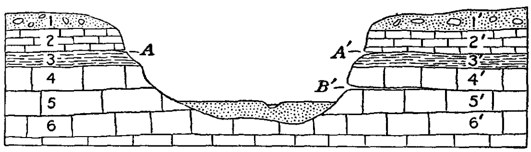


FIGURE 6.—Conditions producing springs in rocks.

In unglaciated limestone regions the upper portion of the limestone is in many places so honeycombed by solution caverns and passages that surface streams of large volume may disappear into these underground channels, to reappear at a distance as large springs. In northern Indiana there may once have been many such underground streams; but the erosion of the glaciers removed the more open upper surface of the limestone, and the larger underground channels have not yet been reestablished. For these reasons the rock springs are all rather small as compared with those of unglaciated areas.

W. S. Blatchley has published a report on the mineral waters of Indiana,[a] which includes descriptions and analyses of several springs and mineral wells in north-central Indiana.

WELLS.

METHODS OF CONSTRUCTION.

OPEN WELLS.

Description.—Open wells are commonly 3 or 4 feet in diameter and 15 to 30 feet deep, though a number ranging from 50 to 70 feet were found. They are ordinarily walled up with brick or broken rock, without cement or mortar, so that water can enter from any bed through which the well passes. The depth is determined by the abundance of the water encountered. The deepening is usually continued until the water comes in so rapidly that digging is impossible, when the wall is laid. Most well diggers can tell of experiences with wells in which little water was found until suddenly a porous gravel or a passage in the clay was opened from which the water poured so rapidly that the well could not be walled up. It may be necessary to fill such a well with broken rock for several feet before a wall can be started.

Disadvantages.—Open wells often "go dry" in dry seasons, when the need for water is greatest. This is always possible unless the well bottom is below the permanent water table and in a material which yields a continual and readily available supply. Open wells are subject to contamination, both from above and below ground. The only protection usually afforded to wells above is a board platform. Constant wetting and drying usually causes the boards to warp and shrink, leaving cracks between them. The drippings from the spout upon the well top carry down into the well whatever accumulations there are of dirt from shoes, domestic fowls, or other sources. In the country the farm well is the congregating place for domestic animals. The waste water allowed to run over the ground near by carries down with it any soluble material it may find and reenters the well.

Many open wells are polluted from below the surface. The liquid materials from cesspools and the drainage from manure piles, chicken yards, and manured fields enters the ground and becomes part of the body of underground water upon which the wells depend. In open wells this polluted water from above can enter at the top of the water table as well as the purer water below.

[a] Blatchley, W. S., Mineral waters of Indiana: Twenty-sixth Ann. Rept. Indiana Dept. Geology and Nat. Res., 1901. Halsall Spring, near Maxwell, Hancock County, p. 57; Cartersburg Mineral Spring, near Cartersburg, Hendricks County, p. 60; Winona Mineral Springs, at Winona Lake, Kosciusko Connty, p. 69.

BORED WELLS.

Bored wells are by no means rare, but are far less common than either of the other two types. They are bored with an auger and lined with tile or wood. The joints in some such wells are filled with cement, but are likely to leak, as the cement must be put in before the tile is lowered into the boring. They have been found to be less satisfactory than the driven or drilled wells.

DRIVEN AND DRILLED WELLS.

General description.—Up to the last decade the dug or open well was the type most commonly used for domestic purposes, both in towns and rural districts. With the ditching of low or marshy tracts and the decrease in the acreage of timber lands, the water table has gradually become lower. Within the memory of many older residents the water table in certain areas has been lowered from 5 or 6 feet below the surface to 15 or 20 feet below. In these areas dug wells which for years furnished an unfailing supply of water are now dry for the greater part of the year. A more general knowledge of the proper sanitary conditions for wells has also led to the abandonment of many dug wells. To replace the unsatisfactory open wells, thousands of driven and drilled wells have been put in and a large number of men now make a profession of drilling or driving them. Throughout the area as a whole the drilled and driven wells now considerably outnumber the open wells. They are much smaller than the open wells and range in diameter from $1\frac{1}{4}$ to 8, 10, or even 12 inches. At least nine-tenths of them are 2 inches or less in diameter. The wells consist of a tightly jointed iron pipe sunk into the earth to a water-bearing bed. If this bed is a loose material, such as sand or gravel, a strainer or screen is placed over the lower end of the pipe to keep the gravel or sand out of the well. If the well is in rock the pipe is left uncovered below.

Driven wells.—Driven wells are those which are made by driving a pipe into the loose surface deposits without first making a hole for the pipe to go into. They can be sunk only in unconsolidated materials and never go into rock. To make the pipe drive more easily and to keep it from filling up with loose material, a conical brass point, full of fine perforations, is fastened to the lower end. There are many methods of driving the pipe, varying from the wooden hand maul to a steam-driven trip hammer, the method used depending on the depth and character of material to be penetrated.

The driven wells are especially adapted to areas of valley alluvium, of gravelly outwash, or of till or morainic drift in which there are gravelly or sandy layers. Many can be driven in a few hours and at very little expense. No pollution can get into the well from above and water is drawn only from the deepest and usually the safest water bed. Many driven wells show a decrease in supply after a few years' use, due to corrosion or clogging of the screen. The pipe can usually be pulled at small expense, the screen cleaned or replaced, and the well redriven, with a renewal of the original supply.

Drilled wells.—Drilled wells are made by first drilling a hole and then driving a pipe into it. The hole is commonly made with a wedge-shaped drill driven by a steam engine. Plate V, *A*, shows a common type of well rig used in this area. Under the classification of drilled wells comes a type of well made by forcing water or steam under high pressure through a pipe into the loose surface deposits, and forcing the pipe down constantly as the materials below are washed out of the top with the water, or forced out by the steam. This process is often called jetting, and sometimes the wells are called driven wells. Still another process is a combination of the jet and the drill. The drill, with a small opening on either side just above the cutting edge, is jointed to an iron pipe. Through this pipe water is constantly forced into the well, and the materials loosened by the drill and the streams of water are carried out of the well top by the water.

Drilled wells are the prevailing type in areas where the rock waters are the chief source of supply. On the till plains the tough clays in some places prevent the driving of deep wells and there drilled wells are more common. The bowlders embedded in the till will stop a driven well, but the drill can cut through them. In any material in which it is necessary to go to a depth of 100 feet or more the wells are usually drilled.

Drilled wells that end in unconsolidated materials are provided with a screen, let down on the inside of the casing after the well is completed. A common method is to lower a screen, 3 or 4 feet long, to the well bottom and then to pull back the casing far enough to expose the screen.

COMBINATION WELLS.

A combination of the dug and driven or of the dug and drilled wells is very common. Many dug wells that fail in dry seasons, or for other reasons have proved unsatisfactory, are deepened by driving or drilling. In such wells care should be taken to continue the casing up through the well to the surface to prevent the dug-well waters from entering the driven or drilled wells. Wells drilled into the bottom of dug wells are likely to receive some water from the old well, unless the casing fits the hole very snugly. It is recommended that when these combination wells are made the dug portion of the well should be filled up with clean clay. This will prevent any possible pollution of the deeper waters by those from the old well.

FLOWING WELLS.

ESSENTIAL CONDITIONS.

In many areas in north-central Indiana the waters in certain beds are under sufficient artesian pressure to cause them to flow at the surface without pumping. These flowing wells are much prized, as they furnish a continual supply of fresh water for city, domestic, or farm uses. Plate IV shows the areas in which flowing wells have been obtained.

The conditions necessary for artesian flow were defined a number of years ago by T. C. Chamberlin.[a] These conditions apply both to the flows from rock wells and to those from surface deposits, and are as follows:

1. A pervious stratum to permit the entrance and the passage of water.
2. A water-tight bed below to prevent the escape of the water downward.
3. A like impervious bed above to prevent the escape upward, for the water, being under pressure from the fountain head, would otherwise find relief in that direction.
4. An inclination of these beds, so that the edge at which the waters enter will be higher than the surface at the well.
5. A suitable exposure of the edge of the porous stratum, so that it may take in a sufficient supply of water.
6. An adequate rainfall to furnish this supply.
7. An absence of any escape for the water at a lower level than the surface of the well.

A recent paper of M. L. Fuller[b] has added a number of modifications to the requisite conditions of artesian flow as outlined by Chamberlin.

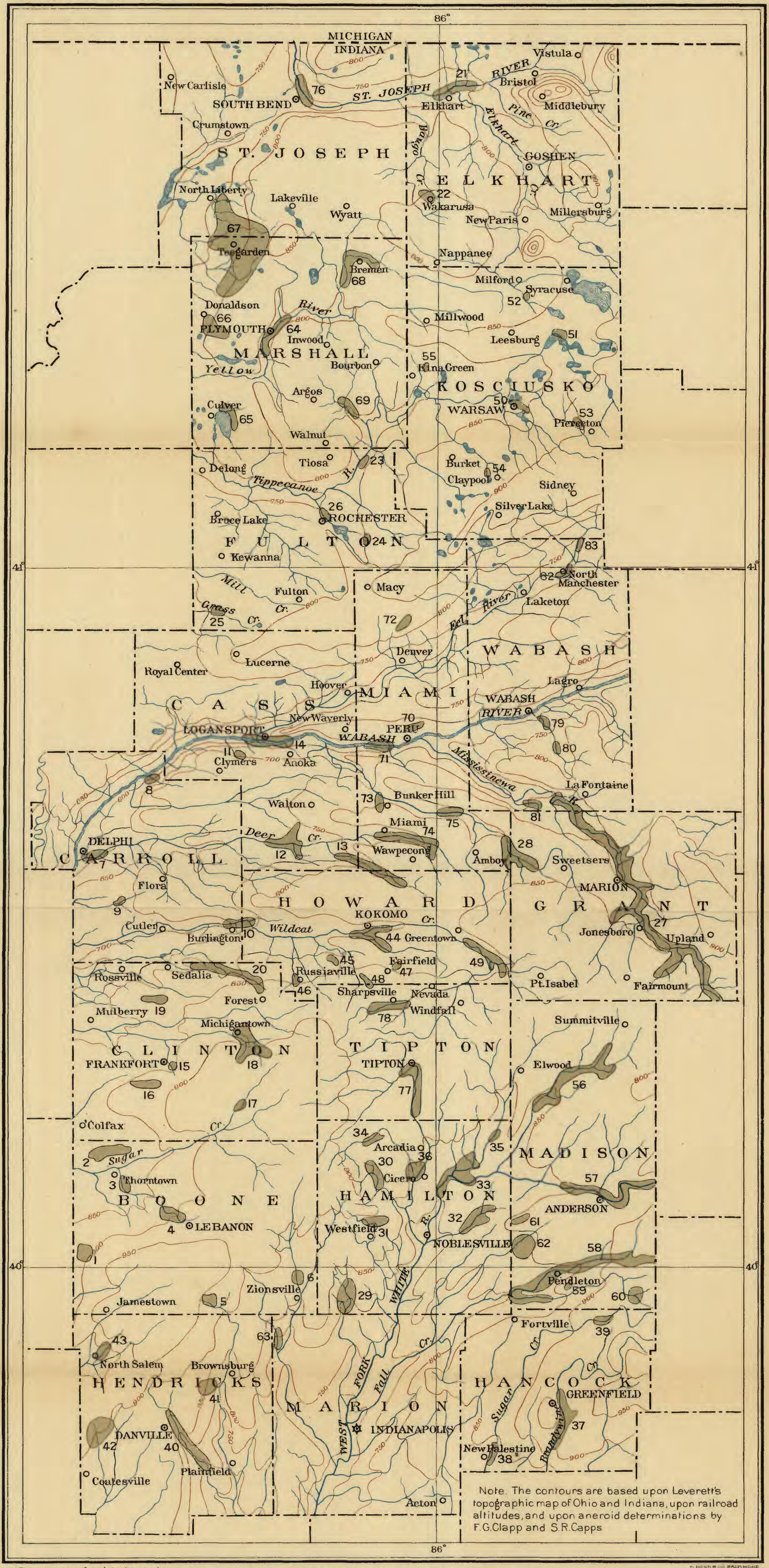
In many wells which do not flow the water rises under artesian pressure, but not to the top. In these the conditions are the same as for flowing wells, except that the pressure is not adequate to raise the water to the surface. In both kinds the waters are under artesian pressure, but in this report only those areas in which actual flowing wells are found are mapped as artesian areas. In the region treated in this report there are two distinct types of flowing wells—(*a*) those whose water is derived from surface deposits, and (*b*) those whose water is derived from rock.

IN SURFACE DEPOSITS.

Most flowing wells in surface deposits reach their supply in gravel beds in the moraines, in the till, or in fluvioglacial outwash plains below the moraines. In figure 7, *A* is a well sunk to a lens of gravel in moraine. The fountain head of the water is at the outcrop of this gravel bed higher up on the moraine. The area in which flowing

[a] Requisite and qualifying conditions of artesian wells: Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 125-173.

[b] Summary of the controlling factors of artesian flows: Bull. U. S. Geol. Survey No. 319, 1908.



The areas are referred to by number in the descriptions under the county headings in the text.

MAP OF NORTH-CENTRAL INDIANA
SHOWING ARTESIAN WELL AREAS

BY STEPHEN R. CAPPS

Area in which flowing wells occur

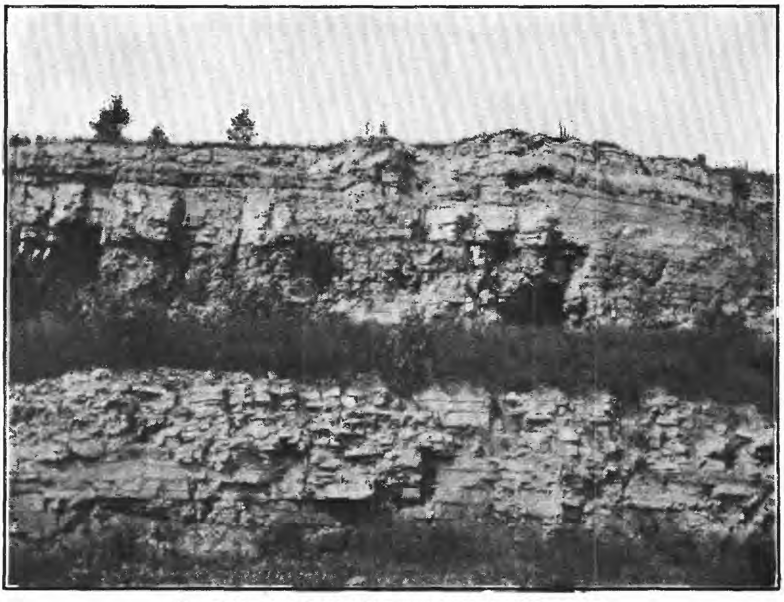
Scale $\frac{1}{625,000}$

10 0 10 20 Miles

Contour interval 50 feet

1909

A. COMMON TYPE OF WELL-DRILLING RIG.



B. SOLUTION CHANNELS IN NIAGARA LIMESTONE.

wells might be obtained is very small. In the well at *C* the water would rise under artesian pressure almost to the surface, but would

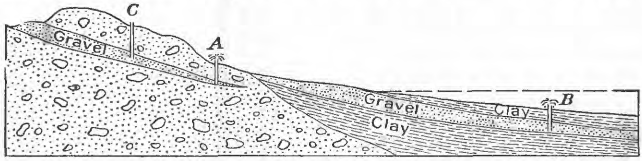


FIGURE 7.—Conditions that yield artesian flows in moraines and in outwash gravels.

not flow. Flowing well *B*, on the outwash plain, taps a gravel bed between two impervious clay beds. The head for the water comes

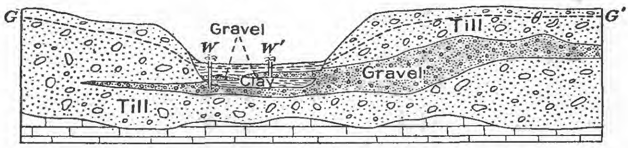


FIGURE 8.—Conditions of flow in alluvial gravels with head supplied from the drift gravels. Artesian waters are found in alluvial gravel by well *W'*, and the head is supplied by an irregular gravel bed in the drift. Flows may also be obtained by wells at *W* from the drift gravels. *G-G'*, water table.

from the gravel outcrop at the base of the moraine. Wells anywhere on the plain around *B* would get flowing water.

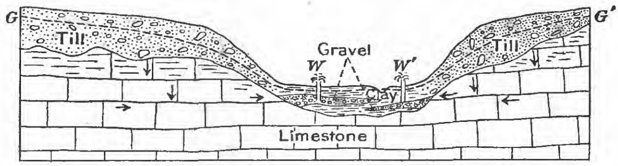


FIGURE 9.—Conditions of flow in alluvial gravels with head supplied from the limestone. *G-G'*, water table. Water for wells *W*, *W'* is supplied to the gravel by the limestone, which receives the water from the till.

Figure 8 shows conditions in which wells in valley alluvium may find flowing waters, the head being supplied from the surface deposits; in figure 9 the head of water is supplied from the limestone.

IN ROCK.

In the part of this area which lies south of Wabash River there are in every county numerous wells that penetrate rock. North of

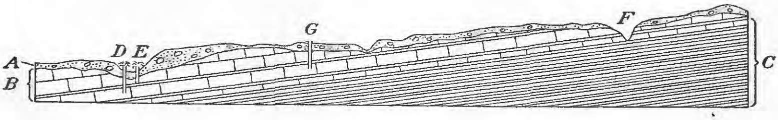


FIGURE 10.—Conditions that yield artesian flows in rocks.

the Wabash the surface deposits are very deep and few wells go through them. In all parts of the area, however, the wells that go deep into the Silurian limestones ("Niagara") encounter water under artesian pressure. This pressure is generally not sufficient to give flows in the uplands, but in the river valleys many deep wells get flowing waters from these rocks. The question naturally arises as to the source of the waters. Most writers in discussing flows from rock ascribe the source of head to some higher outcrop of the water-bearing formation at a point where it can receive the rainfall directly or from pervious overlying beds. In applying such an interpretation to the flows from rock in parts of this area grave difficulties are encountered, and the ordinary hypothesis seems to fail. The opportunities for water to enter the "Niagara" limestone at distant and higher outcrops are outlined below.

At a point 7 miles east of Richmond, Ind., the "Niagara" has an elevation of almost 1,200 feet above sea level, but is covered by 25 to 50 feet of drift. At Richmond, at an elevation of about 950 feet, this limestone comes to the surface on the sides of the canyon-like valley of the East Fork of Whitewater River, but the cliff-like outcrops are unfavorably situated for absorbing large quantities of surface waters. Between this high outcrop and the flowing wells above mentioned there is a distance of about 50 miles, throughout the whole of which distance the "Niagara" lies immediately below the drift. The drift itself varies so in texture that it can hardly be supposed to form an impervious covering for the limestone for so long a distance.

The Richmond area lies on the flank of the Cincinnati arch, from which the rocks all dip to the west. It may be that waters entering near the base of the Niagara at Richmond and flowing westward along the gently dipping bedding planes pass beneath impervious shale beds and accumulate enough head to supply flowing wells in the lowlands. The possibilities of flows from this source are illustrated in figure 10. *A* is the covering of glacial deposits; *B* is the "Niagara" limestone with its interbedded shales. The surface waters, entering the base of the limestone at *F*, pass downward under an impervious shale bed. A well at *G* will find water under artesian pressure, but owing to loss of head from friction the well will not flow. Well *D*, in the lowlands, gets flowing water. At well *E* the waters have entered the limestone through the thin drift toward *G*, but the thick drift of the valley has prevented their escape, and a flow is obtained in the upper part of the limestone. The flows from the "Niagara" are all found in the deeper valleys or in depressions somewhat below the level reached by the surrounding surface deposits, and the head is generally not more than a few feet above the surface. In certain wells the flowing waters are procured from below impervious shale beds, or "breaks" in the limestone, and in these wells the head of the waters is probably transmitted from a distance. (See fig. 10.) In most wells, however, the flows are from the upper part of the limestone, and such a distant source for the waters seems improbable.

The head for most of the flows from rock seems to be furnished by the heavy overlying mantle of glacial drift. In the drift the water table stands high above the valley bottoms, and even where the transmission of water from the drift to the rock is slow a constant pressure may be maintained in the rock waters if there is no ready escape for them. Wells tapping such a rock supply may obtain flows if they are situated in the deeper valleys or at the foot of the drift hills. Figure 11 shows the conditions for flow in such an area.

Most of the deep wells which obtain flowing waters from great depths were drilled originally for gas or oil. In these wells an outer casing or drive pipe, usually 8 inches in diameter, is driven down to the surface of the rock, and within this pipe a 6-inch casing is carried down to the bottom of the "Niagara" to shut out the water from that rock. The flowing waters, if such are encountered in the limestone, come up between the drive pipe and the casing. When no oil or gas

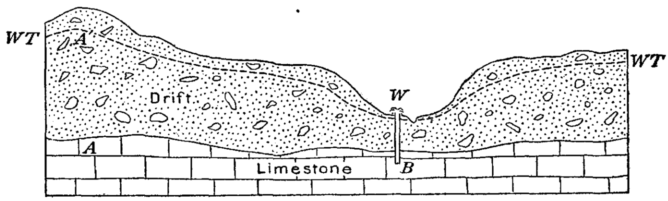


FIGURE 11.—Conditions for artesian flows in limestone, with head supplied by the overlying drift. *WT* is the water table. The water percolates slowly into the limestone from the drift and at *A* is under pressure from the hydrostatic column between *A* and *A'*. The pressure is transmitted through the open bedding planes and joints to *B*, and well *W* obtains an artesian flow.

is found or when the supplies fail the casing and drive pipes are as a rule pulled. Pulled wells are required by state laws to be plugged below the limestone to prevent the interchange of waters between the "Trenton" and the "Niagara." In many flowing wells the drive pipe is left in and the well used to supply water.

LOCATION OF FLOWING WELLS.

It is often difficult to predict just where artesian wells can be had, and no general statement will cover all parts of this area. It can only be said that wells in depressions or at the base of high moraines are more likely to obtain flows than those on higher ground.

The areas in which flowing wells from rock are obtainable are usually long, narrow belts occupying the bottoms of the larger valleys. Most flowing wells from surface deposits are due to local conditions, which are confined to small areas. The map (Pl. IV) gives the location and outlines of the areas in which flowing wells have been obtained. Future borings will doubtless modify the outlines of certain of the districts, enlarging some and reducing others. Probably some entirely new flowing-well districts may be found. The map has been compiled from the fullest data obtainable at this time.

LIFTING DEVICES.

Bucket and windlass.—A few open wells from which the water is drawn by buckets on a windlass are still in use. The owners of such wells are commonly convinced that water drawn in this way is superior in taste to that taken from a pump. There is always danger from pollution, however, in these wells by small animals or other objectionable matter entering the well mouth. A tight well cover should always be put in place when water is not being drawn.

Siphon.—The siphon principle may locally be utilized when running water is desired at some point below the level at which the water stands in a well. This system is used at the Kokomo city waterworks. A number of wells are drained by a siphon into a large well at the waterworks. The water is pumped directly from this large well.

Pumps.—Of the many pumps of various makes and kinds on the market, the greater number are so simple and so familiar as to need no description. For shallow wells the iron pitcher pump with the valve near the spout is much used. For open wells of moderate depths the wooden pump is popular. Most of the deeper dug, driven, or drilled wells for household and farm uses are equipped with iron force pumps with the valve below the water level. Some of these pumps are connected to windmills and may be pumped either by hand or by wind power. Factories, city waterworks, and large users of water in general employ water pumps operated by steam, gas, or gasoline. The chief types of power pumps are the reciprocating steam pumps, the air lifts, and the gasoline engines of various makes. Hot-air engines have also been used to some extent.

Hydraulic rams.—Throughout the area here discussed, but especially in the country districts, there are many flowing wells of good head and volume from which only a small fraction of the flow is used. If the pressure of these wells is sufficient to raise the water a few feet above the surface, or if there is a decline of the surface near the well, a hydraulic ram can be installed which will pump sufficient water for domestic and farm uses. The efficiency of hydraulic rams has been observed to vary from 30 to 71 per cent. That is, a ram at a well with a head of 10 feet and a flow of 10 gallons a minute will lift from 3 to 7 gallons a minute to a height of 10 feet, or 0.3 to 0.7 gallon to a height of 100 feet. Many houses in small towns or in the country are supplied with running water in this way, and water systems could be installed in many more at a small initial expense. The cost of maintenance of such a system is exceedingly small. In New

Palestine, Hancock County, there is a privately owned water system, supplied by artesian wells and pumped by a hydraulic ram, which furnishes water to 20 or 30 families.

PUBLIC SUPPLIES.

In the area under discussion there are 54 towns and cities which have public water supplies drawing waters from surface streams, lakes, wells, springs, or a combination of wells and streams, as follows:

Source of public supplies in towns and cities.

From lakes	3
From streams	3
From wells	44
From springs	1
From streams and wells	3

Of the public systems 48 out of 54 obtain all or part of their water from underground sources.

RELATIVE MERITS OF SOURCES.

SURFACE WATER.

In all regions as thickly settled as north-central Indiana the larger surface streams are sure to be contaminated to some extent, and the pollution may enter the streams in a number of ways. If towns or cities are located along the banks of a stream, the sewage is discharged into it. If there are no municipalities along the stream course, the drainage from dwellings and from manured fields or pastures is almost certain to supply objectionable organic matter. The salty or oily waters from the wells in oil or gas regions also are turned into the natural drainage channels. Even in the absence of sewage the streams all become turbid after every rain storm, so that for some time the water in its raw state is unfit for use.

The three cities which use river water altogether are Logansport, Anderson, and Mishawaka. The waters at Logansport and Mashawaka are unfiltered, and therefore subject to contamination. A filtration system has been installed at Anderson, and the filtered water is greatly superior to the raw water. At Indianapolis, Peru, and Goshen part of the water supply is from wells and the rest from streams. At Indianapolis White River water, used only after filtration, is very good. At Peru the water is ostensibly supplied from wells, but inasmuch as a considerable proportion of raw river water is constantly pumped into the mains the supply must be considered a serious menace to the health of the city. Part of the city water of Goshen is supplied from Rock Run, which flows for some distance through the town, having on its banks dwellings, barns, and outhouses that unquestionably pollute the water.

Other things being equal, lakes are less likely to become contaminated than rivers, for their length of shore line is much shorter, as compared with the volume of water, than that of streams, and almost all pollution enters surface waters from the shores. It is, moreover, much easier to guard the shores of a lake from pollution than to control conditions along the banks of a stream which traverses a considerable stretch of country.

Three of the 54 municipalities are supplied from lakes. These are Warsaw, Rochester, and Syracuse. Center Lake, the source of supply at Warsaw, lies at the edge of the town, and the character of the water is questionable. The water from Rochester Lake at Rochester is itself of fair purity, but it becomes polluted in its passage through a mile-long mill race in the town. The conditions at Syracuse are much the same as at Rochester. Syracuse and Turkey lakes are bordered by extensive marshes, and the water is noticeably colored by organic matter, besides being exposed to contamination in its passage from the lake to the pumps through an open mill race. To summarize, in every instance in this area in which surface water is used for a public supply the water in a raw state is unsafe. In two instances it has, by careful filtration, been purified and converted into a very satisfactory supply.

The surface waters are superior to underground waters for many industrial purposes, because they contain a much smaller proportion of incrustants. This lower mineralization makes them especially desirable for locomotive-boiler supplies and for steaming purposes in general. On the other hand, the lower temperature of the ground waters especially recommends them for cooling purposes in brewing, distilling, and ice manufacture.

WELLS.

Of the 44 public supplies in which well water is used altogether or in part it is probably true that the worst of the well waters is as good as or better than the best of the surface waters mentioned above, in the raw state. Most of the well supplies are greatly superior to the surface supplies, at least with regard to their healthfulness. The wells at public waterworks are usually drilled deep in order to secure large quantities of water, and waters from deep beds are much less likely to be polluted than waters from near the surface. The wells for public supplies can be located at a distance from possible sources of contamination, and the ground around the wells can be guarded to prevent unhealthful conditions.

In a few towns in this area the wells for the public supply are shallow and are surrounded by barns, buildings, and dwellings, with the accompanying manure piles, slops, and privy vaults. It is a curious fact that people who are ordinarily careful about their habits of life should be careless about so vital a thing as the condition of their drinking water. Typhoid fever, one of the most dreaded forms of sickness in this area, is caused by the transfer of the infection from a typhoid patient into the alimentary system of another person. Contagion is spread largely through the pollution of drinking water by sewage which carries the typhoid-fever bacillus. Above all things a public water supply should be protected from this danger. Wells to be absolutely safe should be drilled or driven to a considerable depth, 50 or 60 feet at least, and should be lined with a tightly jointed iron pipe to keep out all the waters except those at the well bottom. Commonly, the deeper the well is the safer the water. If the wells are located at a distance from buildings or other sources of sewage, the danger is reduced to a minimum. In a few places it has been found to be impossible to obtain sufficient water from deep drilled or driven wells. Fairly safe waters may be obtained, as at Elkhart, from open dug wells if a considerable area of land around the wells is reserved and carefully guarded. Open wells should be several hundred feet from the nearest outhouse and carefully protected from surface wash to be safe from pollution.

SPRINGS.

Springs furnish the water for only one public supply in this region. At Delphi excellent springs emerge from a gravel terrace 3 miles northeast of the city, and the city waterworks collect this water and supply it to the people. There is every reason to believe that this supply is pure and good, but the common idea, that all springs are pure, is by no means true. Springs are subject to exactly the same dangers of pollution as wells. The waters are the same as those secured from wells, the only distinction being that springs have a natural instead of an artificial outlet. If the waters issue from shallow depths in towns or below manured pastures, near outhouses or barnyards, they should be avoided with the same care as should similarly situated dug wells.

CARE OF PUBLIC WATER SUPPLIES.

When sanitary conditions are assured for the wells at public waterworks, it is still essential that care should be taken to avoid all danger of pollution of the waters while they are stored and before their distribution through the mains. There is no danger of such pollution in tight iron standpipes which are covered over. Covered wooden tanks are also safe. Open tanks will receive slight deposits of dust and possibly some pollution from birds and insects, but this is likely to be of negligible quantity. Open reservoirs should be carefully guarded to prevent the entrance of surface waters or of sewage by underground circulation. Cement-lined reservoirs are safe except from surface wash and from dust and dead animals. The amount of dust should be unimportant and other pollution can be avoided by proper care. Cisterns, if tight, are safe, and if the surface of the stored water is kept above the level of the ground-water table any leakage from cracks will be outward from the cistern. Cisterns below the water table should be inspected as often as possible in order that means may be adopted to prevent the entrance from without of waters through cracks or flaws in the masonry.

In water mains in which the water is under pressure the pressure from within the pipes is much greater than that from without, and any defect in the pipes will cause a leak outward. No water from without can by any chance get into a high-pressure pipe. Where the water flows by gravity from one well to another, or where suction is used to draw water from wells or reservoirs a loose joint or hole in the mains might permit the entrance of sewage from without. Constant care is necessary to avoid such a contingency.

PUBLIC AND PRIVATE OWNERSHIP OF WATER SUPPLIES.

The obvious advantage of public water supplies over private wells is their greater convenience. With the constant pressure maintained in a municipal system, running water can be had at any time wherever it has been piped. Furthermore, there is the important advantage of abundant water and high pressure for protection from fire. But beside these two commonly recognized advantages, there is the all-important one, the health of the consumers, to be considered. In thickly settled communities, and especially in towns that have no sewerage system, a great quantity of liquid sewage is constantly soaking into the ground, some of which finds its way to the shallow wells used for drinking water. Such a condition is unpleasant to contemplate and extremely dangerous, but strangely enough it exists in most towns. Each well owner is sure that his water is the best in the world. He is accustomed to it, and it tastes just right to him. Yet examination of the water may show it to be heavily polluted. The best solution of the water problem is a carefully planned public supply. Wherever they are possible, deep driven or drilled wells are recommended. They should be located as far as possible from any source of pollution, and if practicable should be drilled to some water-bearing bed below an impervious bed of clay. These conditions should give a water supply far superior in every way to that obtained from shallow private wells.

Of the 54 public water supplies of this region, 19 are owned by private individuals or companies; 2 by the United States Government (at the National Military Home near Marion, and at Fort

Benjamin Harrison); and the remaining 33 by the different municipalities.

There are certain advantages, both in municipal and in private ownership. The principal arguments in favor of private ownership of public water supplies are as follows:

1. The officials of a private water company do not hold office by political favor, but their connection with the business is permanent and their interest in and knowledge of the details is proportionately great.

2. As a result of better business methods, the cost of running a water plant is usually less in private than in public concerns.

3. The installation of improvements by a private company is simpler and does not require the tedious city-council legislation often necessary for such expenditures in a municipal system.

4. It is to the advantage of a private company to furnish as good and as cheap a supply as possible, in order to encourage the use of the system.

On the other hand, there are many advantages in a system owned by the town or city:

1. It is not necessary in a municipal system to charge enough for the water to pay a dividend on the capital invested.

2. In private companies there is always the tendency to insist that the water is pure, no matter what the actual conditions are. In municipal supplies there is a better opportunity for knowing the actual condition of the water.

3. It is not necessary, with a municipal supply, to postpone improvements until there is a sufficient increase in the receipts of the company to insure dividends on the cost of extension.

4. As the public officers hold their positions at the will of the people, there is a tendency for them to furnish as good a water supply as possible at a fair rate.

For these and other reasons municipal ownership of public waterworks has proved more satisfactory than private ownership in the area under discussion, as shown by the proportion of 33 to 19.

Public water supplies in north-central Indiana.

[Abbreviations: A. l., air lift; a. p., air pressure; d. p., direct pressure; g. e., gasoline engine; gr., gravity; hy r., hydraulic ram; st. p., steam pumps; w. p. p., water-power pumps.]

Town.	County.	Owner of supply.	Source of supply.	Distributed from—	Capacity of reservoirs.	Elevation of reservoir above wells.	Carried to distributing point by—	Distributed by—	Length of mains.	Diameter of mains.	Number of taps.	Estimated proportion of population supplied.	Number of fire hydrants.	Average amount used daily.	Capacity of pumps per day.	Domestic pressure.	Fire pressure.	Analysis. No.	Analysis. Page.
					Gallons.	*Ft.*			*Mi.*	*In.*		*P. c.*		*Gallons.*	*Gallons.*	*Lbs.*	*Lbs.*		
Alexandria	Madison	City	7 wells	Standpipe	235,000	100	St. p.	Gr.	10	4-12	500	50	121	300,000	1,500,000	50	100—	5	175
Anderson	do	do	White River	Pumps	500,000			D. p.	32½	4-20	2,200	33	288	1,500,000	6,000,000	65	100—		
Argos	Marshall	do	1 well	do	25,000			D. p.	3⅓	4-6	86	20	27	30,000	1,000,000	50	80	1	194
Bourbon	do	Union Water, Light and Power Co.	2 wells	Standpipe	65,000	100	St. p.	Gr.		4-10	70	15	27	50,000		43	80	2	194
Bremen	do	City	5 wells	do	30,000	104		Gr.	7	2-6	320	75	30	600,000	1,500,000	40	150—	4	194
Brightwood	Marion	City of Indianapolis.	3 wells	Pumps	40,000			D. p.	6	¾-10	400		39	93,000	1,400,000	40	100—		
Camden	Carroll	E. C. Rice	1 well	Tank		40	G. e.	Gr.	⅓	2	14		0					2	86
Converse	Miami	City	1 well	do	3,500	72	St. p.	Gr.	2	4-8	180	60		200,000		32	32	3	202
Culver	Marshall	do	3 wells	A. p. tank.			G. e.	A. p.	⅕	4-6								5	194
Danville	Hendricks	do	6 wells	Standpipe		200	St. p.	Gr.	5	4-8	600	95	40	450,000	1,500,000	120	120	4	149
Delphi	Carroll	do	Springs	do	37,000	116	St. p.	Gr.	5½	4-8	459	95	50		1,500,000	55	80	6	86
Elkhart	Elkhart	Elkhart Water Co.	3 wells	Pumps				D. p.	33	6-24	3,320	25	281	3,000,000	19,000,000	55	100	2, 8	109
Elwood	Madison	Elwood Water Co.	14 wells	do	1,500,000			D. p.	14	4-14	1,100	40	149	650,000	5,000,000	40	100—	16	175
Fairmount	Grant	City	6 wells	do				D. p.	4	4-10	400	65	45	300,000	720,000	40	90—	2	127
Flora	Carroll	Flora Water Co.	1 well	A. p. tank.	60,000			A. p.		4-8						45	75	12	86
Fort Benjamin Harrison.	Marion	United States	4 wells	2 standpipes.			St. p.	Gr.											
Frankfort	Clinton	Frankfort Water Works Co.	12 wells	Pumps	400,000			D. p.	23	4-12	2,000	75	229	1,000,000	5,500,000	50	90—		
Frankton	Madison	City	1 well	do				D. p.	4			40	31	25,000	300,000	60	110—	17	175
Galveston	Cass	W. H. Sprinkle	1 well	Tank	15,000	50	G. e.	Gr.	5	2-4			25		150,000	35		3	94
Gas City	Grant	City	3 wells	Pumps	150,000			D. p.		Up to	500	60	46			30	100—	4	127
Goshen	Elkhart	do	2 wells and Rock Run.	Standpipe	266,000	146	St. p.	Gr.	25	4-20	1,800	80	292	1,500,000	8,000,000	60	100	13-15	109
Greenfield	Hancock	do	8 wells	Pumps				D. p.	8	4-12	900	75	84	300,000	1,000,000	45	100—	4	143
Greentown	Howard	Delon & Davis	1 well	Tank	10,000	65	G. e.	Gr.	1	¼-3	95	25		5,000 to 20,000	40,000	30			
Indianapolis	Marion	Indianapolis Water Co.	White River and wells.	Pumps				D. p.	284	4-36	18,863	75	2,291	17,883,800	80,000,000	65	125—	19, 20	186
Jonesboro	Grant	Trowbridge & Niver.	1 well	do				D. p.		4-10	150	33	52	225,000	1,500,000	45	130—	8	127

Kewanna	Fulton	City	1 well	A.p.tanks			G.e.	A.p.	$1\frac{2}{3}$	Up to 6			13			40	75—		
Kokomo	Howard	American Water Works and Guarantee Co.	13 wells	Pumps				D.p.	30	4–12	2,500	75	295	2,000,000	7,000,000	40	100—	3-6	157
Lebanon	Boone	City	5 wells	Standpipe	189,000		St. p.	Gr		4–12	1,400	60	124	600,000	2,000,000	50	52	2, 3	77
Logansport	Cass	do	Eel River	Pumps				D.p.	33	2–20	3,220	50	202	3,500,000	9,000,000	50	100		
Marion	Grant	do	14 wells	do	2,950,000		A.l.	D.p.				75			2,500,000	50	120	10, 12–15	127
Milford	Kosciusko	do	4 wells	Standpipe	83,000	110	St. p.	Gr	$2\frac{1}{2}$	4–8	71	33	23	20,000	600,000	47	200—	7	165
Mishawaka	St. Joseph	do	St. Joseph River.	Pumps				D.p.	17	4–12	1,550	66	170	2,000,000	5,000,000	60	110		
Nappanee	Elkhart	do	3 wells	Tank	75,000	116	St. p.	Gr	4	4–8	315	50	31	65,000		44	100—	19	109
National Military Home.	Grant	United States	14 wells	Standpipe	240,000	125	St. p.	Gr	3	4–8				500,000	2,000,000	60	150		
New Carlisle	St. Joseph	City	4 wells	Tank	33,000	85	St. p.	Gr	$2\frac{3}{4}$	2–6		80	18	100,000	1,200,000	35	100—	5, 6	213
New Palestine	Hancock	Max Herrlick	2 wells	do	6,000	86	Hy.r.	Gr	2	2	35	20	0		14,000	28			
Noblesville	Hamilton	Noblesville Water and Light Co.	17 wells	Pumps			St. p.	D.p.	13	2–16	750	35	102	480,000		40	80—	8, 9	137
N. Manchester	Wabash	City	12 wells	Standpipe	160,000	110	St. p.	Gr	9		250	33	58	130,000	750,000	65	65	7	229
Peru	Miami	do	Wabash River and 14 wells.	Reservoir	1,200,000	93	St. p.	Gr	24	6–16	1,765	65	221	1,300,000	3,000,000	39	100	14, 16	203
Pierceton	Kosciusko	do	1 well	Tank	15,000			D.p.	$1\frac{3}{4}$	4–6	200	50	32	20,000		40	60	8	165
Plymouth	Marshall	do	12 wells	Pumps				D.p.	$7\frac{3}{4}$	4–8	430	45	52		1,000,000	40	120—	16, 17, 18	194, 195
Rochester	Fulton	do	Mill race from Manitau Lake.	Standpipe	105,000		St. p.	Gr	10			25		400,000				10	116
Royal Center	Cass	do	1 well	Tank	68,000	90	G.e.	A.p.	2	Up to 6			13	25,000		40	75	16	94
Russiaville	Howard	C. W. Hollingsworth.	2 wells	do	5,000	60	G.e.	Gr		$\frac{3}{4}$–2	20		6	5,000 to 20,000		30	60	10	157
Sheridan	Hamilton	G. H. Farmer	2 wells	do	10,000	65	St. p.	Gr		$\frac{3}{4}$–2	25	5		10,000	25,000	20			
South Bend	St. Joseph	City	70 wells	Standpipe	33,000	225	St. p.	Gr	80	4–24	7,000	75	827	5,300,000	14,000,000	80	80	17, 18	214
Summitville	Madison	do	1 well	Pumps				D.p.	$2\frac{1}{2}$	4–8	130	50	25	150,000	750,000	40	120	29	176
Syracuse	Kosciusko	do	4 wells	Standpipe	32,000	95	W.p.p.	Gr		4–10		20	27	15,000 to 30,000		45	120—	13	165
Tipton	Tipton	do	15 wells	Pumps				D.p.	13	4–12	900	66	81	350,000	500,000	30	120—	1, 2	220
Upland	Grant	Upland Water Works Co.	1 well	do				D.p.	$\frac{2}{3}$	2–4	140	60		40,000	60,000	20			
Vanburen	do	E. S. Sutton	1 well	Standpipe	15,000	65	St. p.	Gr	$1\frac{1}{8}$	2–5	130	25	12	75,000		30	110	23	128
Wabash	Wabash	Wabash Electric Light and Water Works.	9 wells	do	385,000	100	St. p.	Gr	26	6–12	1,790	75	243	1,300,000	4,000,000	88 to 40	120	14, 15, 16	229
Walkerton	St. Joseph	City	4 wells	Tank	55,000	105	St. p.	Gr	3	4–6		50	20	100,000		45	85	20, 21	214
Warsaw	Kosciusko	Winona Water and Light Co.	Center Lake	Standpipe		125	St. p.	Gr	$7\frac{1}{2}$	4–10	800	66	63	1,000,000	2,000,000	50	80	16	165

DETAILED DESCRIPTIONS.

BOONE COUNTY.

SURFACE FEATURES AND DRAINAGE.

Boone County comprises 427 square miles and in 1900 had a population of 26,321, or 61 people to the square mile. Lebanon, the county seat, is in the center of the county, 25 miles northwest of Indianapolis.

This county extends along the divide between White and Wabash rivers and includes the highest land in Indiana west of White River. The surface has an elevation of 825 to 975 feet, or a range of approximately 150 feet (Pl. I). The greater part of the surface consists of slightly undulating uplands unbroken by any notable irregularities of surface. Across this plain and crossing the area from southeast to northwest is a narrow belt of low irregular hills. A part of another belt, of much the same character, crosses the southwest corner of the county. As usual in till-plain areas there is an almost complete absence of natural lakes or ponds. There are a few artificial ponds, used for stock, but the county as a whole is well drained.

The county contains no large streams. Eagle Creek flows along the eastern edge, and in the neighborhood of Zionsville its valley is about 60 feet below the level of the uplands. Sugar Creek, in the northwest corner, has also a well-developed valley. The other streams are still smaller and flow from 10 to 30 feet below the level of the upland.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

Immediately below the surface in Boone County unconsolidated deposits which vary in thickness from 25 to more than 200 feet are everywhere present. They consist of alluvium, morainic drift, and pebbly till, and most of the wells draw their supplies from these materials. A general discussion of the character and water supplies of the surface deposits is given on pages 27–35.

The alluvial deposits are limited to the valleys of Sugar and Eagle creeks and to the flats of the still smaller streams. Their total area can not be more than a few square miles.

The moraines of this county (see Pl. I) are not of great height or thickness. In the moraine areas satisfactory wells can almost everywhere be obtained at moderate depths. The porous character of the deposits enables them to store large quantities of water and to yield it readily to wells. It is ordinarily not necessary to go through the drift into the underlying rock for sufficient water supplies.

The larger portion of the county is a level till plain. The till ranges from 25 to 300 feet in thickness, notwithstanding the fact that its surface is flat and plainlike (Pl. II). This variation in thickness is due to the irregular surface of the underlying rock. The glacial ice moved over this surface and deposited enough detrital matter to fill the depressions and to level over the whole area.

The water moves very slowly through the fine-grained till, and to obtain it loosely curbed wells of large wall area have been much used. Of late years most of the open wells have been abandoned. It has been found that deep driven or drilled wells will almost certainly strike porous gravel beds in the till, and the gravel water so obtained is so much better and the supply so much more abundant than that from the clay that many people have preferred to bear the additional expense of sinking a deep well rather than to put in a cheaper shallow dug well. Drillers have been so successful in finding water in the till that few wells have gone through it into the rock.

CONSOLIDATED MATERIALS.

As stated above, the underlying rock formations are everywhere covered in this county by surface deposits, and no outcrops occur. Our knowledge of their distribution is derived altogether from comparisons with known outcrops in neighboring areas and from the records of well drillings. The probable distribution of the geologic formations is shown on Plate III.

The "Knobstone" group lying immediately below the till, in the west and southwest portions of the county, consists of limestones, sandstones, and shales. As a result of their superior hardness these rocks withstood the preglacial and glacial erosional agencies much better than the underlying New Albany shale. Wherever the "Knobstone" beds remain, they rise within 40 to 60 feet of the present surface. The older, less resistant shale has been deeply eroded beyond the edge of the "Knobstone," which, if the glacial materials were removed, would stand up as a sharp escarpment 100 to 200 feet above the shales to the east.

Over most of the areas underlain by the "Knobstone" the till has furnished sufficient water for domestic use. A few wells at Jamestown, Advance, Max, and in that part of the county south of Lebanon, have encountered a limestone 40 to 70 feet below the surface, which wherever penetrated has yielded abundant waters within a few feet of its top.

The New Albany shale underlies the surface deposits in all of central and eastern Boone County except the extreme northeastern corner (Pl. III). Although it is everywhere covered with till to a depth of 100 to 300 feet, this close-grained blue or black shale has been entered by the drill at many points. It contains much water, but it is so fine-textured that wells procure little or none. The formation is also too deep to be easily reached by the ordinary well-drilling rig.

Below the New Albany shale are two Devonian limestone formations known as the Sellersburg limestone and the Jeffersonville limestone, which are believed to outcrop below the drift in the extreme northeast corner of the county (Pl. III). The overlying drift is about 200 feet deep in this locality, and no records could be found of wells which have gone deeply into the rocks. No water is now drawn from them, and in Boone County it has yet to be determined whether these limestones contain available waters for wells.

ARTESIAN AREAS.

In Boone County there are six separate areas in which flowing wells have been found. In Plate IV these areas have been outlined and numbered.

In the northwest corner of Boone County, between Thorntown and Colfax, there is a narrow area about 4 miles in length, east and west, in which flowing wells may be obtained in the lowlands. (Pl. IV, No. 2.) These wells yield moderately and obtain their water in gravel at a depth of about 80 feet.

In the east edge of Thorntown, on the flat of Prairie Creek, there is a flowing well on the property of Mr. Samuel Jett. (Pl. IV, No. 3.) This well, which is 900 feet deep, was drilled in 1887 for gas, but gas was not found in paying quantities. In drilling an abundant supply of water was encountered in a gravel bed at a depth of about 90 feet. The drive pipe was drawn back to this bed and the well was plugged at 95 feet. It is reported that the well when first drilled would spout an 8-inch jet of water 7 feet above the well mouth. This indicates a flow of over 3,000 gallons per minute. The top of the well has now been plugged, leaving a small opening that leads to a hydraulic ram, which pumps abundant water for the house and barn. For a record of this well see page 76, No. 9, and for analysis of the water see page 77, No. 4. A number of the deeper wells in Thorntown, 30 feet above the creek flat, get water under artesian pressure, but they do not flow. It seems almost certain that other flowing wells might be obtained in the creek bottom both above and below Mr. Jett's well.

Between Lebanon and Hazelrig, along a low morainic plain and in the valley of Prairie Creek, is an area in which a number of wells that flow have been sunk. (Pl. IV, No. 4.) The flows were obtained in beds of gravel or coarse sand at a depth of about 50 feet. The yield of the wells is small and is growing more feeble with the general lowering of the water table.

Mr. J. F. Kersey, a well driller of Lebanon, reports that a flowing well was obtained north of Whitelick, on the farm of Mr. W. Johnston. (Pl. IV, No. 5.) This well was reported to be 60 feet deep and to have flowed 30 gallons per minute when first drilled. No further information was obtainable.

A flowing well is reported in the valley of Eagle Creek, on the farm of Mr. Perry Moore, 2½ miles northwest of Zionsville. (Pl. IV, No. 6.) This well is 81 feet deep and its water comes from a bed of sand and gravel in the glacial till. The water rises in the pipe 6 feet above the surface, and the flow is about 1 gallon per minute. It is probable that the area in which flowing wells may be procured is small.

SUPPLY FOR THE CITY OF LEBANON.

Lebanon, the county seat of Boone County, had in 1900 a population of 4,465, and is the only city in this county which has a public water supply. The supply for the waterworks, which are owned by the city and were built in 1894, was originally from three wells. One of these is a dug well 20 feet in diameter and 43 feet deep. It has a cement wall and receives all its water from a gravel bed at the bottom. The other original wells were 97 and 230 feet deep, and both received their supply from gravel beds. Since the plant was built four more wells, 8 inches in diameter and 97 feet deep, have been drilled, and one well was sunk to a depth of 816 feet. The materials penetrated by this well were as follows:

Partial log of deep well at Lebanon waterworks.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil Clay	43	43
Gravel Stiff clay	54	97
Gravel Stiff clay Gravel	133	230
Shale	170	400
Limestone.		

This well found no satisfactory supply. The pipe was later blown in two at 230 feet for the purpose of obtaining water at that depth, but the well was never productive and is now abandoned. The water from all the wells comes from gravel below blue clay, and there seems to be little likelihood of pollution from the surface. Up to January, 1908, this water was distributed from a standpipe with a capacity of 189,000 gallons, giving a pressure throughout the town of 45 to 50 pounds. A new underground cement reservoir, with a capacity of 500,000 gallons, was completed during 1907, and direct pressure from the pumps can be furnished in emergencies. Analyses of the water from the city wells are given on page 77, Nos. 2 and 3.

In Lebanon many people still supply themselves with water from private wells, and although there are a few open wells in use the driven and drilled wells are in greater favor. In the west part of town water is obtained at depths of 40 to 60 feet; in the east part wells 100 to 300 feet deep are more common. Occasionally a drilling will fail to reach an open gravel bed in the till, and two or three have penetrated the underlying shale without obtaining satisfactory supplies of water. The records of a number of wells in and near Lebanon are given by Leverett.[a]

VILLAGE AND RURAL SUPPLIES.

Thorntown.—Thorntown, with a population of 1,511 in 1900, is situated on a till ridge which slopes downward to the valley of Prairie Creek on the east and to Sugar Creek on the north. The town has no public waterworks and all the supplies are obtained from wells, of which shallow, open wells 15 to 25 feet deep are most common. In a town of this size, as there is no sewer system, a large amount of objectionable matter from cesspools, barnyards, and other sources enters the ground to join the body of water from which the shallow wells are supplied, and such a supply is unsafe. On the other hand, there are a few drilled or driven wells which penetrate through a thick layer of till into a gravel bed, and the water there obtained is much safer than that from the shallow wells.

Thorntown should have a public water supply. The large flowing well in the creek bottom east of the town would easily furnish sufficient water for the entire village. The water is of good quality for domestic purposes, as shown by the chemical analysis on page 77, No. 4. Pneumatic pressure tanks or some other simple water system could be installed here at a relatively small cost, and would furnish fire protection, of which the town is greatly in need.

Section of deep boring at Thorntown.[b]

	Feet.
Drift	65
Subcarboniferous limestone and shale	238
Hamilton shale	87
Corniferous limestone	37
Niagara limestone	407
Hudson River and Utica	373
Trenton	80
	1,287

Whitestown.—Whitestown is situated on a till plain, and the wells, of various types, range in depth from 12 to 110 feet. The dug wells depend upon seepage water from the till, but the deeper driven and drilled wells enter lenses of gravel or sand and the supply from these

[a] Water-Supply Paper U. S. Geol. Survey No. 26, 1899, pp. 13-17.
[b] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 263.

is more abundant. In one well 105 feet in depth the water rises within 9 feet of the surface and shows no variation in head either with the seasons or with heavy use. For the record and analysis of this water see page 76 (No. 14) and page 77 (No. 5).

Zionsville.—Zionsville lies in the lowlands near Eagle Creek, and the water table is nowhere far below the surface. Its water supply is drawn for the most part from shallow dug and driven wells, although there are a few drilled wells from 50 to 110 feet in depth. All the wells obtain water from gravel beds and none penetrates to rock. The deeper wells encounter water under artesian pressure. A well in the cellar of J. W. Brendel flows with a small stream 3 feet below the surface. (See p. 76, No. 15, and p. 77, No. 6.)

Jamestown.—The wells in Jamestown are drilled and dug, the dug wells getting water in the glacial clays or gravels and the drilled wells entering limestone at about 40 feet. The dug wells receive water through their walls at all levels and are subject to pollution, but the deeper drilled wells case off the surface waters, and are supplied only by the limestone, in which cool, palatable, and abundant water is commonly found. The town well, opposite the hotel, is drilled into rock.

Rural districts.—On the farms of the county wells supply water for domestic purposes and for watering stock. Most of them obtain their waters from the surface deposits, though a few enter the rock. Until within the last few years the open well was the rule, but with improved methods drilled and driven wells have gradually superseded the less sanitary dug wells.

Other communities.—The table below gives a list of other communities, with information regarding their water supply:

Other village supplies in Boone County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Advance	310	Wells, drilled, driven, and dug.	40	110	65	65	8	Gravel and limestone.
Bigspring	97	Wells, driven and dug; springs.	20	100	25		10	Gravel.
Dover	46	Wells, dug and driven.	8	120	12	100	8	Sand, gravel, and limestone.
Gadsden	32	do	14	150	16		12	Gravel.
Hazelrigg	64	do	11	96	15		8	Do.
Max	134	Wells, driven, drilled, and dug.	10	125	20,75	70	4-15	Gravel and limestone.
New Brunswick	66	Wells, dug and driven.	20	150	25,60			Gravel.
Pike		do	18	150	25		16	Do.
Reese	127	do	40	150	45		40	Do.
Rosston	100	do	15	175	20		1-10	Do.
Royalton	149	do	10	116	25		7-15	Do.
Whitelick	178	do	10	150	25		13	Sand and gravel.

TYPICAL WELLS AND ANALYSES.

The two tables that follow give complete information regarding a number of typical wells in Boone County and their waters. The numbers in the last column in each table refer to identical wells in the other table.

Records of typical wells in Boone County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head, above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Temperature.	Analysis No.
			Ft.		*In.*	*Ft.*	*Feet.*		*Ft.*	*Galls.*	*°F.*	
1	Town well	½ square S. of Advance railroad station.	90	Drilled	2	90	− 8	Limestone	60	......	....	1
2	Otis Crane	2½ miles E. of Hazelrigg.	47	Driven	1½	47	+ 2	Gravel	....	......	....	...
3	Do	2 miles E. of Hazelrigg.	175	...do	3	175	− 6	......	....	......	....	...
4	J. W. Wills	Kirkland	51	...do	2	51	......	Gravel	....	......	....	...
5	City of Lebanon.	At waterworks	230	Drilled	8	230	−20	.....do	230	......	....	2
6	Do	.....do	816	...do	8	....	......	......	230	......	....	...
7	Do	.....do	97	...do	8	97	−20	Gravel	230	......	....	3
8	George W. La Follette.	1 mile SE. of Shannondale.	60	...do	4	60	+ 7	Blue limestone.	30	......	51	...
9	Samuel Jett	E. edge of Thorntown.	1,700	...do	8	90	+12	Gravel	....	......	....	4
10	Albert Wetherald.	3½ miles NW. of Thorntown.	187	Driven	2	120	−10	Clay	....	......	....	...
11	John Leatherman.	3 miles NE. of Thorntown.	140	Drilled	4	....	+ 4	Sand	....	......	50	...
12	J. E. Leatherman.	3½ miles NE. of Thorntown.	140	...do	4	140	+ 7	Gravel	....	......	....	...
13	Willis Johnston.	1 mile N. of Whitelick.	60	...do	2	60	+ 5	......	....	30	....	...
14	Isaac Isenhour	Whitestown	105	...do	4	105	− 9	Gravel	....	......	....	5
15	Jas. W. Brendel.	Zionsville	108	...do	3	108	− 3	.....do	....	......	....	6
16	Town well	At Farmers' Bank, Zionsville.	.....	Open	....	....	......	Till	....	......	....	8
17	A. Perry Moore.	2½ miles NW. of Zionsville.	81	Drilled	2½	78	+ 6	Gravel and sand.	....	1	54	...

Mineral analyses of waters in Boone County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of well.
1	Public well	Advance	Drilled well, 90 ft. by 2 in.	H. E. Barnard	1907	Limestone	...	0.01	...	61	25	...	...	0.0	366	0.0	16	0.20	0.001	2	412	1
2	City supply	Lebanon	Drilled well, 230 ft.	Chase Palmer	1907	Gravel	24	2.3	...	78	37	99		24	564	1.6	4.2	.05	......	...	622	5
3	do	do	Drilled well, 97 ft.	do	1907	do	24	.4	...	53	30	31		14	301	3.6	2.5	4.0	......	...	352	7
4	Samuel Jett	Thorntown	Drilled well, 1,700 ft.[a]	do	1907	do	22	1.0	...	67	28	50		7.2	378	9.5	12	.0	......	...	390	9
5	Isaac Isenhour	Whitestown	Drilled well, 105 ft. by 4 in.	H. E. Barnard	1907	do	...	1.2	...	64	27	...	...	.0	451	.0	12	.05	.001	4	512	14
6	J. W. Brendel	Zionsville	Drilled well, 108 ft. by 3 in.	do	1907	do	...	.01	...	114	35	...	...	.0	345	120	112	4.0	.001	4	754	15
7	Zionsville Water and Electric Co.	do	Wells				10	4.4		96	22	14		163	....	57	22	......	......	...	432	...
8	Public well	do	Open well	H. E. Barnard	1907	Till	...	.4	...	49	28	...	...	.0	388	.0	32	.05	2.0	9	454	16

[a] Water from only 90 feet below the surface.

CARROLL COUNTY.

SURFACE FEATURES AND DRAINAGE.

Carroll County, which lies on the western edge of the area treated in this report and halfway between its northern and southern borders, has an area of 370 square miles and in 1900 had a population of 19,953. That part which lies east and southeast of Wabash River is a dissected till plain with level upland areas between the valleys of the larger streams. A few small areas of terminal moraine give locally a somewhat more rolling topography (Pl. I), and an area of irregular moraine lies between Wabash and Tippecanoe rivers.

Carroll County is exceptionally well provided with surface streams, the most important being Wabash River, which crosses the northwest corner of the county. The valley of this river is broad and well developed, and varies in width from one-half mile to 2 miles. The river lies 100 to 130 feet below the surrounding plain, and its valley bottom is occupied by alluvial deposits of low slopes. Above the bottom lands the bluffs rise sharply for about 100 feet and then merge with the till plains of the upland. The lowest point in the county is where Wabash River crosses the county line below Delphi, about 575 feet above sea level; the highest point in the county is about 800 feet above sea level, giving a range of elevation of approximately 225 feet.

Next in importance to the Wabash is Tippecanoe River, which flows along the west edge of the county. Its valley is neither so broad nor so deep as that of the Wabash and is less than 100 feet below the uplands. It varies from one-fourth to 1 mile in width, and the bluffs at the valley sides are steep. The Tippecanoe joins the Wabash 3 miles south of the county line.

Wild Cat and Deer creeks are both important streams, and flow from east to west across the county to join the Wabash. Both these creeks have developed flood plains in proportion to their size, and they, with numerous smaller streams, have aided in dissecting the till plateau.

As a result of the complete drainage of this county, there are no large natural lakes or ponds. A few artificial ponds have been formed by damming a stream valley or a gully, but all are small.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

In the valleys of Wabash and Tippecanoe rivers and of Wild Cat and Deer creeks, as well as in the valleys of many smaller streams, there are alluvial plains of varying width. The alluvium occurs either as flood-plain flats, usually known as the "first bottom," or as terraces above the flood plain. The terraces that lie at different heights up to 75 feet above the stream are remnants of older flood plains, which have been partly removed since their formation. In the Wabash Valley the stream deposits vary in thickness up to 30 feet, or may be missing, for in flood time the river scours its channel down to bed rock.

The alluvial beds have a large pore space, and a capacity for holding a great deal of water, almost all of which is readily available if reached by wells. In the valley bottoms sufficient water is usually present to saturate the alluvium well up toward the surface, so that conditions are ideal for obtaining plentiful water at shallow depths. For farm use driven wells have been found to be cheapest and most satisfactory for procuring waters from alluvium, and they are in general use wherever these deposits occur.

The moraines of Carroll County are nowhere prominent topographic features. They occur as disconnected patches (see Pl. I), with bowlder-covered surfaces of slight relief, and the low hills nowhere stand more than a few feet above the surrounding plains. Those patches which occur near Wabash River are outlying remnants of the great interlobate moraine which extends from Carroll County northeast into Michigan. There is generally enough gravel or sand in the moraines to afford domestic wells a fair yield of water from drilled or driven wells. In the absence of coarse beds open wells in the bowlder clay will obtain moderate amounts of seep water.

The till, which covers most of the surface of the county, is generally thickest on the stream divides and thinnest along the valleys. In a number of valleys the streams have cut entirely through the till, exposing the bed rock below; in other places, as at Cutler, wells 150 feet deep have failed to reach the bottom of the till. At Delphi Wabash River has removed the glacial deposits and exposed the rocks. In those areas where porous gravel or sand beds occur in the till water can be best obtained by drilled or driven wells, although such beds are in many places too deep to be easily reached by open wells. The only recourse in those areas where gravels and sands are absent is to sink open dug wells, into which the water seeps gradually from the till.

CONSOLIDATED MATERIALS.

The New Albany shale, which underlies the surface deposits in the southwest half of the county (see Pl. III), outcrops near Delphi and in the valley of Rock Creek, but is covered, except in the deep valleys, by surface deposits up to 150 feet thick. These black shales seldom serve as the source of well supplies, for although the pore space is large and the proportion of water contained is considerable, this water is not yielded to wells unless well-defined open passages are encountered. In Rockfield one or two wells have obtained good supplies from this shale.

The Devonian limestones are the uppermost beds of rocks in much of eastern and northern Carroll County (Pl. III). Most of this area is covered by the till plateau, and the only reported outcrops of these limestones are along Wabash River above Delphi and in Rock Creek east of Tilman. Only a few wells have penetrated the limestones, though such wells have always been successful. A well north of the village of Darwin obtained a fine supply when the drill in limestone dropped 8 inches into an opening of some sort. As the overlying drift nearly everywhere furnishes enough water it is unnecessary to sink to the rock.

A limestone which is usually classed with the Niagara but which has also been referred to as Devonian, outcrops at the surface in the neighborhood of Delphi, and forms the rock surface below the drift in a portion of the east and north parts of the county (Pl. III). The fracture joints, solution passages, and bedding planes of the limestone are filled with water to a level within 12 or 15 feet of the surface. Below this level drilled wells commonly find good supplies of water in the openings of the rock. Wells drilled into the rock should be put down to a considerable depth and cased for some distance below the ground-water level, as the deeper waters are less likely to be contaminated than those nearer the surface. The broad outcrops of limestones are so broken that any liquid matter is readily absorbed at the surface and shallow rock wells might easily be polluted in this way.

ARTESIAN AREAS.

At Delphi waters under artesian pressure have been found in all borings that have gone deeply into the "Niagara" limestone. (Pl. IV, No. 7.) Two such wells are now flowing, the best known of which is the "Delphi artesian well,"[a] drilled originally for gas or oil to a depth of 912 feet.

Section of deep well at Delphi.[b]

	Feet.
Niagara limestone	587
Hudson River limestone and shale	220
Utica shale	93
Trenton limestone	12
	912

The principal flow of water is said to come from a depth of 165 feet, but the temperature of the water (57° F.) would indicate that at least part of it comes from greater depths. The water is much

[a] Described by J. N. Hurty, Twenty-sixth Ann. Rept. Indiana Dept. Geology and Nat. Res., pp. 29-30.
[b] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 241.

used for drinking. A second well, producing a similar water but yielding a smaller flow, is situated at the Monon Railroad bridge across Deer Creek.

Two flowing wells are reported from the Wabash Valley northwest of the village of Burrows. (Pl. IV, No. 8.) As limestone outcrops along the river in this neighborhood, it is presumed that these wells enter rock.

Along the valley of Sugar Creek, near Radnor, there is an area in which good flowing wells have been obtained. (Pl. IV, No. 9.) There are five flowing wells in this valley, which range in depth from 29 to 39 feet. All but one of these were put in during 1907. The artesian waters occur in a gravel bed in the till and are obtained by driven wells, which can be sunk here for 75 cents per foot. A complete flowing well may thus be obtained at a cost of less than $30.

At Burlington, near Wild Cat Creek, there are several flowing wells. (Pl. IV, No. 10.) The only one of these about which information could be obtained was drilled to a depth of 97 feet, the lower 7 feet being in limestone, from which the flow was obtained. The well is on the slope of the river bluff, about 35 feet above the creek, and the water is used at a creamery. There is good reason to believe that other flowing wells may be obtained in this neighborhood if situated upon ground as low as or lower than the creamery and drilled into the limestone.

CITY AND VILLAGE SUPPLIES.

Delphi.—Delphi, the county seat of Carroll County, is situated in the broad valley of Wabash River and about 30 feet above that stream. It has one of the best city water supplies in Indiana, obtained from springs about 3 miles northeast of the city. The springs are three in number, and issue from the base of a gravel terrace which rises about 40 feet above them. In the present waterworks, which were built in 1891, the water is collected from the springs, which are covered by spring houses, and carried by gravity through wooden pipes to a buried reservoir of 387,000 gallons capacity. From the reservoir it is pumped by steam to a 37,000 gallon standpipe, 116 feet high, from which the water is distributed by direct pressure to about 5½ miles of city mains, ranging from 8 to 4 inches in diameter. There are 459 service taps, which supply more than 90 per cent of the people of Delphi. Practically everybody in the city proper depends upon the city supply, but in North Delphi and the later additions the city water is not so generally used.

The healthfulness of the water supply is attested by the general health of the city. There is no record of a single case of typhoid fever among the people who use only the city water. Up to the present time the supply has been adequate, but additional water will be needed if the growth of the city continues.

A large additional supply could be obtained from springs known as "Falling Springs," 2 miles southwest of the court-house, between the Wabash Railroad and the river, near the county line. These springs apparently emerge from above the rock and below the till and are cold and clear. The land above is under cultivation, and there are no houses near by, so there is little danger of pollution of this water. The flow of the largest spring is estimated at 100 gallons a minute, enough to supply at least 50 per cent of the present population of the city. There are many other large springs which issue from the bluffs of the Wabash above and below Delphi.

In the outskirts of the city a good many families rely on cisterns and shallow wells for their water. Such wells are either in the surface alluvial gravels or in the upper part of the limestone, and waters from either source are likely to become contaminated, especially near settlements.

It is reported that some wells in the limestone have been spoiled by the artesian sulphur waters from unplugged gas wells. The state law which requires that all abandoned wells must be plugged at the base of the limestone should be more strictly enforced, as the leakage from such wells is continuous when the waters are under artesian pressure and may affect the upper waters for considerable distances from the wells.

Flora.—Flora, with a population, in 1900, of 1,209, is a thriving town situated on the till plateau, 8 miles southeast of Delphi. A public supply was installed in the summer of 1907 by the Flora Water Company, a part of the stock in this company being owned by the city. An 8-inch well has been drilled to a depth of 195 feet, of which the last 60 feet are in limestone. The principal water supply was obtained at 185 feet, and none was found below this. The well was tested and was found to yield 100 gallons per minute during a half day's continuous pumping.

A pneumatic pressure system with two 60,000-gallon tanks is used. The water is pumped into the tanks, which are partly filled with air, and the air pressure forces the water through the mains, of which there are about 3 miles, 8, 6, and 4 inches in diameter.

Before the installation of the public system the town was supplied by private wells, most of which were shallow driven wells, obtaining water in the sand and gravel in the till at depths of 16 to 40 feet, though a few drilled wells which enter rock at about 140 feet were used. The shallow wells are dangerous and to their use may perhaps be ascribed the prevalence of typhoid fever in the town at certain times.

Camden.—Camden is situated on a gently undulating till plain near Deer Creek and about 5 miles east of Delphi. It has no public supply in general use, although there is a small private system, the water from which is used for sprinkling. The water for this system is obtained from a 185-foot drilled well, sunk 65 feet into limestone, and the water obtained from this limestone is pumped by a gasoline engine to a tank 40 feet high, from which it is distributed by gravity. The system has 1,500 feet of 2-inch mains and supplies 14 taps. Only 20 barrels of water per day are consumed. An analysis of this water is given on page 86 (No. 2).

In Camden most of the water for domestic use is obtained from open wells 15 to 30 feet deep, which secure water from gravelly beds or from seepage from the clay. The open wells are always a source of danger, as they readily receive any drainage from kitchen slops, outhouses, or any other liquids which may be absorbed at the surface. Wherever it is possible, water from the deep wells should be used and the open wells abandoned and filled up.

Burlington.—The village of Burlington is situated on the edge of a rolling till plain near the valley of Wild Cat Creek, and about 60 feet above it. Beneath the town the till is 130 to 140 feet in thickness, so that most of the wells are driven into gravel in the till, although a few deep drilled wells go into the limestone at the base of the till and get water under artesian pressure. On the slope of the bluff and below the plain some wells in limestone will flow at the surface.

A number of large springs issue from a gravel bed near the base of the creek bluffs, the largest of which, on property belonging to the heirs of Amos Miller, flows about 15 gallons per minute. The spring emerges from just below the cemetery, and there is a possibility of pollution from this source.

Pittsburg.—Pittsburg lies on a narrow strip of terrace and on the side of the bluff of Wabash River, opposite Delphi, and its water supply is obtained from springs and dug wells. The springs flow out from the base of the bluff, apparently from gravel beds. One of the best of the springs is owned by the county, and its water, which has been piped to a watering trough at the principal crossroads, is used by many families for drinking purposes. The wells in the town are almost all of the open type. Near the river they reach to limestone at depths of 12 to 15 feet, but on the higher ground the limestone is deeper, and the water is found in gravel beds in the till. In a 60-foot section of the till, offered by a cut along the Monon Railroad, at the edge of the town, the upper 30 feet consist of beds of oxidized gravel which have been cemented into a conglomerate. Below these the section consists of blue, unoxidized till.

Other communities.—A tabulated list of other communities in the county, with the conditions of water supply in each, is given below:

Other village supplies in Carroll County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Bringhurst...	448	Wells, drilled and dug...	14	120	65	125	12	Gravel and limestone.
Burrows.....	187	Wells, driven and drilled.	35	90	35	....	20	Gravel and sand.
Cutler........	150	Wells, dug and drilled...	12	150	80	....	6-12	Gravel.
Darwin......	....	Wells, dug and driven ..	10	96	15	....	10	Do.
Deer Creek...	120	Wells, dug and drilled...	10	175	12	50-60	....	Gravel and limestone.
Hopedale....	25	Dug wells and springs...	13	150	40	....	3-20	Gravel.
Lockport.....	117	Wells, driven and dug...	20	115	30	22	....	Gravel and limestone.
Ockley.......	102	.....do.................	18	106	70	....	16	Gravel.
Owasco......	30	Wells, dug..............	19	40	30	....	4-35	Do.
Patton.......	75	Wells, dug and driven...	12	115	20	....	8	Do.
Pyrmont.....	100	Wells, dug..............	18	30	20	....	15	Do.
Radnor......	150	Wells, dug and drilled...	15	55	15	....	5	Do.
Sleeth........	46	Wells, dug and driven...	11	14	12	....	10	Do.
Walker.......	25	Wells, driven...........	30	130	45	135	10	Gravel and limestone.
Wheeling....	177	Wells, dug and drilled...	20	118	30	....	....	Do.
Yoeman.....	50	Wells, driven and dug...	16	60	20	....	....	Gravel.

Rural districts.—In the county there are great numbers of wells for household use and for watering stock. Some of these are in the surface deposits, and some go into the underlying rock. In the matter of deep driven and drilled wells, the inhabitants of Carroll County have been rather backward, and there are still an unusually large number of open wells in use. The popularity of the driven and drilled wells is increasing, however, and almost all new wells are of one of these two types.

Carroll County is especially fortunate in the possession of a large number of springs. Most of these rise from the base of the bluffs along stream valleys, and the waters, always cold and clear, are commonly free from contamination and where available afford an unexcelled supply.

TYPICAL WELLS AND ANALYSES.

The two following tables give detailed information regarding typical wells in Carroll County and analyses of their waters. The numbers in the last column of each table refer to identical wells in the other table.

Records of typical wells in Carroll County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Temperature.	Analysis No.
			Feet.		*Inches.*	*Feet.*	*Feet.*		*Feet.*	*Gallons.*	*° F.*	
1	Henry Carter	Bringhurst	103	Drilled	2	100	−16	Gravel				
2	D. F. Beck	Burlington	97	do	2	90	+	Limestone	90			
3	Fort Wayne and Wabash Valley Traction Co.	Burrows	37	Driven	2	37	−20	Gravel				1
4	E. C. Rice	Camden	185	Drilled		150	−40	Limestone	120			2
5	Daniel A. Eller	do	125	do	4	125		do	113			
6	Philip Ray	do	25	Dug				Drift				3
7	J. E. Snell	Carroll	20	do			−10	Gravel				
8	Dr. G. L. McNeal	Deer Creek	176	Drilled		176	−12	Limestone	60			5
9	Odd Fellows	do	13	Dug				Drift				4
10	John Crecraft	Flora	200	Drilled	4	200	−32	Limestone	149			11
11	Public well	Center and Columbia sts., Flora	28	Driven	2	28	− 6	Gravel				12
12	Jerome Etter	North Delphi	35	Drilled	4		−10	Limestone	2			9
13	Price Shortridge	Patton	103	do	2	100		Gravel				
14	R. A. Newell	¼ mile W. of Pyrmont	100	do	4	100		do				
15	John Closson	Radnor	29	Driven	1¼	29	+ 8	do		8	52	14
16	Charles Raber	Rockfield	92	Drilled	2½	40	− 7	Shale	40		51	
17	W. A Trobaugh	South Delphi	14	Driven				Gravel				10
18	Harvey Ross	SW. ¼, sec. 24, T. 25, R. 2	145	Drilled	3	140	−50	Limestone and shale	52		52	
19	John Brookie	Walker	98	do	4	98	−25	Gravel				

Mineral analyses of waters in Carroll County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	Fort Wayne and Wabash Valley Traction Co.	Burrows	Well, 37 ft.	H. E. Barnard	Nov., 1907	Gravel	....	0.8	....	117	44	....	....	0.0	295	130	14	0.10	.000	4	562	3
2	E. C. Rice	Camden	Well, 185 ft.[a]	do	do	Limestone	....	1.0	....	84	30	....	....	.0	306	25	2.0	.70	.000	13	374	4
3	Philip Roy	do	Open well, 25 ft.	do	do	Drift	....	.40	....	127	37	....	....	.0	300	64	36	7.00	.000	9	632	6
4	Odd Fellows	Deer Creek	Open well, 13 ft.	do	do	do	....	.00	....	136	44	....	....	.0	347	60	71	2.00	.000	23	706	9
5	Dr. G. L. McNeal	do	Well, 176 ft.	do	do	Limestone	....	1.00	....	84	34	....	....	.0	303	1.2	22	.40	.001	19	414	8
6	City supply	Delphi	Springs	R. B. Dole	Sept., 1907	Gravel	21	.07	....	81	24	4.4		.0	350	32	1.4	16	....	....	332	....
7	C. B. Landis	do	Spring	do	do	do	25	.06	....	46	22	2.5		8.4	189	11	1.0	30	....	....	243	....
8	....	1½ miles SW. of Delphi.	"Falling springs."	H. E. Barnard	Nov., 1907	do	....	.1	....	101	31	....	....	.0	299	26	3	2.00	.001	9	420	....
9	Jerome Etter	North Delphi.	Well, 35 ft. by 4 in.	do	do	Limestone	....	1.60	....	72	37	....	....	.0	224	34	8.0	3.00	.02	4	266	12
10	W. A. Trobaugh	South Delphi.	Well, 14 ft.	do	do	Gravel	....	.05	....	106	33	....	....	.0	282	58	32	4.00	.002	9	534	17
11	John A. Crecraft	Flora	Well, 200 ft. by 4 in.	do	do	Limestone	....	.30	....	66	33	....	....	14.0	232	29	82	.10	.001	23	646	10
12	Public well	do	Well, 28 ft. by 2 in.	do	do	Gravel	....	.20	....	111	30	....	....	.0	316	35	8.0	.05	.000	13	546	11
13	County	Pittsburg	Spring	do	do		....	.80	....	122	36	....	....	31.0	207	65	18	12	.001	9	496	....
14	John Closson	Radnor	Well 29 ft. by 1½ in.	do	do	Gravel	....	.6	....	116	33	....	....	.0	302	18	2.0	.10	.001	4	384	15
15	T. G. Timmons	Rockfield	Open well, 10 ft.	do	do	do	....	.01	....	194	71	....	....	.0	274	396	41	.70	.001	4	1,048	....
16	J. E. Snell	Carroll	Open well, 20 ft.	do	do	do	....	.00	....	89	38	....	....	.0	252	80	74	3.00	.000	23	770	7
17	I. N. Wagner	do	Drilled well, 118 ft.	do	do	Limestone	....	.20	....	36	33	....	....	.0	199	9.5	2	.10	.00	9	348	20

[a] Water from 150 feet.

CASS COUNTY.

SURFACE FEATURES AND DRAINAGE.

Cass County, in the west-central part of the region under consideration, has an area of 420 square miles. Its population in 1900 was 34,545, an average of 82 inhabitants to the square mile. The county seat, Logansport, 68 miles from Indianapolis and 100 miles from Chicago, lies a little northeast of a line connecting these two greater cities.

The county exhibits more diversity of surface than many equal areas within the State, chiefly because it contains parts of two important stream valleys. The most striking topographic feature is the valley of the Wabash, which crosses the county from east to west as a very definite trough that ranges in width from a few hundred feet to a mile and is incised from 100 to 150 feet below the level of the uplands north and south of it. The valley of Eel River, roughly parallel to that of the Wabash, joins the latter at Logansport, and is a similar but slightly less prominent topographic feature.

The uplands north of the Wabash Valley are diversified by low morainal hills, and another belt of similar irregular topography occupies the strip between Deer Creek and the south line of the county. Except where streams are cut below them or moraines rise above them the uplands are flat, featureless plains.

The Wabash and the Eel are the chief streams of the county, as their valleys are the principal depressions. Where either river has cut below the glacial mantle into the underlying rock its valley is narrow, its banks are cliff-like, and its channel is impeded by rapids, but in the drift areas the valleys broaden, and the water courses are bordered by narrow belts of alluvial bottoms. The other streams of the county are small and their valleys are cut but a few feet below the level of the uplands across which they flow.

A few small lakes in the northern part of the county, like other lakes in northern Indiana, occupy depressions in the morainal drift. Lake Cicott, the largest, 9 miles west of Logansport, is 1 mile long and one-fourth mile wide. The county as a whole is well drained and contains no large marshes.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

The alluvial sands and gravels, since they are stream-laid deposits, are confined practically to the strips of bottom and bench land that border the rivers. Not every terrace, however, overlies deposits of this character, for in a few localities, where the streams flow over rock, the benches also are cut in rock which may be veneered by a film of alluvial gravels a few feet or a few inches thick. Deposits of the strictly alluvial type in this county are confined almost entirely to the valleys of Wabash and Eel rivers, but in the western part, north, west, and south of Lake Cicott, there are similar surface deposits of sand.

Water is generally abundant, of good quality, and easily obtained in the bottom lands. The alluvium remains saturated at least up to the level of the streams, so that wells sunk in it are less affected by drought than those in the glacial deposits of the uplands, and the thorough washing and sorting that the material has undergone during the process of deposition has removed from it much of the mineral matter that it originally contained, so that the water obtained from it is softer than that from the till, and, where protected from contamination, is pure.

Driven wells are easily and cheaply installed in the bottom lands, and few fail to yield a supply that is excellent and ample for all purposes.

Morainal drift occupies the greater part of the upland surface of Cass County, the underlying till, at places scarcely distinguishable from it by the drillers, appearing at the surface only in two areas, one south of the Wabash, between it and Deer Creek, the other in the north half of the county (Pl. I).

The thickness of both the moraine and the till varies in different parts of the uplands. Southwest of Adamsboro, between Wabash and Eel rivers, wells 100 feet deep do not reach rock, and the topography of this divide indicates that the greater part of this thickness is morainal material. North of Eel River the moraine may be even thicker, while along the south edge of the county it is so thin that all except the shallowest wells pass through it into the till below.

In the areas of rougher topography the drift is almost everywhere of open texture, permitting free circulation of water. Wells sunk in these areas yield abundantly, but the water table is at many places 50 to 70 feet below the ground surface. Because of the free circulation and the abundance of the supply, however, continued pumping fails to lower the water level. In those morainal areas where the relief is less marked the water table is nearer the surface.

The till, wherever it may be found either beneath the moraines or at the surface, where it forms a level or slightly undulating plain, is of the usual type—that is, it is a compact clayey mass which yields water but sparingly except from interbedded sand or gravel layers. These layers, however, are in most localities sufficiently abundant to make it highly probable that any deep drilled well will pass through one or more such beds, from which abundant water may as a rule be procured.

Generally speaking, the waters derived from the till are the hardest that are obtained from the unconsolidated materials in this county, those derived from the moraines being next in hardness.

CONSOLIDATED MATERIALS.

The Devonian limestones, the youngest of the hard rock deposits of Cass County, immediately underlie the glacial material in the south-central part of the county and appear at the surface in the valleys of Wabash and Eel rivers. Beneath the Devonian in this part of the county and just below the drift throughout the remainder of the county lie the Silurian ("Niagara") limestones. These limestones also outcrop in the valleys of Wabash and Eel rivers east of the zone along which the Devonian beds appear. Deep borings at Logansport indicate a thickness of 540 feet for the Silurian there and prove that several so-called "breaks" or beds of shale are interstratified with the more massive limestone. These shale layers serve as confining beds and, where other conditions are favorable, make possible the accumulation of sufficient head in the water beneath them to cause it to flow at the surface.

The depth to rock varies widely within the county. The fact that it appears at the surface in the valleys of the Wabash and the Eel has already been mentioned. In the southern half of the county scattered wells reach the Devonian rocks, but in the area north of the Wabash the Silurian is so deeply buried that few wells extend to it.

Some wells obtain good supplies of water from the unconsolidated beds just above the limestones, but better yields are almost everywhere to be had from the rock itself a few feet below its upper surface. Both of the limestones are intersected by open joint and bedding planes that form crevices which afford free passage for water. These crevices are especially numerous near the surface of the rock, and few wells that penetrate it for a short distance fail to obtain an abundant supply. Plate V, *B*, shows solution passages in the limestone. Such openings, if encountered by wells, commonly supply large quantities of water.

ARTESIAN AREAS.

At the Northern Indiana Insane Asylum at Longcliff, 2 miles southwest of Logansport, there are two deep wells in the limestone, one of which flows 2 and the other 3 gallons a minute. (Pl. IV, No. 11.) One of these wells is 230, the other 618 feet deep, but as neither of them is cased below the rock surface the depth from which the water rises is not known.

Near the southern edge of the county, along the lowlands of Deer Creek and its tributaries, is another area of flowing wells. (Pl. IV, No. 12.) The surface deposits here are 50 or 60 feet thick, and the wells passing through this mantle strike the artesian water in the upper part of the underlying limestone. The conditions that cause this flow, shown diagrammatically in figure 12, seem simple and clear. In the vicinity of Kokomo the limestones are near the surface, and so are favorably situated for the absorption of rainfall. Between Kokomo and the Deer Creek lowlands the limestones are covered by a sheet of impervious till, which confines the water sufficiently to give it the necessary head.

At Galveston, in the southeast corner of the county (Pl. IV, No. 13), there is an old well, drilled originally for gas, that yields about 20 gallons of water a minute. This water is under sufficient pressure to rise over 5 feet above the surface. No record of the well could be obtained, but there can be little doubt that the water comes from the "Niagara" limestone, which is here 40 to 60 feet below the surface. The fact that the water is sulphurous (analysis No. 4, p. 94) adds to this probability. It is likely that the head which causes this water to flow originates farther east and south.

In the Wabash Valley in the vicinity of Logansport all of the deep wells in the limestone encounter water under artesian pressure. In a number of these the pressure is sufficient to produce a flow. (Pl. IV, No. 14.) The strongest yield is reported from a boring for gas, said to be the deepest in Cass County. This well, the property of John W. Kennedy, is in the west end of the city. When it was first drilled the water is said to have spouted 2 feet above the top of the 6-inch casing, indicating a yield of nearly 1,000 gallons a minute at that time. Since then the well has been plugged to stop the waste.

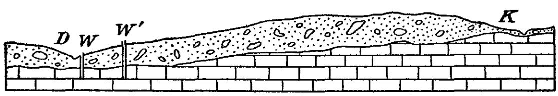


FIGURE 12.—Diagram showing source of artesian head in the valley of Deer Creek. At Kokomo (*K*) the limestone is near the surface and can absorb the rainfall. Between Kokomo and Deer Creek (*D*) the rock is covered by a sheet of impervious till. In the valley of Deer Creek the water, which is under artesian pressure, will flow at the surface at *W*. At *W′* the water from the same depth will rise toward the surface but will not flow.

In addition to the flowing wells there are in Logansport many rock wells in which the water rises to or nearly to the surface. They probably derive their supply from open connected channels in the limestone, for some wells that are near together are apparently interdependent. For example, it has been proved by the Logansport Ice and Cold Storage Company that when either of its four wells is pumped the water in the others is lowered. Strong drafts on the ice company's wells also lower the head in other neighboring wells.

CITY AND VILLAGE SUPPLIES.

Logansport.—Logansport, the county seat of Cass County, with a population in 1900 of 16,204, is situated in the valley bottom at the junction of Wabash and Eel rivers, at an altitude of about 600 feet above sea level. The waterworks, which are owned by the city, were built in 1875. Eel River is the source both of the water supply and of the power by which it is distributed, the power being developed by a dam built across the stream.

About half the population uses the city water, which is distributed by direct pressure through 33 miles of mains from 2 to 20 inches in diameter. These mains supply 202 fire hydrants and 3,220 taps, the total consumption being from 3,000,000 to 4,000,000 gallons a day.

Since the city water is derived from a surface source, it is very soft, contains little scale-forming material, and has the reputation among the railroads of being an ideal boiler water. For manufacturing and steaming it is superior to the limestone water obtained from the wells, but for drinking, used as it is in Logansport without filtration, it is less desirable. Eel River, like other surface streams in closely settled regions, is in constant danger of pollution. In periods of flood the unsatisfactory condition of the water is obvious, but there may be greater danger in the clearer water that is pumped into the mains during periods of low water in the streams. The installation of a filtration plant would greatly improve conditions here.

The 50 per cent of Logansport's inhabitants who do not use the city water depend on cisterns and private wells for their supply. The wells are 15 to 90 feet deep, dug or drilled, and obtain water either from gravels or from the underlying limestone, which is at most places found at less than 40 feet below the surface. In the past, shallow, open dug wells have been much used, but it is now recognized that they are very unsafe in an area that is so closely settled, hence most of them have been wisely abandoned for drilled wells, 40 to 60 feet deep, that penetrate the underlying rock and obtain from it safe, though hard, waters.

Royal Center.—Royal Center is a thriving town in the northwest corner of Cass County, with a population of about 1,000. A municipal waterworks system owned by the city has been installed and a well 6 inches in diameter and 280 feet deep has been drilled as a source of supply. This well, which derives its water from the "Niagara" limestone, has been tested and found to have a capacity of 15,000 gallons an hour. The water is pumped from the well to a 68,000-gallon wooden tank at an elevation of 90 feet. This elevation gives a domestic pressure of 40 pounds, but for protection from fire the water is pumped directly into the mains and a much higher pressure is thereby obtained. The system, with its 2 miles of 4 to 6 inch mains and its 72 services, supplies about one-third of the inhabitants of the city, the average daily consumption being about 25,000 gallons.

The remaining two-thirds of the people still use private wells, the greater number of which are 40 to 60 feet deep. The water supply for these wells comes from gravel beds in the till, and since these gravels are protected from pollution by the compact clay above them, they form safe reservoirs. Typhoid fever is therefore almost unknown in Royal Center.

Galveston.—Galveston, in the southeast corner of Cass County, stands about 20 feet above Deer Creek on a gently undulating till plain. The town supply is drawn from an 8-inch drilled well, 180 feet deep, owned by W. H. Sprinkle. At 63 feet below the surface this well enters the "Niagara" limestone, whence it procures its supply.

A pump with a capacity of 110 gallons a minute is operated by a gasoline engine which forces water into a 500-barrel tank that stands 50 feet above the ground. From this tank it is distributed to the users through 5 miles of 2 and 4 inch mains. Twenty-five hydrants are provided for fire protection, and direct pressure is used when needed. Nearly all the people in Galveston use the public supply, but there are a few private drilled wells, from 80 to 180 feet deep, one of which flows.

Walton.—Walton, 9 miles southeast of Logansport, with a population in 1900 of 498, has no waterworks system. All the local water supplies are drawn from wells, of which many types are represented, open dug wells predominating. The wells range in depth from 15 to 25 feet and they rarely fail, but those that stand near outhouses or other buildings are unsafe. In this village there are a few deeper drilled wells that enter rock at 60 to 100 feet below the surface and procure plentiful supplies of perfectly safe potable waters. (Analyses 18 and 19, p. 94.) Wells of this deeper type are strongly recommended.

Young America.—Young America is a flourishing and progressive village in the southwest corner of the county, 9 miles from the nearest railroad station. Until within a few years all water has been obtained from dug wells, but the tendency of late has been to sink deep-drilled wells. The village is very favorably situated to procure the deeper supplies, for excellent potable waters (analysis No. 20, p. 94) are found here in limestone at depths of 60 to 80 feet, and when tapped the waters rise to within 20 feet of the surface. Under these conditions all of the shallower wells should be abandoned, and when this step is taken typhoid fever should be much less prevalent than it is now.

Other communities.—A tabulated list follows of other communities in Cass County, with the conditions of water supply in each.

Other village supplies in Cass County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Adamsboro	143	Wells, dug and drilled.	16	30	25	4	....	Limestone.
Anoka	86	....do	16	120	20	90	16	Gravel and limestone.
Clymers	138	....do	20	80	30	....	10	Gravel.
Deacon	40	....do	18	100	23	70	....	Gravel and limestone.
Georgetown	100	Wells, drilled	10	47	40	4	....	Limestone.
Hoover	105	Wells, driven and dug.	20	45	45	....	....	Gravel.
Lake Cicott	40	Wells, driven and drilled.	27	87	30	....	....	Sand.
Lincoln	170	Wells, dug and drilled.	15	115	20	56	8	Clay and limestone.
Lucerne	30	Wells, drilled and driven.	20	110	60	....	20	Gravel.
Metea	35	....do	60	90	70	....	15-30	Do.
New Waverley	280	Wells, driven, drilled, and dug.	10	60	15	8	12	Gravel and limestone.
Onward	175	Wells, dug and drilled.	9	112	16	80	9	Do.
Twelve Mile	100	Wells, driven, drilled, and dug.	12	120	80	280	....	Gravel.

TYPICAL WELLS AND ANALYSES.

In the two following tables are given detailed information regarding typical wells in Cass County and analyses of their waters. The numbers in the last column of each table refer to identical wells in the other table.

Records of typical wells in Cass County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Temperature.	Analysis No.
			Feet.		*In.*	*Ft.*	*Ft.*		*Ft.*	*Galls.*	*°F.*	
1	G. P. Dykeman	Anoka	120	Drilled	4	115	−15	Limestone	90	......	....	1
2	B. Castaldi	Dunkirk	80	...do	....	80	....	....do	...		....	21
3	W. H. Sprinkle	Galveston	190	...do	8	....	−20	....do	63	......	....	3
4	Pliny Morgan	....do	....	...do	....	....	+ 5	....do	...	20	52	4
5	J. W. Griffin	5 miles W. of Galveston.	100(?)	...do	2	....	+ 3	....do	...	10	52	2
6	T. Saunders	Lake Cicott	75	...do	2	75	....	Sand	...	......	....	...
7	F. M. Million	....do	30	Driven	$1\frac{1}{4}$	30	....	....do	...	......	....	5
8	A. V. Watkins	Lincoln	115	Drilled	4	115	−16	Limestone	56	......	....	...
9	Logansport Ice and Cold Storage Co.	Logansport	600	...do	8	100	0	....do	2	......	....	...
10	....do	....do	104	...do	8	100	0	....do	2	......	....	8
11	City of Logansport.	Riverside Park	447	...do	8	447	+21	....do	...	1	54	7
12	....do	Electric-light plant.	380	...do	8	370	+ 3	....do	8	$\frac{3}{4}$	....	...
13	John W. Kennedy.	Logansport	1,606	...do	6	....	+	....do	25	......	....	...
14	J. S. Kline	$3\frac{1}{2}$ miles NE. of Logansport.	101	...do	3	100	−50	Gravel	...	......	....	9
15	Northern Indiana Insane Asylum.	Long cliff	618	...do	8	....	+	Limestone	9	2	....	12
16	John Winn	Lucerne	61	...do	2	60	....	Gravel	...	......	....	13
17	D. J. Forgy	New Waverly	18	Driven	$1\frac{1}{4}$	18	....	....do	...	......	....	14
18	Daniel Moon	1 mile S. of Onward.	12	Dug	....	....	+ 3	....do	...	......	....	15
19	City waterworks	Royal Center	290	Drilled	6	280	− 6	Limestone	...	......	....	16
20	Schoolhouse	Twelve Mile	130	...do	....	....	....	Gravel	...	......	....	17
21	W. S. Kepner	Walton	78	...do	4	....	−10	Limestone	70	......	....	18
22	Uriah Starry	....do	106	...do	4	....	−10	Sandstone	81	......	....	19
23	Public well	Young America	65	...do	4	65	−20	Limestone	60	......	....	20
24	Dr. N. W. Cody	Logansport	87	...do	5	....	....	....do	...	......	....	6

Mineral analyses of waters in Cass County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in rec. of wells.
1	G. P. Dykeman	Anoka	Drilled well, 120 ft. by 4 in.	H. E. Barnard	1907	Limestone	...	2.4	...	94	31	...	...	0.0	305	12	8.0	0.40	...	20	392	1
2	J. W. Griffin	5 miles W. of Galveston.	Drilled well, 100 ft. by 2 in.	do	1907	do	...	1.6	...	44	28	...	...	.0	264	0.0	4.0	.10	.001	2	346	5
3	W. H. Sprinkle	Galveston	Drilled well, 190 ft. by 8 in.	do	Oct., 1907	do	...	.3	...	69	28	...	...	.0	324	318	3.0	.10	.00	19	390	3
4	Pliny Morgan	do	Drilled old gas well	do	1907	do	...	.10	...	106	30	...	...	.0	320	263	3.0	.001	.01	9	562	4
5	F. M. Million	Lake Cicott	Driven well, 30 ft. by 1¼ in.	do	Nov., 1907	Sand	...	.1	...	66	25	...	...	.0	206	18	12.0	2.50	.001	9	340	7
6	Dr. N. W Cody	Logansport	Drilled well, 87 ft. by 5 in.	do	do	Limestone	...	.5	...	94	34	...	...	.0	306	18	4	.10	.002	4	378	24
7	Riverside Park	do	Drilled well, 447 ft.	R. B. Dole	Aug., 1907	do	12	.02	1.8	87	54	304	26	Tr.	416	85	514	.00	...	...	1,274	11
8	Logansport Ice and Cold Storage Co.	do	Drilled well, 104 ft. by 8 in.	do	do	do	18	.08	112	147	46	101	11	.0	411	166	200	.4	...	...	906	10
9	J. S. Kline	3½ miles E. of Logansport.	Drilled well, 101 ft. by 3 in.	H. E. Barnard	1907	Gravel	...	1.4	...	112	39	...	...	.0	348	57	8	2.50	.005	9	490	14
10	D. D. Dykeman	3 miles E. of Logansport.	Spring	do	1907		...	.2	...	106	26	...	...	.0	499	42	8	4.0	.005	9	414	...
11	Northern Indiana Insane Asylum.	Long cliff	Wells		1907	Limestone	39	5.0	4.6	95	34		13	341	...	53	31	...	...	...	...	...
12	do	do	Drilled well, 618 ft. by 8 in.	H. E. Barnard	1907	do	...	1.6	...	113	62	...	...	.0	360	36	860	.10	...	9	1,992	15
13	John Winn	Lucerne	Drilled well, 61 ft. by 2 in.	do	1907	Gravel	...	1.0	...	113	35	...	...	.0	350	24	56	.0	.001	2	542	16
14	D. J. Forgy	New Waverley	Driven well, 18 ft.	do	1907	do	...	1.0	...	121	35	...	...	.0	285	60	26	10	.003	13	464	17
15	Daniel Moon	1 mile S. of Onward.	Open well, 12 ft.	do	1907	do	...	1.2	...	100	32	...	...	.0	346	0.0	3	.0	.001	2	384	18
16	Public supply	Royal Center	Drilled well, 290 ft. by 6 in.	do	1907	Limestone	...	0.5	...	54	29	...	...	.0	305	0.0	5	.20	.001	2	354	19
17	Schoolhouse	Twelve Mile	Drilled well, 130 ft.	do	1907	Gravel	...	2.4	...	58	17	...	...	.0	216	37	7	.0	.00	9	268	20
18	W. S. Kepner	Walton	Drilled well, 78 ft. by 4 in.	do	1907	Limestone	...	1.0	...	106	33	...	...	.0	336	79	4.0	.0	.20	12	402	21
19	Uriah Starry	do	Drilled well, 106½ ft. by 4 in.	do	Oct., 1907	Sandstone	...	1.6	...	103	27	...	...	.0	318	126	7.0	.30	.00	33	292	22
20	Public well	Young America.	Drilled well, 65 ft. by 4 in.	do	1907	Limestone	...	3.6	...	34	35	...	...	.0	252	0.0	14	.05	.001	4	408	23
21	B. Castaldi	Dunkirk	Drilled well, 80 ft.	do	Nov., 1907	do	...	.01	...	131	28	...	...	.0	253	84	70	.60	.001	9	490	22

CLINTON COUNTY.

SURFACE FEATURES AND DRAINAGE.

Clinton County, in the western tier of the counties here discussed, has Carroll and Howard counties on the north, and Boone on the south. With an area of 402 square miles, it had in 1900 a population of 70 inhabitants to the square mile. Frankfort, the county seat, is 40 miles northwest of Indianapolis.

Practically the whole of the county, which lies on the plateau between Wabash and White rivers, is to be classed as uplands. The surface slopes from an elevation of 900 feet above sea level in the southwest quarter to less than 700 feet in the valley of Middle Fork of Wild Cat Creek, where it crosses the west county line. Through the whole county the rock is overlain by a thick layer of glacial till, which has entirely obscured the topography of the underlying rock. The present relief is entirely due to the form given to the surface deposits by the glacier and to the subsequent shaping of the materials by erosion. The greater part of the county is a level till plain, although in the north half there are several small areas of a few square miles each which are occupied by morainal drift, and in these areas the surface is less regular and the relief greater than in equal areas of till surface, although the moraines are nowhere very prominent topographic features.

Clinton County has no large streams. Several creeks have their sources here, but only one, South Fork of Wild Cat Creek, flows across the county from a source outside of it. The valley of this creek north of Michigantown is merely a shallow dip in the till plain, but becomes gradually deeper toward the west. Middle Fork of Wild Cat Creek rises in the northeast corner of the county, flows northwest into Carroll County, and then curves southwest to reenter Clinton County and flows across its northwest corner. All the other creeks are small and have valleys that lie only a few feet below the plain.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

As there are no large, well-developed valleys, the alluvial deposits of the county are unimportant. In the lower courses of Middle and South Forks of Wild Cat Creek there are narrow flood plains of alluvium, and these deposits, even in small areas, are good water bearers. The water lies near the surface and the open gravels yield their waters readily to wells. Driven wells are the cheapest and most satisfactory type for use in alluvium, but care should be taken not to drive the wells through the alluvium into the underlying till for the gravels are not of great depth in the small valleys.

The moraines of this county are patchy in distribution (Pl. I) and occur only as rather thin deposits on top of the till. Wells in them locally find water above the till, but in most places it is necessary to go through the morainal beds into the till. Driven or drilled wells are commonly employed for this purpose.

As shown in Plate I, the till occupies most of the surface of the county and is actually continuous over it, though covered locally by moraines. In the southwest corner of the county the rock is within 125 to 150 feet of the surface, but throughout the county the till probably averages 250 feet thick, and at Frankfort it is 275 feet and at Kirklin 300 feet to the underlying rock (Pl. II). In this county the gravel beds of the till are in many places far below the surface or are too thin to supply much water. Consequently most of the wells are dug or open and are supplied by seepage from the close-textured till. Such wells, if dug below the level of the water table during the dry seasons, will usually supply enough water for family use. For the use of stock or for manufacturing purposes such wells are inadequate. Large users of water must supply themselves from surface waters or put in deep drilled or driven wells, which are commonly successful in reaching gravel or sand beds. At Frankfort large quantities of water for the city supply are drawn from open gravel beds in the till.

CONSOLIDATED MATERIALS.

The outcrops of three great groups of rocks extend across this county beneath the surface deposits, and occur as belts running from northwest to southeast (Pl. III). At the east edge of the county the uppermost rocks are the Devonian limestones, the oldest of the three series. Next younger and uppermost in the central and northwest portions is the New Albany shale. In the extreme southwest corner of the county the highest rocks are the shales of the "Knobstone" group, of Mississippian age. These rocks have all been described in previous parts of this report. None of them furnishes water to the wells in Clinton County.

ARTESIAN AREAS.

At Alhambra Lake, one-quarter mile south of the court-house at Frankfort (Pl. IV, No. 15), there is a single flowing well. As this well is below the surface of the lake, there was no opportunity to determine its yield. In 1884 there were five flowing wells at this lake, one of which yielded 96 gallons per minute, and the area in which flowing wells could be obtained was at that time much larger than it is now. Flowing wells could then be obtained all along the creek, and the water at the city pumping station would rise 6 feet above the surface. Alhambra Park was for many years a thriving resort, with boating and bathing in the lake. The artesian waters were all obtained from a gravel bed, 65 feet below the surface, and the head is from the uplands near by.

Area 16 extends from Manson eastward for about 4 miles along the creek. (Pl. IV, No. 16.) At Manson the wells are almost all driven into gravel in the till to depths of 35 to 45 feet, and although none of them flows constantly several flow at the surface in wet weather. One flowing well is reported two miles south of Frankfort.

Two miles north of Kirklin there is a single flowing well in the lowlands (see Pl. IV, No. 17), driven into gravel at 40 feet, from which the water will rise 9 feet above the surface. The artesian conditions are local, though probably other flows could be procured in the neighborhood, on ground as low as that near the existing well. The water comes from the higher ground not far away.

There are a number of flowing wells along the valley of Middle Fork of Wild Cat Creek, north of Boyleston and Hillisburg and in the vicinity of Michigantown. (Pl. IV, No. 18.) The strongest of these, 1 mile north of Michigantown, is driven over 100 feet through the till into gravel and is said to flow with a 1-inch stream. All the wells of this area are in the lowlands, and wells on higher ground striking the same gravel beds, would not flow.

In the vicinity of Moran there are two flowing wells (Pl. IV, No. 19), one of which, on the property of N. E. White & Co. (No. 15, p. 100), is a dug well 19 feet deep. It obtained a flow of about 1 gallon per minute from a gravel bed, and a pump is used to raise the water to a convenient height. The second artesian well, 1½ miles west of Moran (No. 16, p. 100), is a driven well 60 feet deep and flows almost enough to fill a 2-inch pipe. Though the above wells are some distance apart and obtain their flows from different depths, they are both in the till and have been classed as in a single artesian area.

Along the valley of North Fork of Wild Cat Creek, between Forest and the county line, and in the valley of the tributary east of Sedalia, there are five or six artesian wells (Pl. IV, No. 20), all of which are driven into gravel beds in the till, at depths of 35 to 100 feet. The waters from these gravels have just enough head to give flows in the valleys. The conditions for flows seem to be favorable along much of this valley, if the wells are located on low enough ground. Records of these wells are given on page 100.

CITY AND VILLAGE SUPPLIES.

Frankfort.—Frankfort, the county seat, is the only city in Clinton County which has a public water supply. It lies 3 miles southwest of the geographic center of the county, and its population in 1900 was 7,100. The waterworks of this city are the property of the Frankfort Water Works Company, and the water is drawn from 12 drilled wells, 6 inches in diameter. One well penetrates to a depth of 208 feet into an 8-foot stratum of sand, and formerly flowed with a head 6 feet above the surface. For the last twenty years this head has gradually become lower, and the well has long since ceased to flow. The other wells are about 82 feet deep, and a gravel bed is reported at 55 feet. The water from this gravel enters the well and formerly rose under artesian pressure almost to the surface. The head is now 20 feet below the surface. Although the wells are situated in the center of the town, the gravel bed from which the water comes is protected above by impervious blue clay and hardpan, and should be safe from contamination. There has been some complaint that the water is turbid, but on the whole the supply seems to be very good. Direct pressure is used, the water being pumped from a 400,000-gallon reservoir into the mains. There are now over 16 miles of mains of thin wrought iron lined with concrete. In 1907 the company was engaged in laying 7 miles of additional mains, part of this work being already completed at the time the town was visited. There are about 2,000 services, and 75 per cent of the people of Frankfort use this water, requiring about 1,000,000 gallons per day.

Many families in this city still use water from private wells, most of which are driven to depths of 30 to 60 feet and obtain good water from the gravels. Unfortunately many shallow dug wells are still in use. Some of these, when examined, showed strong evidences of pollution by their appearance and odor. Cesspools and wells were found side by side and the one very evidently was in direct connection with the other. Analyses 3 and 4 (p. 101) are of the waters of two dug wells that show evidences of the presence of sewage.

From water-well borings and from the record of a well sunk for gas the geologic section at Frankfort has been found to be as follows:

Log of well drilled for gas at Frankfort.[a]

	Feet.
Clay and hardpan with some gravel	55
Gravel	32
Till	113
Sand	8
Till	70
Niagara limestone and shale	380
Trenton [meant for Clinton]	10
Hudson River and Utica shale	400
Trenton limestone	260
	1,328

Colfax.—Colfax, a village of 768 inhabitants (1900), is in the southwest corner of the county. It has no public water system and the water used is drawn from private wells. Most of these are open wells, 15 to 25 feet deep, though a few wells, driven and drilled to

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 245.

depths of 40 to 50 feet are used. The water rises within 6 or 8 feet of the surface, but no flows have been found. The deeper wells go through the till into gravels and get pure, safe water. An analysis of water from a depth of 102 feet is No. 2 (p. 101). The dug wells are very likely to become polluted, and are not safe to use when located in a town and surrounded by barnyards and privies.

Kirklin.—Kirklin, in southeastern Clinton County, is situated on the till plain about a mile south of Sugar Creek. The water supply is drawn from dug and driven wells and cisterns, and no public water supply has been installed. Most of the wells in use are dug wells less than 30 feet in depth. There are, however, a number of driven wells, the deepest of which extend to more than 100 feet below the surface. None reach bed rock, the water being obtained from gravel beds. Under the town there are three gravel beds which may be encountered, the first at 15 to 20 feet, the second at 50 to 60 feet, and the third at 100 to 115 feet. The shallowest of these is the one most commonly drawn upon, but the water at this depth is not safe from pollution. From time to time, there has been considerable typhoid fever in this town, doubtless due to the use of shallow wells. The water in the second gravel is very much safer, and that from the third gravel is subject to but very slight chance of becoming contaminated. Analyses of the third gravel waters are Nos. 7 and 8 (p. 101).

Rossville.—Rossville, in the northwest part of the county, is on a rolling plain. The source of supply is from wells, which are about equally divided between the dug and driven types. The most common depth for wells is 30 feet, though some are shallower and some deeper. The water is obtained from gravel beds which occur at about 25 to 30 feet, and at 40 feet. The general health of the town has been good, but the 40-foot wells are recommended as a much safer source of supply than the shallower ones. An analysis of water from a depth of 40 feet is No. 12 (p. 101).

Mulberry.—Mulberry, 8 miles northwest of Frankfort, is supplied almost altogether from dug wells, which range from 12 to 30 feet in depth and in which the water from gravel beds rises within 12 feet of the surface. Two deeper wells were sunk but were unsuccessful, as both encountered quicksand at a depth of about 100 feet and had to be abandoned. As the shallow gravel beds seem to be the only available source of supply, it would be advisable to sink driven wells to these gravels. These wells, if properly cased, would be superior to the loosely walled dug wells, because water could enter them only from the bottom. The open wells receive water through their walls from all depths and are subject to pollution from many sources.

Other communities.—A list of other villages with particulars regarding their water supply is given in the following table.

Other village supplies of Clinton County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head above (+) or below (−) surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Beard	34	Wells, dug and driven	20	101	25		−20	Gravel.
Boyleston	120	do	15	45	33		−15	Do.
Edna Mills	72	do	10	18	15		− 5	Do.
Forest	286	do	15	100	30	225	−10	Do.
Greetingsville		do	20	110	40			Do.
Hillisburg	268	do	15	64	40		−5 to −10	Do.
Jefferson	100	do	20	82	26			Do.
Manson	175	Wells, driven	35	45	40		0 to − 3	Do.
Michigantown	417	Wells, dug and driven	19	125	23		0 to −12	Do.
Middlefork	119	do	20	70	60		+4 to − 6	Do.
Moran	200	do	15	60	25		0 to − 3	Do.
Pickard	150	Wells, dug, driven, and drilled.	15	150	35		−13	Do.
Scircleville	167	Wells, dug and driven	30	135	40		−12	Do.
Sedalia	300	do	15	80	20		−12	Do.

TYPICAL WELLS AND ANALYSES.

In the two following tables are given detailed information regarding typical wells in Clinton County and analyses of their waters. The last column of each table gives the numbers of identical wells in the other table.

Records of typical wells in Clinton County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Analysis No.
			Ft.		*In.*	*Ft.*	*Ft.*		*Ft.*	*Gals.*	
1	G. T. Myers	1 mile SW. of Boylestown.	35	Driven	1¼	35	−15	Gravel			1
2	Wm. Powers	Colfax	102	Drilled	2	80	− 8	do			2
3	George Dukes	do	216	do	2	86	− 6	do			
4	W. H. Davis	Forest	100	do	8		−	Limestone	225		
5	Frankfort Water Works Co.	Frankfort	82	do	6	50	−20	Gravel			
6	Milton Oliver	do	15	Dug		15		do			3
7	D. A. Coulter	do	20	do				do			4
8	James I. Miller	Jefferson	83	Driven			−18	do			6
9	Bert McKinney	Kirklin	52	do	2	50		do			
10	R. C. Gorham	do	102	do	2	100	−16	do			7
11	Marion Anderson	2 miles N. of Manson.	80	do	1¼	80	−12	do			
12	M. E. Miller	Michigantown	120	do	2		−14	do			
13	F. Ridenow	Middlefork	65	do	1¼	65	+ 3	do		6	9
14	John Revis	¾ mile N. of Middlefork.	65	do	1¼	30	+				
15	N. E. White & Co.	Moran	19	Dug		19	+ 2	Gravel		1	10
16	Markwood Slipher	1½ miles W. of Moran.	60	Driven	2	60	+ 3	do			
17	Dr. I. S. Earhart	Mulberry	21	Dug		21	−15	do			11
18	Rossville Bank	Rossville	40	Drilled	1¼	40	−30	do			12
19	Charles Fulkerson	Sec. 25 T. 21, R. 1 E.	40	Driven	2½		+ 9	do		2½	
20	H. F. Cheney	Sec. 24, R. 1 W., Owen township.	46	do	2½	40	+ 7	do		12	
21	John Kemner	Sedalia	46	do	3		−20	do			
22	Carl Peitsch	do	90	Drilled	2	88	−37	do			
23	Simms & Ashpaugh.	Scircleville	115	do	3	115		do			13

Mineral analyses of waters in Clinton County.

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
							Parts per million.															
1	G. T. Myers	1 mile SW. of Boylestown.	Driven well, 35 ft. by 1¼ in.	H. E. Barnard.	Oct. 1907	Gravel	...	2.2	...	61	27	...	...	0.0	344	55	4.0	0.30	0.0	33	398	1
2	Wm. Powers	Colfax	Well, 102 ft. by 2 in.[a]	do	do	do	...	2.0	...	111	24	...	...	.0	358	96	9.0	.0	.001	0	448	2
3	Milton Oliver	812 First street, Frankfort.	Open well, 15 ft.	do	do	do	...	4.8	...	133	41	...	...	.0	402	158	20.0	.0	.0	33	614	6
4	D. A. Coulter	908 Second street, Frankfort.	Open well, 20 ft.	do	do	do	...	1.2	...	116	39	...	...	.0	436	269	39.0	.20	.06	7	706	7
5	Lake Erie and Western R. R.	Hillisburg	Well, 265 ft.	L. E. & W. R. R.	Sept. 1903	...	...	7.7		82	32	13		202	....	21	4.8	...	...	...	...	...
6	Jas. I. Miller	Jefferson	Well, 83 ft.	H. E. Barnard.	Oct. 1907	Gravel	...	.8	...	79	6.5	...	...	.0	267	85	7.0	.00	.001	15	370	8
7	R. C. Gorham	Kirklin	Well, 102 ft. by 2 in.	do	do	do	...	2.0	...	71	24	...	...	.0	302	60	4.0	.00	.000	19	419	10
8	J. W. Wills	do	Well, 51 ft. by 2 in.	do	do	...	...	1.6	...	34	24	...	...	9.0	202	32	5.0	.00	...	0	314	...
9	Fred Ridenow	Middlefork	Well, 65 ft. by 1¼ in.	do	do	Gravel	...	.6	...	64	20	...	...	.0	320	38	12	.50	.000	6	414	13
10	N. E. White & Co.	Moran	Open well, 19 ft.	do	do	do	...	1.0	...	103	40	...	...	.0	403	66	11	.00	.001	19	512	15
11	Dr. I. S. Earhart	Mulberry	Open well, 21 ft.	do	Sept. 1907	do	...	.0	...	126	30	...	...	.0	347	107	67	2.00	.10	0	528	17
12	Rossville Bank	Rossville	Well, 40 ft. by 1¼ in.	do	Oct. 1907	do	...	1.0	...	116	21	...	...	.0	345	210	15	.00	.001	19	536	18
13	Simms & Ashpaugh.	Scircleville	Well, 115 ft. by 3 in.	do	do	do	...	.6	...	34	18	...	...	.0	286	60	6.0	1.5	.001	33	340	23

[a] Water at 80 feet.

ELKHART COUNTY.

SURFACE FEATURES AND DRAINAGE.

Elkhart County, in the northeastern corner of this area and at the north edge of the State, is rectangular in outline, measuring 21 miles from east to west and somewhat more than 22 miles from the north to the south border. The total area is approximately 470 square miles and the average population (1900) 96 to the square mile. The county seat, Goshen, is near the center of the county, and lies 92 miles east of Chicago and 125 miles north of Indianapolis.

Elkhart County has a topography of great diversity. From St. Joseph River north to the county line, and for some distance south of that stream, the country is low and has very slight relief, and this flat area extends to the southeast corner of the county, along the valley of Elkhart River (Pl. I). At the edges of the flat area, moraine ridges rise sharply from the plain. South of Bristol the highest points of the moraine are over 200 feet above the flat and reach an altitude of over 1,000 feet above sea level. No other county in the area here treated has so great a range of elevation as Elkhart County, the surface of which rises from less than 750 in the valley of St. Joseph River to over 1,000 feet at a number of points. The southwest corner, though covered by glacial deposits, consists of a rolling plain of low relief, and is not so high as the moraine-covered areas. The surface features of the county are entirely due to the form of the unconsolidated materials, as only in the deepest valley, that of St. Joseph River, have borings reached rock, which here lies 120 to 160 feet below the surface. In the high moraines the surface deposits have doubtless a thickness of 250 to 400 feet.

Elkhart County lies wholly within the basin of St. Joseph River, which enters the county from the north, near Bristol, and, flowing somewhat south of west as far as Elkhart, turns west to enter St. Joseph County. The stream occupies a rather narrow channel in a very wide valley of alluvial materials. The principal tributary is Elkhart River, which flows across the county from southeast to northwest. Like that of the St. Joseph, its valley is wide and contains extensive alluvial beds. Bauge Creek, Pine Creek, and Little Elkhart River are other tributaries to the St. Joseph from the southeast. It receives no important branches from the north.

There are about a score of small lakes in the county which occupy depressions in the moraines. The largest is Simonton Lake, 4 miles north of Elkhart, and its area is but little more than one-half square mile.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

Alluvial deposits here have a considerable area and are of great importance as water producers. They lie on both sides of St. Joseph River, the alluvial flat ranging from 3 to 5 miles in width. Alluvium also occurs in a strip from 1 to 3 miles wide along the Elkhart River valley. At Elkhart wells penetrate about 34 feet of gravel and sand before they strike the underlying glacial clay. At Bristol the deepest wells have been sunk only 30 feet and have failed to reach the bottom of the alluvium. At Goshen, which is near the edge of the alluvial plain, the gravels are thinner but increase in depth toward the valley center.

Bordering the terminal moraines and occupying the gentler slopes below them there are in some places plains of alluvial material of different origin from the above-described valley deposits. These are outwash plains of the kind described on page 31.

Underground water is abundant throughout almost the entire alluvial area, for rainfall is rapidly absorbed at the surface and the relief is so slight that the waters are not readily drained from the lowlands, while the open and porous character of the beds makes the water readily available. The very fact that deep wells are absent in these alluvial areas is a sufficient indication that satisfactory supplies can be obtained at moderate depths. Driven wells from 15 to 30 feet deep are commonly used, and for household or farm uses these have proved satisfactory.

The moraines have a greater surface area than any other class of deposits in Elkhart County, occupying about one-half the surface. They all lie south of St. Joseph River, and there is a sharp topographic break between the alluvial plain along this river valley and the ridgelike moraines. Much of the surface is strewn with large and small bowlders. Driven or drilled wells are preferred in these deposits, as with them it is possible to go to greater depths if water is not found near the surface. The wells range in depth from 15 to 200 feet and the best supplies of water are usually found in gravel or sand beds in the clay.

It is probable that the till underlies all the other surface deposits of the county and exists as a continuous sheet below them and above the rock, although it occupies the surface only in the southwest corner of the county (Pl. I). There the topography is that of a rolling plain, broken only by the shallow valleys of small streams. Few surface cuts show gravel beds in the till, but the drill commonly reveals their presence at some depth. The clayey portions of the till yield water slowly to wells, and to procure satisfactory quantities of water it is commonly necessary to sink open wells of large surface area from 15 to 40 feet in depth to obtain the seepage from the clay. Driven and drilled wells are generally successful in procuring abundant water in beds of gravel.

CONSOLIDATED MATERIALS.

A study of the position, succession, and character of rock beds in this county explains why the rock beds here have never been utilized as a source of water supplies and demonstrates that these rock waters can never be exploited to any great extent. A well boring at Elkhart (Pl. I), in the lowest portion of the county, shows the surface deposits to be 122 feet deep. Below this there is a thickness of 429 feet of shales which yields no water. It is therefore 551 feet down to the first rock formation, the "Corniferous" limestone of the well drillers, which might be expected to yield abundant supplies of water, and even this water would be likely to contain objectionable quantities of sulphur and salt. In the higher portions of the county, where the glacial deposits are thicker, an additional 100 or even 200 feet must be added to the above depth at which limestone will be encountered. The cost of such deep borings will prevent them from ever becoming common, and underground waters must be obtained from the surface materials.

ARTESIAN AREAS.

In and about the city of Elkhart, along the lowlands of St. Joseph River, is an area in which about a dozen flowing wells have been obtained (Pl. IV, No. 21), the best known of which are at Island and McNaughton parks. These wells are reported to obtain the flowing waters from sand and gravel beds at depths of 60 to 90 feet. As shown in the well log on page 105, the water-bearing beds are protected from pollution from above by many feet of close-grained blue till. Flows can be obtained only in the bottom lands, where the waters will rise 2 or 3 feet above the surface. On higher ground the same artesian waters may be encountered by wells, but the head is sufficient to carry the water only a few feet above the level of the river. An analysis of water from the Island Park flowing well is No. 11 (p. 109).

Area 22 (Pl. IV) includes the low ground in and near Wakarusa, where there are 10 or 15 flowing wells and a large number in which the water is under artesian pressure but does not rise to the surface. The flows are all obtained from a gravel bed lying from 28 to 40 feet below the surface of the till. The wells are all driven, and the pipe most used is 1¼ inches in diameter. None of the wells gives a large flow, but the yield, from a fraction of a gallon to 5 gallons per minute, continues throughout the year. The temperature of the wells tested was 51° F. An analysis of the water from one of these wells is No. 21 (p. 109).

CITY AND VILLAGE SUPPLIES.

Elkhart.—Elkhart lies at the junction of Elkhart and St. Joseph rivers and in 1900 had a population of 15,184. The public water system, installed in 1884, is owned by the Elkhart Water Company, a private corporation. The water is drawn from three dug wells, 34 feet deep, two of which are 40 and the other 30 feet in diameter. The materials penetrated were sand and gravel, clay being encountered at the bottom. The wells, situated at the edge of the town, in a grove owned by the water company, are a considerable distance from the nearest dwellings and outhouses, and the supply seems to be a very satisfactory one. The city health officer reports that no case of typhoid fever has ever been traced to the city water. There is some objection, however, to a yellowish color which the water has after a fire has necessitated more than the ordinary pumping. The extra pressure tends to loosen deposits of iron which have formed in the mains, and this discoloration of the water lasts for a few hours. Up to the present time the supply from the wells has been sufficient for all purposes. The company has an emergency connection with Christiana Creek, so that in case of fire an additional supply can be obtained.

Direct pressure is used to supply about 33 miles of mains, which range from 6 to 24 inches in diameter. There are 3,320 taps, and it is estimated that about one-fourth of the people of Elkhart use this water, from 2,000,000 to 6,000,000 gallons per day being required to meet the demand.

About three-fourths of the people of this city still use private wells, most of which are driven, though many dug wells are still in use. The common depth from which water is drawn is 25 feet, or practically the same depth as the city wells, but the waters of private wells are more likely to become contaminated, for many of them are located near houses where kitchen slops are thrown out, and are often close to dug privy vaults. In the open-textured gravels and sands the liquids from these quickly penetrate to the ground-water table and become a part of the water supply. It is probable that safer waters could be secured from beds of gravel in the underlying till. From a deep boring for gas and from shallow well records, the following succession of beds has been determined for this vicinity:[a]

Log of well drilled for gas at Elkhart.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, etc.	5	5
Sand and gravel	29	34
Blue clay	88	122
Subcarboniferous gray shale	213	335
Hamilton blue shale	215	550
Corniferous limestone.		

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 242.

Goshen.—Goshen lies on Elkhart River, near the center of the county. The public waterworks, built in 1880, are owned by the city, and the water is drawn from Rock Run and from two dug wells, 24 and 36 feet deep and 24 and 40 feet in diameter. They are dug through gravel, the walls being cemented, so that water can enter only from the bottom. The water from these wells is unsatisfactory. One of them is situated near the gas plant, and the water is covered with a thick, greasy scum and has a decided odor. Part of the city water comes from Rock Run, which flows for more than a mile through the edge of the town before it reaches the waterworks. There are many dwellings, barns, and outhouses along its course, and pollution from some of these sources is almost certain.

The city water is pumped by steam pumps to a standpipe 146 feet high, from which the water is distributed by gravity to 25 miles of mains ranging from 4 to 20 inches in diameter. An average of 1,500,000 gallons per day is needed to supply 1,800 services and 292 fire hydrants. In case of fire the standpipe is cut off and direct pressure is used.

The city has spent large sums of money in trying to obtain well water at the city plant. It is reported that $70,000 was spent in completing one dug well.

In the south part of the town the supply of underground water is very abundant. All driven wells have encountered plentiful waters at depths of 30 feet or less, and excavations for buildings are difficult on account of the inflow of ground waters. A fine city supply could be obtained by drilling shallow wells into the gravel a little distance beyond the settled portion of the town. An analysis of water from these gravels is No. 16 (p. 109).

About 20 per cent of the people of this city use private wells for domestic purposes, and a number of manufacturing establishments also have their own wells, most of which are driven, though there are still a few dug wells in use. All penetrate into gravel, and they range in depth from 18 to 90 feet. No water wells strike bed rock, for the record of an old gas boring shows that the rock here lies 165 feet below the surface. The log of this well is as follows:[a]

Log of well drilled for gas at Goshen.

	Feet.
Drift	165
Shale, Subcarboniferous and Devonian	308
Corniferous limestone	60
Water lime	32
Niagara limestone	728
Hudson River limestone and shale	307
Utica shale	215
Trenton limestone	239
	2,054

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 246.

Nappanee.—Nappanee owns its own waterworks, the water for which is drawn from three drilled wells 160 feet deep, two 6 inches and one 12 inches in diameter. The town is situated on a rolling till plain and the waters are found in gravel beds below the till. The water is pumped by steam to a 75,000-gallon tank 116 feet high, from which it is distributed by gravity. There are 4 miles of 8, 6, and 4 inch mains and 315 taps, and about half of the people use this water.

Besides the public supply there are many private wells in Nappanee. Most of them are driven, but some are drilled and a few dug. Only the dug wells are shallow and receive the water by seepage from the till, while the driven and drilled wells are 60 to 120 feet deep, the common depth being about 70 feet. The water comes from gravel beds, and for domestic uses the supply seems to be an admirable one.

Wakarusa.—Wakarusa, on a rolling till plain 10 miles southwest of Goshen, has no public water supply. The wells are driven and drilled and range in depth from 15 to 165 feet. The most common depth is 35 feet, and all the wells enter gravel. There are many flowing wells in the town which afford an excellent supply (Nos. 18, 19, 20, p. 108). An analysis of the water from one of these flowing wells is No. 21 (p. 109).

Middleburg.—Middleburg is situated on an alluvial plain at the base of a very high, steep moraine ridge. Almost every family has its own private driven or drilled well, and there is no public supply. As a result of the topographic situation of this town the conditions for obtaining wells differ greatly in short distances. In the alluvium it is rarely necessary to drive a well more than 30 feet deep to obtain plenty of water, but on the moraine a depth of 150 feet is in some places required before a satisfactory supply is obtained.

Bristol.—In Bristol, on the great St. Joseph River alluvial plain, the wells are all driven and all have reached unfailing water. The deepest well in town is but 25 feet deep, and the depth of the alluvium at this place is not known. The water rises in the wells within 10 or 12 feet of the surface, and even the driest seasons fail to lower the head to any noticeable extent.

Millersburg.—Millersburg is situated on a low moraine in the southeast part of the county. All the wells here are driven, usually to a depth of about 28 feet. The deepest well in town is 65 feet deep and does not reach rock. The water supply comes from a gravel bed in the moraine and rises within 18 feet of the surface.

Rural districts.—In the rural districts the conditions vary with the material at the surface. In alluvial areas driven wells are largely used and are generally not sunk to depths of more than 30 feet. Water is more difficult to obtain in the morainic deposits, and driven or drilled wells, ranging in depth from 15 to 200 feet, are most common, the water being usually found in gravel in the drift. In those portions of the county where the till comes to the surface the conditions for wells are least favorable. Here dug wells are most common, and the water is yielded to them slowly by seepage. Deep drilled wells, almost without exception, encounter water-bearing gravel beds in the till if they reach sufficient depths.

Other communities.—A list of other villages in Elkhart County, with particulars of their water supply, is contained in the following table:

Other village supplies of Elkhart County.

Town.	Population (1900).	Source.	Depth of wells.			Head below surface.	Character of water beds.
			Least.	Greatest.	Common.		
			Feet.	*Feet.*	*Feet.*	*Feet.*	
Boston	181	Wells, driven	10	20	15	3-8	Gravel and sand.
Dunlaps	33	do	18	28	25	14	Do.
Foraker	52	Wells, driven and drilled.	60	125	80		Gravel.
Jamestown	50	Wells, driven	25	65	50	6-12	Do.
Locke		do	25	110	65		Do.
New Paris	456	do	10	50	15	8	Gravel and sand.
South West	52	Wells, driven and drilled.	45	135	45		Gravel.
Vistula	141	Wells, driven	20	30	25	8	Gravel and sand.
Waterford		do	10	20	16	8	Do.

TYPICAL WELLS AND ANALYSES.

In the following two tables are given the records of typical wells in Elkhart County and analyses of their waters. The last column in each table gives numbers referring to identical wells in the other table.

Records of typical wells in Elkhart County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing material.	Depth to rock.	Flow per minute.	Temperature.	Analysis No.
			Ft.		*In.*	*Ft.*	*Ft.*		*Ft.*	*Galls.*	*°F.*	
1	Town well	Bristol	22	Driven	1¼	22	−10	Gravel and sand.				
2	Elkhart Water Co	Elkhart	34	Dug	*a* 40	30	− 6	Gravel				1,2,8
3	Island Park	do	85	Drilled	2	80	+ 3	do		10		3
4	McNaughtons Park	do	80	do	2	80	+ 3	do				
5	Chicago Telephone Supply Co.	do	25	Driven	1¼	25	− 6	do				
6	R. L. Evans	do	124	do	2	65	+ 0	do	122			
7	M. W. Huston	do	80	do	2	65	+ 2	do				
8	Sidway Mercantile Co.	do	20	do	2	20	−12	do				
9	City waterworks	Goshen	36	Dug	*a* 40	20	− 2	do				15
10	Hawks Furniture Co.	do	80	Driven	1½	80		do				
11	Goshen Manufactur- Co.	do	25	do	1¼	20	−18	do				16
12	Banta Furniture Co.	do	25	do	1¼	20	−13	do				17
13	L. J. Pritchard	Jamestown	26	do	1¼	26	−12	do				
14	Town well	Middleburg	24	do	1¼	24		do				
15	do	Millersburg	28	do	1¼	28	−18	do				18
16	Public supply	Nappanee	160	Drilled	6	100	−40	do				19
17	Town well	New Paris	15	Driven	1¼	15	− 8	do				20
18	Henry Wagner	Wakarusa	28	do	1¼	28	+ 2	do		2	51	21
19	Irene Smeltzer	do	30	do	1¼	30	+ 7	do		5	51	
20	Leroy Mullenauer	do	60	do	1¼	60	+ 2	do		4	51	

a Feet.

Mineral analyses of waters in Elkhart County.

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
							Parts per million.															
1	Public supply	Elkhart	Open wells, 34 ft			Gravel	15	2.5		68	4.3	3.9		99		23	6.1				234	2
2	Do	do	do	Chase Palmer	Oct., 1907	do	10	0.5		46	21	6.3		12	182	9.2	2.0	0.6			221	2
3	Island Park	do	Well, 85 ft. by 2 in	H. E. Barnard	1907	do		.10		29	11				231	12	52	.40	.000	2	254	3
4		do	Elkhart River[a]	Lake Shore and Michigan Southern R. R.	1903			2.0		67	19	4.7		129		33	3.2	.00				
5		do	do[b]	do	1903			2.7		71	18	8.8		132		41	3.9	.00				
6		do	St. Joseph River[c]	do	1903-1907			1.5		59	18	3.5		121		22	2.8	1.5				
7		do	do[d]	do	May, 1903			1.5		57	17	2.0		116		17	3.0					
8	Public supply	do	Wells, 34 ft	do	Feb., 1903	Gravel		1.2		53	20	5.5		125		15	3.8	.00				2
9	A Zimmerman	do	Well, 80 ft. by 4 in	do	June, 1903	do		1.5		61	18	5.8		132		17	1.9					
10	(Field House addition.)	do	Well, 65 ft. by 2½ in	do	do	do		.98		97	23	16.00		157		73	25					
11	Island Park	do	Well, 60 ft. by 2½ in	do	do	do		1.2		66	19	4.2		141		12	4.6					
12	(Johnson's addition.)	do	Well, 75 ft. by 2½ in	do	do	do		1.5		73	20	10.00		148		26	7.9					
13	City supply	Goshen	Rock Run	do	Aug., 1903			2.9		55	19	2.9		118		16	4.5	4.0				
14	Do	do	do	do	Dec., 1904					67	22	2.5		141		18	3.8	4.5				
15	Do	do	Open wells, 24 and 40 ft.	Chase Palmer	Oct., 1907	Gravel	18	0.2		50	21	8.2		11	198	15	1.8	Tr.			240	9
16	Goshen Manufacturing Co.	do	Well, 25 ft. by 1¼ in	H. E. Barnard	1907	do		.01		76	19			0.0	239	66	11	2.0	.001	2	370	11
17	Banta Furniture Co.	do	Well, 23 ft. by 1¼ in	do	1907	do		.01			28			.0	334	564		3.5	.001	4		12
18	Public well	Millersburg	Well, 28 ft. by 1¼ in	do	1907	do		.00		93	38			.0	306	46	20	8.0	.00	9	484	15
19	Public supply	Nappanee	Wells, 100 to 160 ft.[e]	do	1907	do		1.0		76	36				365	46	28	.30	.00	9	380	16
20	Public well	Farman Bros. store, New Paris.	Well, 15 ft. by 1¼ in	do	1907	do		.10		89	30			.0	263	101	260	6.0	.00	4	412	17
21	Henry Wagner	Wakarusa	Well, 28 ft. by 1¼ in	do	1907	do		.10		74	27			.0	291	107	12	.10	.00	.2	362	18

[a] Average of three analyses. [b] Normal stage. [c] Average of five analyses. [d] Low stage. [e] Water at 100 feet.

FULTON COUNTY.

SURFACE FEATURES AND DRAINAGE.

Fulton County is in the western tier of counties of this area and is bordered on the north by Marshall and Kosciusko counties and on the south by Cass and Miami. It is irregular in outline and is notched on its east edge by the corners of Kosciusko and Miami counties. It has an area of 382 square miles, and had, in 1900, a population of 17,453, or an average of 45 inhabitants to the square mile. The county seat is Rochester.

The surface is of mild relief and a large part of it lies between 750 and 800 feet above sea level. At the southwest corner and in that part of the Tippecanoe Valley which lies northwest of Rochester the land surface falls below the 750-foot level, but in the narrow east end of the county it reaches a height of 900 feet. (See Pl. I.) Almost all of the county may be classed as uplands. A great interlobate moraine (Pl. I) crosses the southeast and east edges of this area, and the Tippecanoe River valley forms the south border of the great Maxinkuckee moraine. A narrow belt of low moraine also extends across the county from north to south near its western edge, and there is still another patch of moraine southeast of Rochester, in which Lake Manitau has its basin. In all of the morainic areas the surface is rolling and irregular. On either side of Tippecanoe River, and extending from this valley through the center of the county southward as far as Rochester, is a plain formed of alluvial sands and gravels which have locally been blown to form low dune ridges. That part of the surface which is not occupied by morainal or alluvial material consists of gently undulating till plains. (See Pl. I.)

Fulton County contains about two dozen natural lakes and ponds. The largest of these, Manitau Lake, near Rochester, has an area of little more than a square mile, while most of them only occupy a few acres of ground. All are in the moraine-covered portions of the county and lie in depressions in the irregular surface of the moraines.

Tippecanoe River, in the north part of the county, is its only important stream. Its valley makes a great crescentic curve around the south edge of the Maxinkuckee moraine, and the stream bed is not more than 30 or 40 feet below the alluvial plain to the south. With the exception of a small area in its extreme southeast corner, the entire county drains into the Tippecanoe. The principal tributaries are Grass, Mill, Mud, and Chippewanuck creeks from the south and Eddy Creek from the north.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

As stated above, the alluvial deposits of Fulton County are of considerable extent in the Tippecanoe Valley and cover a part of the plain to the south of it. The alluvium consists of gravels and clayey sand and was here deposited beyond the edge of the retreating glacier by the streams which flowed from it. The surface is flat and has suffered little from stream erosion. West of Rochester the winds have blown the alluvial sands into low ridges or dunes.

Throughout the area of alluvial deposits (Pl. I) the ground-water supply is abundant and easily obtained. In the valley of the Tippecanoe and in the prairie west of Rochester only driven wells are used. These wells are obtained easily by driving a 1¼-inch pipe with a perforated point 20 or 30 feet into the sand or gravel. Some of the wells become clogged with fine sand, but if gravel beds can be reached, this trouble is avoided.

Over most of the morainal areas, shown in Plate I, the morainal drift is only moderately thick and the relief is mild. The most vigorous moraine of the county lies north of Tippecanoe River in the neighborhood of Tiosa and Richland Center. In the high moraine in northern Fulton County the wells are almost all driven or drilled. The shallowest are about 30 feet deep, but occasionally it has been necessary to sink wells 150 or even 200 feet. The best supplies of water are always found in gravel or coarse sand beds, which in the areas of thin morainal drift can commonly be reached at depths less than 100 feet.

The occurrence of the till at the surface is shown in Plate I. The surface is in some parts a flat featureless plain, but more generally it consists of gentle, wavelike undulations with the crests only a few feet above the troughs. In those areas where the till occurs at the surface it extends downward to bed rock, which is everywhere more than 150 feet below the surface, and it therefore follows that all wells of ordinary depth must get their water in the till. For this reason dug wells, which obtain the water by slow seepage from the clayey till, are most common.

CONSOLIDATED MATERIALS.

In only two towns in the county were records obtained of wells which have penetrated to bed rock. At Rochester rock was found at 150 feet and at Kewanna 170 feet below the surface. Deep borings in the surrounding country show the surface deposits to reach similar thicknesses. With such meager data it has been impossible to ascertain closely the distribution of the various rock formations beneath the glacial deposits. Furthermore, up to the present time it has nowhere been necessary in this county to go to rock for water supplies and no wells now receive their supplies from the rock. If occasion should arise in the future for seeking additional water-bearing beds, it is likely that water will be found in the Silurian ("Niagara") limestone which here underlies the surface deposits. The Silurian waters are discussed on pages 42–43.

ARTESIAN AREAS.

At Talma, which lies on a gravel terrace along Tippecanoe River (Pl. IV, No. 23), there are three flowing wells and others in which the water rises nearly to the surface. These wells are all about 30 feet deep, the water coming from a gravel bed below hardpan. One bored well, 12 inches in diameter (No. 14, p. 115), for many years yielded 36 barrels of water per hour, but its flow has now diminished somewhat. In this area flows can be expected only from wells in the lowlands near the river.

Several flowing wells are reported to occur in an area 2 miles east of Lake Manitau. (Pl. IV, No. 24.) The surface is here covered by a moraine of low relief, and the artesian waters are doubtless obtained from local gravel beds in the moraine. No information could be obtained in regard to the character or depth of the wells.

In the valley of Grass Creek, 2 miles southwest of the town of the same name, there is a fine flowing well (Pl. IV, No. 25) 2 inches in diameter and 35 feet deep. The water, from a gravel bed, rises 4 feet above the surface, and the flow is about 20 gallons per minute. The yield diminishes somewhat in the dry months of the summer, showing that the head of the water is local and that the supply furnished by the rainfall on the surface is at no great distance from the well. Other flowing wells could doubtless be obtained in the neighboring lowlands.

Flowing wells have been obtained in the lower portions of the city of Rochester. (Pl. IV, No. 26.) In 1887 a deep well was bored for gas and encountered artesian waters which for a while had sufficient pressure to rise in the pipe 8 feet above the surface. It is not known certainly from what depth this flow came. In 1907 another flowing well was obtained. (No. 12, p. 115.) This well was driven 72 feet into a gravel bed, and flows about 2 gallons per minute 8 feet above the surface of the ground. Probably other flows could be obtained from this same gravel at points near by.

CITY AND VILLAGE SUPPLIES.

Rochester.—Rochester, the county seat of Fulton County, lies on the edge of an alluvial plain which extends westward from the city for several miles and north to Tippecanoe River, while southeast of the city the surface is covered with moraine deposits. The city installed a waterworks system in 1893, the water being drawn from an old mill race fed by Manitau Lake, a shallow lake lying in the low moraine a mile southeast of the city. The lake itself is surrounded by timber and open land and should afford a good city supply, for although there are a number of houses along its shores there should be little difficulty in preventing pollution of the lake water from these. The water is soft, and though not well suited for drinking it is otherwise of good quality. Unfortunately the water is not drawn directly from the lake but flows for about three-fourths of a mile through an old mill race and is drawn from this near the pumping works. Between the lake and the intake pipe the race is open, and there is every opportunity for it to become polluted. Privies and barns line the banks in town, and the drainage from these and from kitchen slops and swill barrels can enter this open ditch, which itself is foul with weeds and débris. A pipe line directly to the lake from the pumping works would greatly increase the safety of this source of supply.

The city water is pumped from the mill race to a standpipe, holding 105,000 gallons, from which it is distributed by direct pressure to 10 miles of mains. About one-fourth of the people are supplied by the city and use an average of 400,000 gallons per day. Each family has a private well for drinking water, and the city water is only used for other domestic purposes, for irrigation, and for industrial purposes.

At Rochester wells may be sunk cheaply and with great probability of success. The underlying materials are alluvial gravel and fine sands and silts. Driven wells, from 15 to 80 feet deep, are numerous and almost without exception find never-failing supplies of good water. Some few wells have gone deeper than 80 feet, but the most abundant waters are found at moderate depths. Analyses of gravel waters from this city appear on page 116 of this report. As shown by the records of many shallower wells and of one deep boring at Rochester, the succession of beds is about as follows:

Generalized section of the strata at Rochester.[a]

	Feet.
Alluvium	35
Glacial till	115
Subcarboniferous and Devonian shale	395
Devonian and Silurian limestones	525
Hudson River and Utica shales	391
Trenton.	

Kewanna.—The town of Kewanna installed public waterworks in 1907, the supply being drawn from a 10-inch drilled well, 150 feet in depth, which penetrated a gravel bed in the till and yielded a large volume of water when tested. A pneumatic pressure system operated

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 257.

by a gasoline engine is used. The water is pumped into two tanks 10 feet in diameter and 30 feet long, partly filled with air, and from the tanks the water is forced by the air pressure through the mains. At the time the town was visited (October 25, 1907) about 1⅝ miles of mains had been laid.

Before the public water system was installed the water supply of Kewanna was obtained from privately owned dug or driven wells. The dug wells range from 20 to 90 feet in depth; the average depth of the driven wells is about 90 feet, at which depth a gravel bed is generally encountered. The deeper waters are cool and pure and form an excellent source of supply.

Akron.—Akron is situated at the east end of the county near the line where the till plain to the west gives place to the more irregular topography of the moraine. There are still a few dug wells in use in this town, though driven wells, which range in depth from 40 to 60 feet, are much more common. A bed of gravel is in most wells encountered between these depths, and the water from it rises within 20 feet of the surface. There is no public water supply, as the private wells furnish an abundance of pure water.

Tiosa.—Tiosa is in the north-central portion of the county, in the hilly area of the Maxinkuckee moraine. Driven wells are used here almost altogether, and gravel, bearing abundant water, is commonly found at about 50 feet below the surface. This is known locally as the "second gravel," and the water, though hard, is pure and wholesome.

Fulton.—The town of Fulton lies in the south-central part of the county, 9 miles south of Rochester. Its water supply is drawn altogether from driven wells, all 30 feet or less in depth. They pass through a loose sandy clay into gravel at 10 to 15 feet below the surface, and most of them are driven but a short distance into this gravel. There is no sewage system in Fulton, and each dwelling has a dug privy vault. Much of the liquid matter from the outhouses and from kitchen refuse and barns sinks into the ground and becomes part of the underground water supply from which the well water is drawn. The water from these wells must, therefore, be dangerous for domestic use. Deeper wells would probably find gravel below clays, which would protect the water from pollution and yield a safe water supply.

Other communities.—In the following table is a list of other communities in Fulton County, with particulars regarding their water supply:

Other village supplies in Fulton County.

Town.	Population (1900).	Source.	Depth of wells.			Head below surface.	Character of water beds.
			Least.	Greatest.	Common.		
			Feet.	*Feet.*	*Feet.*	*Feet.*	
Athens	125	Wells, driven	35	40	35	10	Gravel.
Blue Grass	142	.....do	25	35	33	8	Do.
Bruce Lake	50	.....do	23	114	90	25	Do.
Delong	75	.....do	25	55	40	15	Do.
Disko	150	Wells, driven and dug.	12	43	35	15	Do.
Fletcher	20	Wells, driven	60	100	75	....	Gravel and sand.
Germany	17	.....do	10	30	20	6	Do.
Grass Creek	136	.....do	30	110	30, 100	....	Gravel.
Greenoak	32	.....do	40	60	50	....	Gravel and sand.
Leiters Ford	145	.....do	35	60	45	18	Gravel.
Richland Center.	50	Wells, drilled	90	195	160	....	Gravel and sand.
Showley	10	Wells, driven	50	75	65	....	Gravel.
Talma	125	Wells, driven and bored.	12	40	36	0-8	Do.
Wagoner	105	Wells, driven, bored, and dug.	15	170	100	30	Gravel or sand.

TYPICAL WELLS AND ANALYSES.

In the two following tables are given the records of typical wells in Fulton County and analyses of their waters. The numbers in the last column of each table refer to identical wells in the other table.

Records of typical wells in Fulton County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute	Analysis No.
			Ft.		*In.*	*Ft.*	*Ft.*		*Ft.*	*Galls.*	
1	E. A. Spaugy	Akron	13	Dug	....	13	......	Gravel	....	......	2
2	J. Q. Howell	Delong	51	Driven	1¼	50	−15	.....do	....	......	3
3	Town well	Fulton	13	...do	1¼	12	− 8	.....do	....	......	5
4	James Costello	2 miles W. of Grass Creek.	35	...do	1¼	35	+ 4	.....do	....	20	....
5	Public supply	Kewanna	150	Drilled	10	....	−30	.....do	....	......	....
6	Town well	.....do	83	Driven	1¼	80	−20	.....do	....	......	6
7	David Frye	Richland Center	160	Drilled	....	160	......	.....do	....	......	7
8	Court-house	Rochester	580	...do	....	580	......	Limestone	155	......	13
9	Public well	Main and Seventh streets, Rochester.	48	Driven	....	48	......	Gravel	....	......	14
10	.....do	Main and Fifth streets, Rochester.	47	...do	....	47	......	.....do	....	......	12
11	F. C. Morse	Rochester	89	...do	....	....	......	.....do	....	......	....
12	Charles Langdorf	.....do	72	...do	1¼	72	+ 8	.....do	....	2	11
13	Mrs. R. Henry	Talma	36	...do	1¼	36	+	.....do	....	20	15
14	Eschuyler Tipton	.....do	36	Bored	12	36	+	.....do	....	......	....
15	Samuel Kepler	.....do	36	Driven	1¼	36	+	.....do	....	......	....
16	E. S. Bair	1 mile SE. of Tiosa.	160	Drilled	....	160	......	.....do	....	......	....
17	H. Kestner	Tiosa	33	Driven	1½	33	......	.....do	....	......	16

Mineral analyses of waters in Fulton County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	C. F. Hoover	Akron	Well, 57 ft. by 2 in.	H. E. Barnard.	Sept., 1907	....	.....	2.0	....	76	21	...	...	0.0	228	13	10	0.2	.001	4	272	....
2	E. A. Spaugy	....do	Open well, 13 ft.	....do	..do	Gravel	.....	.3	....	87	19	...	...	.0	25	58	30	16	.001	4	564	1
3	J. Q. Howell	Delong	Driven well, 51 ft. by 1¼ in.	....do	1907	....do	.....	2.4	....	73	24	...	...	.0	289	24	10	.010	.001	4	302	2
4	Erie Railroad	Disko	Well, 12 ft.	W. S. Landon.	Mar., 1905	....	.....	1.9		99	29	16		191	....	66	9.1	.....	.....	...	....	....
5	Public well	Fulton	Driven well, 13 ft. by 1¼ in.	H. E. Barnard.	1907	Gravel	.....	.01	....	144	39	...	...	.0	352	206	58	.010	.001	2	782	3
6	....do	First National Bank, Kewanna.	Driven well, 83 ft. by 1¼ in.	....do	1907	....do	.....	.3	....	64	28	...	...	.0	261	84	4	.010	.001	2	388	6
7	David Frye	Richland Center.	Drilled well, 160 ft. by 2 in.	....do	Sept., 1907	....do	.....	.04	....	84	34	...	...	24	241	15	9	.05	.00	4	384	7
8	Public supply	Rochester	Manitau Lake	W. B. Landon.	Apr., 1905	....	0.5	1.0		57	17	2.3		.....	111	22	9.2	.....	.....	...	....	....
9	....do	....do	....do	Lake Shore and Michigan Southern Railroad.	Sept., 1904	....	.....		.36	27	14	2.9		67	....	16	1.3	.....	.....	...	....	....
10	....do	....do	Mill race at waterworks intake.	H. E. Barnard.	Sept., 1907	....	.....	.3	....	24	18	...	...	.0	121	27	2.0	.20	.001	42	218	....
11	Charles Langdorf	....do	Driven well, 72 ft. by 1¼ in.	....do	..do	Gravel	.....	2.8	....	87	20	...	...	.0	253	20	4.0	1.00	.020	4	310	12
12	Public well	Fifth and Main streets, Rochester.	Driven well, 47 ft.	....do	..do	....do	.....	.01	....	81	22	...	...	.0	204	9.9	8.0	.000	.00	13	364	10
13	Court-house well	Rochester	Drilled well, 580 ft.	W. Van Winkle	..do	Limestone	18	.6	....	72	28	21		.0	382	8.2	3.0	.44	.....	...	326	....
14	Public well	Seventh and Main streets, Rochester.	Driven well, 48 ft.	....do	..do	Gravel	17	.9	....	84	24	5.6		.0	369	13	2.0	.5	.....	...	333	9
15	Mrs. R. Henry	Talma	Driven well, 36 ft. by 1¼ in.	H. E. Barnard.	Nov., 1907	....do	.....	.2	....	82	25	...	...	.0	295	9.9	2.0	.20	.00	4	354	13
16	H. Kestner	Tiosa	Driven well, 33 ft. by 1¼ in.	....do	Aug., 1907	....do	.....	.04	....	126	35	...	...	.0	284	78	41	.10	.00	4	590	17

GRANT COUNTY.

SURFACE FEATURES AND DRAINAGE.

Grant County lies in the east-central portion of the area included in this report and extends 7 miles farther east than any other county. It is rectangular and has an area of 416 square miles. The population as shown by the census of 1900 was 54,693, or 131 persons to the square mile. This large population is due both to the excellence of the farming lands and to the boom which the eastern half of the county has experienced from the development of the natural gas and oil fields.

With the exception of the Mississinewa River valley the whole of Grant County consists of uplands. West of this river the surface is a plain of very slight relief. Its character is somewhat undulating, but there are no pronounced prominences, and the valleys are all shallow. The plain is nowhere 100 feet above the river. There are also plains east of the river in the southeast corner of the county and in the northeast corner (Pl. I). East of Mississinewa River, and roughly parallel with it, is a well-defined moraine ridge which lies on top of the till beds. It is nowhere more than 50 feet thick, but its ridgelike form and its irregular surface distinguishes it from the surrounding plains of till.

In the uplands the form of the surface has no relation to that of the underlying rock. All the inequalities of the rock surface have been covered by a filling of glacial deposits, and the rock outcrops at only a few points in the bottom of the Mississinewa Valley.

The largest and only important stream of the county is Mississinewa River, which crosses the county from southeast to northwest to join the Wabash near Peru. Its valley, though shallow, is well defined. At Marion the stream flows about 50 feet below the level of the surrounding uplands, and at the north edge of the county the valley is somewhat less than 75 feet deep. The ledges of limestone which outcrop below Marion have retarded the deepening of the valley above them. The Mississinewa basin is rather narrow in Grant County. Pipe and Wild Cat creeks drain the western part of the county and tributaries of Salamonie River, the northeast portion,

There are no lakes of importance in Grant County, for although lakes are common in moraines in general the moraine here is of low relief and is so close to the Mississinewa Valley that any lakes which may have existed have been long since drained by the natural deepening of their outlets.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

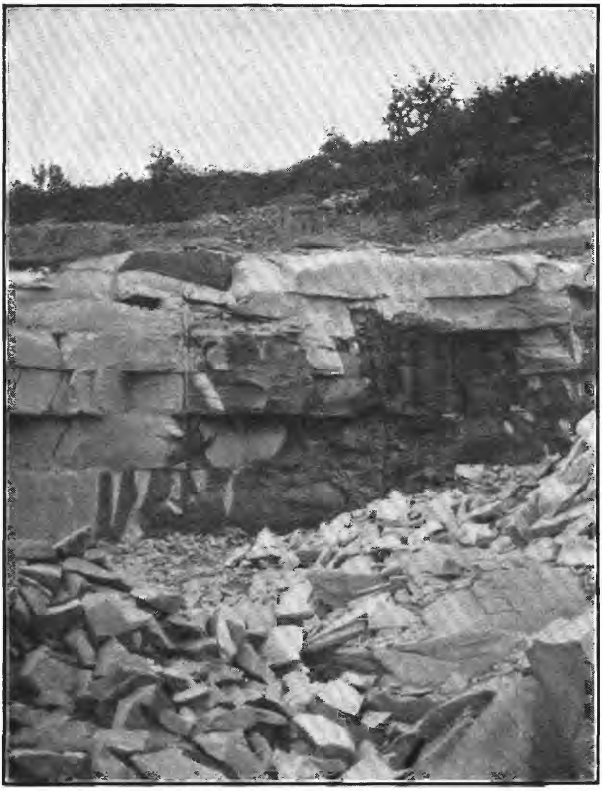
Much information in regard to the thickness of the surface deposits in the county has been obtained from the numerous borings for oil and gas. The rock surface, before it was covered by glacial ice, was crossed by streams which had cut valleys over 300 feet into the rock, but the glacial deposits filled these up and leveled the county over. The old preglacial valleys have had no influence upon the courses of the present streams, but in places cause a great thickening in the unconsolidated surface materials above them.

The alluvial deposits of this county all occur along the bottoms of the larger valleys, more especially that of Mississinewa River, where they have a width of one-fourth to one-half mile. The thickness of the alluvium varies in different portions of the valley. Below Marion the valley has been lowered to the "Niagara" limestone, which outcrops along the stream bed, and here the alluvium, where present at all, forms only a thin veneer over the rock in the river flat. South of Marion the rock surface dips downward and the alluvium is thicker. The smaller stream valleys all have alluvial deposits varying in amount with the size and development of the valley.

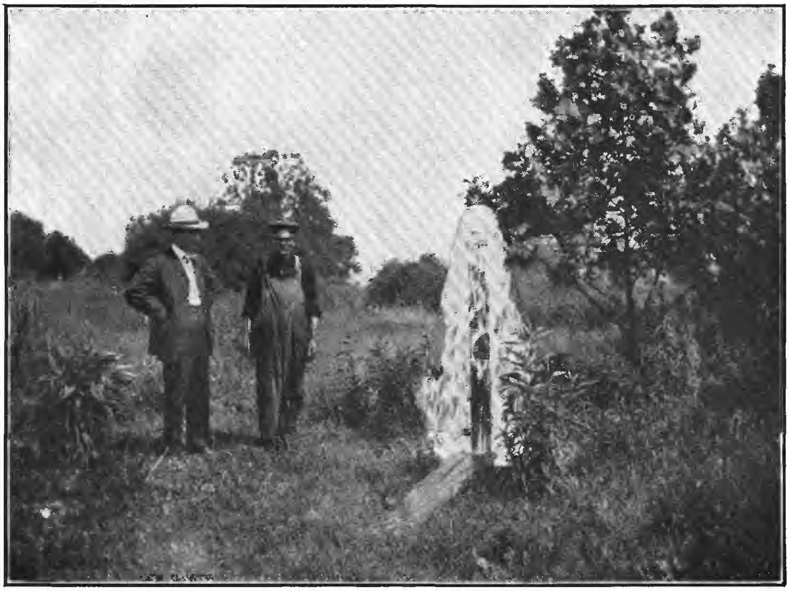
An abundant supply of excellent water can be procured almost anywhere in the alluvium, and it is generally not necessary to sink deep wells in order to reach the waters. In the first bottom the waters are found slightly above the level of the stream, but in the higher gravel terraces the water table is farther from the surface.

Grant County contains a single moraine belt which lies east of and parallel with Mississinewa River (Pl. I). It is 5 or 6 miles wide and continuous, though nowhere of great prominence. The crest of the moraine stands about 50 feet above the adjoining till plains. Throughout the morainal belt most of the wells are drilled, and extend to gravel beds at 70 to 100 feet below the surface. As the moraine is for the most part not more than 50 feet thick it is evident that the supply from these wells is from the till below the moraine. Locally driven wells encounter gravel at 50 feet or less below the surface, and some dug wells in the morainal clay obtain small amounts of water.

Over three-quarters of Grant County is covered by a mantle of till which conceals the rock and varies in thickness in different parts of the county up to 400 feet. This variation is due almost altogether to the irregularities of the underlying rock surface, for the till itself forms a remarkably flat, featureless upland. One of the most prominent features of the rock surface, although there is no trace of its existence in the present surface topography, is a great canyon-like



A. WATER OOZING FROM BEDDING PLANES OF LIMESTONE.



B. FLOWING WELL AT DANVILLE WATERWORKS.

valley, 200 to 300 feet deep, which crosses the northeast corner of the county. Mr. J. A. Bownocker[a] has traced this valley from Ohio River up the valley of the Little Miami to New Carlisle, Ohio, and thence west and northwest into Grant County. Additional well records show it to continue northwest beyond La Fountaine, and it doubtless extends still farther northwest. One well in Miami County, about 4 miles north of Peru, is reported to have penetrated over 300 feet of drift without entering rock, and the suggestion is made that the well may be in a continuation of this same deep preglacial valley (Pl. II). In the Mississinewa Valley below Marion the rock has been exposed by stream cutting, and in the southwest corner of the county, north of Rigdon, it rises within 6 feet of the surface. Thus the thickness of the till is seen to vary within wide limits in different parts of the county. Plate II shows the depth to rock throughout the area.

The till is in some places very clayey and lacking in beds of gravel and sand. When this condition prevails the supply of water is small and has to be obtained from dug wells, most of which yield only enough water for domestic purposes. Where the till is thick deep wells almost everywhere encounter good supplies in gravel, and in that part of the county where the till is thin wells are drilled into the rock.

CONSOLIDATED MATERIALS.

The first rock formation which wells enter below the surface deposits is the "Niagara" limestone. This is true of all deep wells except a few sunk in the deep preglacial valley in the northeast part of the county, where the preglacial stream had cut its canyon through the limestone to the underlying shale. The depth to the "Niagara" varies greatly, as shown in Plate II. The available water in the "Niagara" limestone all occurs in the joints and bedding planes, which have in many places been dissolved out by the circulating waters to form continuous channels. Plate VI, *A*, illustrates the manner in which the water follows the bedding planes. In the deeper valleys and in those areas where this formation comes close to the surface, the "Niagara" has become an important source of water supply. Wells drilled into the limestone are sure to encounter openings from which water can be obtained. It is because of this abundance of rock water that all gas and oil wells are cased below this formation to keep its waters from mingling with the oil and gas from below. In the deeper valleys the waters in many wells flow a few feet above the surface, and in the higher lands they rise to about the same level but will not flow.

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[a] Special Paper No. 3, Ohio State Acad. Sci., 1900.

ARTESIAN AREAS.

Artesian area 27 (Pl. IV) includes all of the lowlands along the valley of the Mississinewa and extends somewhat up the valleys of its larger tributaries. Most of the flowing waters are from the "Niagara" limestone, but some are from gravel. By far the greater number of the wells were originally drilled for oil or gas. In drilling such wells a pipe, 8 or 10 inches in diameter, is driven down to the rock. When the boring reaches the bottom of the "Niagara" its size is commonly reduced to 6 inches, and a pipe, the casing, is put down to the bottom of the rock to keep the rock waters out of the well. If oil or gas is found, the casing is left in and the flowing waters emerge between the drive pipe and the casing. If the well is unsuccessful or becomes exhausted, the pipes are generally "pulled." A state law requires that all "pulled" wells be plugged at the base of the limestone to prevent the mingling of waters from different depths. When both casing and drive pipe are pulled the surface deposits cave in and fill the hole. Many flowing wells in this area have been destroyed in this way, as the pipes are the property of the company which drilled the well. In some places the owner of the land upon which the well is located buys the drive pipe from the company and keeps the well for its water supply. Most of the present flows have been retained in this way.

In some localities wells supplied by water from the "Niagara" limestone are in "sympathy"—that is, if one well of a group is drawn upon heavily it may affect the head of other wells for some distance around. This underground connection is in many places very marked. A striking illustration of this phenomenon is shown in the "sympathy" between the flowing well at Matter Park and the wells of the Marion Paper Company, one-half mile southeast. For six days each week the wells of the paper company are pumped heavily, and during this time the Matter Park well ceases to flow, and the water is raised by a small pitcher pump (Pl. VII, *B*). On Sunday the paper mill is idle, and the park well yields a strong flow (Pl. VII, *A*).

In addition to the flowing waters from the "Niagara," many good flows have been obtained in Marion from gravel beds in the till. The wells range from 40 to 150 feet in depth and the artesian waters are confined in gravel beds below pebbly till. The flows are small, only one well having been observed which flowed more than 2 gallons per minute. The temperature of the gravel waters is 52° F.

Many deep borings for gas in the valley of Pipe Creek above and below Mier have obtained flows of artesian water from the "Niagara" limestone. (Pl. IV, No. 28.) This valley has here about the same elevation as the valley of the Mississinewa between Marion and Gas City. The head of the flowing waters comes from the higher portions

A. FLOWING WELL AT MATTER PARK, NEAR MARION, IND.

B. WELL AT MATTER PARK WHEN WELLS AT PAPER MILL, ONE-HALF MILE AWAY, ARE BEING PUMPED.

of the limestone to the south, and the impervious till covering prevents the natural escape of the waters. Most of the flowing wells of Pipe Creek valley have been destroyed by the pulling of the pipes.

CITY AND VILLAGE SUPPLIES.

Marion.—The public supply of Marion is drawn from drilled wells of various depths. There are 17 wells, of which 14 are now in use, and all are said to flow when not pumped. One well was estimated to flow 50,000 gallons per day when it was drilled, but the head gradually became lower as more wells were sunk. A few wells get water at a depth of 68 feet from a gravel bed below till, but most of the water is obtained from the "Niagara" limestone, which is encountered at 80 to 150 feet below the surface. The water system is owned and operated by the city, and the water is pumped from the wells by an air lift into three reservoirs of 200,000, 750,000, and 2,000,000 gallons capacity. From the reservoirs it is pumped by steam into the mains. About 2,500,000 gallons per day is needed to supply 75 per cent of the population of the city. Analyses of this water are given on page 126.

The conditions for obtaining wells in Marion are so diverse that no general statement can be made to cover them all. The rock is exposed in parts of the river bed, and lies at various depths elsewhere, up to 200 feet in the higher parts of town, the surface deposits consisting of blue till, sand, and gravel. Where the rock comes close to the surface most of the wells are drilled and secure their supply from limestone. If the surface deposits are deep, dug or driven wells are more common. The character of the surface deposits and the depth to rock in different parts of the city are given by Bowman[a] in a paper issued by this Survey. Most wells sunk into either the surface deposits or the rock are successful, and only a few wells out of the many hundreds which have been drilled into the limestone have failed to procure abundant water. The following is a record of a successful gas well in this city:[b]

Log of gas well at Marion.

	Feet.
Drift	70
Niagara limestone	280
Hudson River and Utica	528
Trenton limestone	22
	900

The ground waters in the vicinity of Marion have been considerably polluted by the salty and oily waters from oil wells. The conditions and suggestions for a remedy are set forth in Bowman's paper.

[a] Bowman, Isaiah, and Sackett, R. L., The disposal of strawboard and oil-well wastes: Water-Supply Paper U. S. Geol. Survey No. 113, 1905, pp. 36–42.

[b] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 251.

Gas City.—The Gas City waterworks, built in 1898, are owned by the city, and the water is drawn from three wells located on the Mississinewa River flat, at the west edge of town. The deepest well is an old gas well, which has been plugged at a depth of 325 feet and draws its supply from the "Niagara" limestone. Another well also secures limestone water at 200 feet below the surface, while the third penetrated 28 feet into the alluvial gravel. The water from all three wells is raised by air pressure to a reservoir, from which it is forced by steam pumps directly into the mains. About 500 taps are in use and 60 per cent of the people of the city are supplied by this system.

The sanitary condition of the water from all three wells is good, as they are located at some distance from the thickly settled district. There are only three houses within one-fourth mile of the wells.

Many privately owned drilled and dug wells are in use in Gas City, and over one-third of the people rely on these wells for their water supply. The wells range from 35 to 300 feet in depth, and though some find sufficient water in the surface deposits, others go to rock, which lies from 150 to 180 feet below the surface. The town is situated on a till plain and all the well water is hard. There are no springs or flowing wells.

Fairmount.—The Fairmount public waterworks were installed in 1894 and are owned and operated by the city. The supply is drawn from six wells drilled into the limestone which here lies 20 to 40 feet below the surface, and waters under artesian pressure rise to within a few feet of the level of the ground. No reservoir or standpipe is used, and the water is pumped directly from the wells into the mains. About 400 taps are supplied by 4 miles of 10, 8, 6, and 4 inch mains, and an average of 300,000 gallons of water per day is used to supply 65 per cent of the people of the town. The water furnished is good and is the best available. Analysis (No. 2, p. 127) shows it to be rather high in chlorine and sulphates, possibly from the salt waters from neighboring oil or gas borings, but these minerals do not occur in objectionable amounts.

Most of the privately owned wells in Fairmount are drilled, but a few dug wells are still in use. The drilled wells range from 20 to 90 feet in depth, though the greater number are about 40 feet deep. The best supplies of water are from rock, which is reached at depths of 20 to 40 feet.

Jonesboro.—The Jonesboro public supply, owned by Trowbridge & Niver, is drawn from a dug well, 25 feet deep and 15 feet in diameter, sunk into the gravels in the valley of Back Creek. Direct pressure is used and an average of about 225,000 gallons of water a day is needed to supply 150 services.

The well is at the base of a steep slope and is subject to surface pollution. At times the water is noticeably salty, doubtless from the salt waters from oil wells farther up the creek. At times, too, a reddish deposit collects in the mains in quantities sufficient to color the water. This could be remedied by frequent and thorough flushings of the mains.

A much safer supply of water could here be obtained from the limestone by drilled wells. All danger from surface contamination would be avoided and the water, though harder, would be better for domestic purposes. An analysis of the city water is given on page 127.

In Jonesboro there are many private wells which range from 15 to 60, but are commonly 40 feet in depth. They are dug or drilled and are supplied by waters from the gravel beds in the till. The rock here lies from 130 to 160 feet below the surface and therefore is too deep to be readily accessible for ordinary wells.

Upland.—In 1892 the Upland Water Works Company, a private corporation, installed a public supply for Upland, the water being drawn from a single well, drilled through 192 feet of till into limestone. There are 3,600 feet of city mains, 4, 3, and 2 inches in diameter, into which the water is forced by direct pressure from steam pumps. One hundred and forty taps supply water to about 60 per cent of the inhabitants, and about 40,000 gallons of water are used per day. The city water has a slight taste of oil, doubtless due to the imperfect plugging of abandoned oil or gas wells in the vicinity. Although this oily taste is somewhat objectionable, the water is not known to be unhealthful.

A number of dug or driven wells are still in use in Upland. The dug wells are 15 to 25 feet deep, and all fail in dry seasons, but the driven wells are more successful. A bed of gravel encountered at 110 feet supplies unfailing waters.

Vanburen.—The public waterworks of Vanburen are owned by E. S. Sutton, and a single well, drilled in 1903, furnishes the supply. This well, 8 inches in diameter, was sunk 140 feet through surface deposits and 35 feet into limestone before water was struck. At 195 feet the well was shot with 12 quarts of nitroglycerine to fracture the rock and increase the supply of water. The well now furnishes enough water for the present consumers, but is pumped to about its full capacity. The water is lifted by a steam pump to a standpipe 65 feet high, whose capacity is 400 barrels, and from this it is distributed by gravity. There are 1⅛ miles of mains and 130 consumers, who use about 2,000 barrels of water a day. The water is hard and has a slight taste of iron, but is wholesome. An analysis of it is No. 23 (p. 128).

Vanburen is situated on a gently undulating till plain. Most of the private wells are driven from 60 to 80 feet deep, and procure plenty of water in gravel. There are some dug wells, but many of these fail in times of drouth.

National Military Home.—The National Military Home at Marion is supplied with water from 14 drilled wells, of which 12 are 87 feet deep and reach a water-bearing bed of gravel. Two other wells in limestone, of which one is 340 and the other 500 feet deep, are not used at present, as the gravel wells furnish sufficient water. The water is pumped to a standpipe 125 feet high, which holds 240,000 gallons, and the pressure is furnished by gravity from the standpipe. There are 3 miles of mains and 1,900 people are supplied, the average amount pumped daily being 500,000 gallons. The water is good, though it tastes strongly of hydrogen sulphide and iron.

Matthews.—Matthews has no public supply. Many privately owned drilled, driven, or dug wells are in use. The dug wells, which are 15 to 30 feet deep, are apt to fail in dry seasons and many have been abandoned. The driven wells are commonly about 60 feet deep and furnish good supplies of gravel water. An analysis of water from a gravel well in Matthews is No. 19 (p. 128). Most of the wells are drilled into the rock, which is here entered at 85 to 113 feet below the surface, although along the river bottoms some borings have reached rock within 35 feet of the surface. The rock wells yield abundant waters of much the same character as that from the limestone in other parts of the county.

Swayzee.—Swayzee is supplied by a large number of private wells, most of which are drilled into the limestone. The limestone lies from 18 to 41 feet below the surface, and abundant water is almost always found in it. The average rock well is about 100 feet deep and 2 inches in diameter. A few dug wells are still in use, and obtain water from the till above the rock, but there is always danger that the water from such wells will become polluted, especially in towns, and they should, wherever possible, be abandoned in favor of the deeper, tubular wells.

Other communities.—A list of other villages in Grant County, with particulars regarding their water supply, is given in the following table:

Other village supplies in Grant County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head above (+) or below (−) surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Arcana	50	Wells, drilled and dug	20	120	90	220	−40	Gravel.
Farrville	28	Wells, drilled	25	120	100	95		Limestone and gravel.
Fowlerton	53	Wells, dug and drilled	15	200	100	170-200		Do.
Hackleman	82	.....do	20	40	30	20	−10	Limestone.
Hanfield	100	.....do	10	200	15	400		Gravel, till, and limestone.
Herbst	100	.....do	10	120	10	18	− 8	Gravel and limestone.
Jadden	35	.....do	14	100	85	300	−35	Gravel.
Jalapa	90	.....do	40	60	50	30	−5 to + 3	Limestone and gravel.

Other village supplies in Grant County—Continued.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head above (+) or below (−) surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Landess	194	Wells, dug and drilled	10	150	18	140	....	Gravel and limestone.
Mier	219	.....do	15	104	60	13-26	−20	Do.
Normal	50	.....do	18	34	18	98	−12	Gravel.
Point Isabel	169	.....do	20	125	60	40	−12	Clay and limestone.
Puckett	11	Wells, drilled	90	100	90	185	−60	Gravel.
Radley	30	.....do	20	45	35	20	....	Limestone.
Rigdon	178	Wells, dug and drilled	20	50	30	30-40	−8 to −20	Gravel and limestone.
Roseburg	90	Wells, dug, driven, and drilled.	10	50	......	....	− 5	Do.
Sims	160	Wells, drilled and dug	10	105	60	35-60	−15	Do.
Sweetsers	50	.....do	15	102	60	20-45	−10	Till and limestone.

TYPICAL WELLS AND ANALYSES.

The two following tables contain detailed information regarding typical wells in Grant County and analyses of their waters. The number in the last column in each table refers to identical wells in the other table.

Records of typical wells in Grant County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Temperature.	Analysis No.
			Feet.		*In.*	*Feet.*	*Feet.*		*Feet.*	*Galls.*	*°F.*	
1	Joshua Strange	Arcana	88	Drilled	3	88	−40	Gravel				1
2	Public supply	Fairmount	40	do	4	40		Limestone	20			2
3	do	do	90	do	6	90		do	20			
4	T. H. Snider Preserve Co.	do	166	do	6		− 8	do				
5	E. D. Fowler	Fowlerton	103	do				Sand and gravel.				3
6	Public supply	Gas City	325	do	8			Limestone				4
7	U. S. Glass Co.	do	185	do	6	180	−30	do	160			
8	American Steel and Tin Plate Co.	do	400	do	8	200	−80	do	190			
9	Sarah Baker	Hanfield	200	do				Gravel				
10	Joseph Lewis	Herbst	11	Dug				Quicksand				6
11	Wm. R. Brock	Jalapa	62	Drilled	8	62	+ 5	Limestone	9			
12	C. P. Marks	do	25	Dug		25		Gravel				7
13	Public supply	Jonesboro	25	do			− 3	do				8
14	German Baptist Church	Landess	24	do		24		do				9
15	Public supply	Marion	120–250	Drilled	8	120–150	+ 8	Limestone	80–150			10, 12, 15
16	Matter Park well	do		do	8		+ 2	do	2	500		16
17	Fred H. Weir	do	42	Driven	2	42	+20	Gravel		1⅓	52	17
18	Indiana Brewing Association	do	100	Drilled	3			do				
19	do	do	372	do	8			Limestone				
20	Marion Paper Co.	do	150	do	8		+	do	4			
21	do	do	287	do	10		+	do	4			
22	Mrs. David Overman	do		do	8		+ 3	do	225	½	52	18
23	Zirkle Bros.	Matthews	65	do	3		−40	Sand				19
24	Mrs. M. Johns	Point Isabel	125	do	4			Limestone	40			20
25	Mrs. J. W. McLain	Sims	105	do	2			do	38			
26	Wm. Larkens	Swayzee	98	do	3			do	36			21
27	J. H. Surface	Sweetsers	80	do	4	80		do	40			22
28	Public supply	Upland	240	do	6	226	−80	do	198			
29	E. S. Sutton	Vanburen	195	do	8	175	−15	do	140			23
30	Mrs. John Heffner	do	65	do	2		−	Gravel				24

Mineral analyses of waters in Grant County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	Joshua Strange	Arcana	Drilled well, 88 ft. by 3 in.	H. E. Barnard.	Oct., 1907	Limestone	...	0.40	...	90	45	...	...	0.0	263	642(?)	8	0.30	0.001	0	730	1
2	Public supply	Fairmount	Drilled wells, 40 to 90 ft.	do	do	do	...	.0	...	124	41	...	...	.0	352	290	68	.05	.00	2	730	2
3	E. D. Fowler	Fowlerton	Drilled well, 103 ft.	do	Nov., 1907	Gravel	...	1.2	...	61	28	...	...	.0	322	34	2.0	.00	.050	4	448	5
4	Public supply	Gas City	Drilled well, 325+ ft.	do	Oct., 1907	Limestone	...	.08	...	38	30	...	...	.0	305	84	6.0	.20	.004	0	558	6
5	...	Hanfield, Ind	10 oil wells	do	Nov., 1907	...	...	.4	...	615	370	...	...	.0	428	392	7,640	.00	.001	33	17,604	...
6	Joseph Lewis	Herbst	Open well, 11 ft.	do	Oct., 1907	Sand	...	.3	...	157	37	...	...	.0	286	248	77	.05	.00	4	662	10
7	C. P. Marks	Jalapa	Open well, 25 ft.	do	do	Gravel	...	.01	...	94	27	...	...	.0	268	154	40	3.0	.00	0.0	576	12
8	Public supply	Jonesboro	Open well, 25 ft. by 15 ft.	do	do	do	...	.80	...	40	37	...	...	.0	311	128	5	.00	.00	2	464	13
9	German Baptist Church.	Landess	Open well, 24 ft.	do	Nov., 1907	do	...	.20	...	95	41	...	...	.0	290	82	7	.00	.00	4	542	14
10	Old public supply	Marion	Wells, 68 ft	E. T. Cox	1877	...	28	12	3.2	114	38	1.8	0.32	217	...	47	4.1	...	...	...	...	...
11	Pennsylvania R. R. Co.	do	Wells	Pennsylvania R. R.	...	...	14	.12		72	34	8.7		191	...	4.2	10	...	...	...	364	...
12	Old public supply	do	Drilled wells	(a)	1897	Gravel	...	Tr.	...	123	31	...	...	...	...	26	12	.00	...	...	432	...
13	do	do	Wells in gravel	(a)	1897	do	...	Tr.	...	169	49	...	...	...	...	127	37	.00	...	...	830	...
14	do	do	Drilled well in rock.	(a)	1906	Limestone	...	Tr.	...	107	38	...	...	...	...	29	71	.00	...	...	535	...
15	Public supply	do	Drilled well, 106 ft. by 8 in.	R. B. Dole	Sept., 1907	do	27	.97	...	69	35	28		.0	322	36	24	0.4	...	...	371	...
16	Matter Park Well	do	Drilled old gas well.	do	do	do	21	1.5	...	79	43	55		.0	321	158	28	1.3	...	...	569	16
17	F. H. Weir	do	Driven well, 42 ft. by 8 in.	H. E. Barnard.	Nov., 1907	Gravel	...	1.0	...	102	40	...	...	.0	390	166	6.0	.10	.00	4	548	17

a First Scientific Station for the Art of Brewing, New York City.

Mineral analyses of waters in Grant County—Continued.

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na.)	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle, (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
18	Mrs. David Overman.	Marion	Drilled well, 225 ft.	H. E. Barnard.	Nov., 1907	Limestone	...	1.4	....	70	29	....	....	0.0	320	35	8.0	0.30	0.00	9	418	22
19	Zirkle Bros.	Matthews	Drilled well, 65 ft. by 3 in.	do	do	Sand	...	1.0	....	86	31	....	....	.0	362	45	5.0	.10	.00	6	504	23
20	Mrs. M. Johns	Point Isabel	Drilled well, 125 ft. by 4 in.	do	do	Limestone	...	0.6	....	59	30	....	....	.0	306	138	3.0	.05	.00	2	492	24
21	Wm. Larkens	Swayzee	Drilled well, 98 ft. by 3 in.	do	Oct., 1907	do	...	.4	....	124	38	....	....	.0	326	373	8.0	.15	.01	2	448	26
22	J. H. Surface	Sweetsers	Drilled well, 80 ft. by 4 in.	do	do	do	...	.1	....	71	32	....	....	.0	335	44	8.0	.15	.00	0.0	458	27
23	E. S. Sutton	Vanburen	Drilled well 195 ft. by 8 in.[a]	do	Nov., 1907	do	...	2.0	....	126	29	....	....	.0	335	180	5.0	.10	.00	9	742	29
24	Mrs. J. Heffner	do	Drilled well, 65 ft. by 2 in.	do	do	Gravel	...	2.4	....	111	30	....	....	.0	349	167	6.0	.10	.00	9	622	30

[a] Water from 175 feet.

HAMILTON COUNTY.

SURFACE FEATURES AND DRAINAGE.

Hamilton County is in the southern part of the area under discussion, in the middle north-south tier of counties and in the second tier from the south edge. The county is square, measuring about 20 miles on each side, and had in 1900 a population of 29,914, or an average of 74 people to the square mile.

The county has a total range in elevation of somewhat over 150 feet. The lowest point is at the edge of Marion County, in the White River valley, and the highest portion is in the northwest corner, where the surface lies over 900 feet above sea level. The surface is for the most part a high till plain which has been more or less dissected by streams. Only two streams are large enough to have excavated well-developed valleys. (See Pl. I.) A low, broad belt of moraine runs north and south along the west edge of the county, and in places resembles closely in topography the surrounding till plains.

The surface forms of the entire county are determined by the glacial deposits and by the streams, for the rock is everywhere so deeply covered that its irregular surface has no influence upon the present topography.

White River controls the drainage of the county, and entering it from the east flows west and south to cross the south county line at about the middle. The valley is well developed and the stream is bordered by alluvial bottom lands less than a mile in width.

The most important tributary of the White is Cicero Creek, which flows southward to enter the White below Noblesville. Over the remainder of the county there is a network of small streams tributary to the above two, but their valleys are shallow and small.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

The search for reliable water-producing beds has led to the sinking of many wells throughout the county, and borings of another class, drilled in the attempt to discover oil and gas, have given much information in regard to the thickness of the surface deposits. There is scarcely a community in which one or two wells have not penetrated to rock. The records of borings show a wide range in the thickness of the surface deposits, and the range is not uncommonly great in short distances. An attempt to show the depth to rock has been made in Plate II, though the results can only be considered approximate, as the records are incomplete. It is certain, however, that before the advance of the glaciers over the county the surface was more rugged than at present, and there were deep valleys which have now been filled.

The most extensive alluvial deposits of the county lie along the sides of White River in the bottom of the broad valley. They consist for the most part of flood-plain or first-bottom lands which are overflowed by the stream in flood seasons. Above the flood plain there are occasional benches of alluvium, forming terraces below the river bluffs—all that remains of an earlier flood plain. The valley of Cicero Creek also contains less extensive beds of alluvium, as do some of the other still smaller valleys. The deposits increase in importance as the valleys attain greater size. Water is everywhere abundant in alluvium, and many wells are supplied from it. The looseness of the materials permits driven wells to be easily obtained, and the open gravels allow a ready circulation of the water. Where not exposed to pollution the waters are very desirable, and most of the wells are unfailing.

The morainal part of the county, all of which lies along its west edge (Pl. I), is of low relief and contrasts mildly with the topography of the till plain. The moraine waters are contained both in the clay and in the gravel beds. There are many dug wells which penetrate but a little way below the level of the water table and which fail in particularly dry seasons. The drilled and driven wells, which on the moraines go through the morainal deposits into the till below, are much safer from contamination than the open wells and obtain a more reliable water supply.

The till plains comprise more than three-fourths of the surface of the county, and in this area the depth to rock averages much more than 100 feet. In addition to its surface occurrence (Pl. I) the till underlies both the moraines and the alluvium except in the few places in the valleys of White River and Fall Creek where the alluvium lies directly upon the rock. As a result of the wide distribution of the till at the surface and of its great thickness, more wells in this county draw their water from the till than from all other sources. Open or dug wells, into which the water seeps from all levels, are the most common type. These do not generally enter any distinct water bed or encounter any well-defined water channels, and the water seeps slowly out of the clay below the water table. Most dug wells have been used for many years, and few new ones have been sunk during the last decade. The people have now learned that it is possible, by sinking deeper driven or drilled wells, to obtain more permanent and safer waters from the occasional gravel beds in the till, and the use of driven or drilled wells is constantly increasing.

CONSOLIDATED MATERIALS.

The approximate distribution of the various formations as they lie below the surface deposits is shown in Plate III. In the east half of the county the "Niagara" limestone is the first rock formation encountered, and although the surface of the till plain is very uniform, the depth to rock varies greatly from place to place. The rock surface was first carved by the preglacial streams, then modified by the erosion of the glacial ice, and finally leveled over by the glacial deposits.

As determined by well borings, the "Niagara" is here of the same character as it is farther north. It outcrops at only a few points in the valley of White River above and below Strawtown and in the valley of Fall Creek. In the White River and Fall Creek valleys and in the neighborhood of Clarksville and Fishers Switch this limestone is close enough to the surface to be available for its water supply. Many wells draw upon the rock waters, the joints and bedding planes yielding abundant water of good quality, as it is protected from pollution from above by the thick mantle of drift.

The Devonian beds that lie immediately below the till in the west half of the county nowhere outcrop at the surface, but are known to consist largely of limestones, with the New Albany shale probably occurring in the extreme southwest corner. The same formations outcrop in Carroll County, and are described with the rocks of that county. At Westfield and Carmel and in the surrounding country many wells that extend into the Devonian limestones obtain abundant waters, which are in many places under artesian pressure, especially in Clay Township. There is but little possibility that rock waters from such depths could contain harmful organic matter, and they have always been considered a most satisfactory supply.

ARTESIAN AREAS.

There are seven separate areas in the county in which flowing wells occur. These are outlined and numbered on Plate IV, and are described separately below.

Clay Township, in the southwest corner of the county, has many fine flowing wells. (Pl. IV, No. 29.) The area in which they occur is in the lowlands bordering Williams Creek and its tributaries. In this neighborhood the Devonian limestones lie about 140 feet below the surface, and the flowing waters found in the upper part of the limestone or in sand or gravel immediately above it will in many wells rise 7 or 8 feet above the surface. All flows are found in the lowlands. On higher ground the same waters occur in the rock, but the head is not sufficient to give flowing wells. A moraine extends along the west edge of the county, and the wells penetrate much gravel before rock is reached. The head of the flowing waters is probably in the higher land of this moraine, the waters passing through open gravel beds into the limestone, while the head of the water is maintained by the impervious beds of clayey drift.

Flowing wells occur in the creek valley, 5 miles west of Cicero. (Pl. IV, No. 30.) The artesian water, which has a temperature of $51\frac{1}{2}°$ to 52° F., is from the "Niagara" limestone, which here lies below 150 to 170 feet of clayey till. Doubtless other flowing wells could be obtained along this creek bottom by drilling into the limestone.

In Westfield the shallow flowing wells, which are located in the lower parts of the town (Pl. IV, No. 31), are all driven into gravel to depths of 14 to 35 feet, and the flows are weak, usually less than 1 gallon a minute. The temperature of the water in one well was found to be 54° F. The waters are protected above by clay, and should be free from pollution. The source of the waters is probably in the slightly higher moraine to the west.

In flowing-well area No. 32 (Pl. IV), which lies along the valley of Stony Creek in the east part of the county, the artesian waters are from the "Niagara" limestone, which is here covered by 40 feet of pebbly till. It was necessary to drill 75 feet into the rock in one well before large enough openings were encountered to give a good flow.

A few flowing wells have been obtained along the valley of White River and its larger tributaries in White River Township (Pl. IV, No. 33), the strongest of which, an abandoned gas well, belongs to E. P. Whisman, and is 1½ miles north and 1 mile east of Strawtown. The water is from the "Niagara" limestone, and will rise 9 feet above the surface. The record of this well, so far as known, is No. 14 in the table on page 136. Its strong pressure indicates that other wells in the lowlands in this section of the county should also obtain flows.

Two miles west of Arcadia there are flowing wells in the lowlands. (Pl. IV, No. 34.) One is a driven well, 61 feet deep, and another a dug well, 16 feet deep, and both are supplied from gravel or sand beds below the till. Another well, on the farm of E. A. Hollett, enters gravel at 65 feet and is reported to have a strong flow of water, which will rise 14 feet above the surface. The conditions of flow are local and can not be expected to obtain for more than a short distance up and down stream from the above wells. Records of two of these wells are Nos. 3 and 4 in the table on page 136.

In the valley of Duck Creek, near Aroma, are two flowing wells (Pl. IV, No. 35), one of which (No. 5, p. 136) was drilled for water to a depth of 80 feet and is reported to have gone into the rock. The other is an abandoned gas well and its flow certainly comes from the "Niagara" limestone.

Several flowing wells have been obtained in the lowlands west of Cicero. (Pl. IV, No. 36.) In these wells, all of which are deep borings drilled for oil or gas, the flows come from the "Niagara" limestone, which is first entered at about 90 feet below the surface, though the flowing waters are encountered at depths of 300 to 500 feet. The largest flow is about 60 gallons per minute. (See No. 15, p. 136.)

CITY AND VILLAGE SUPPLIES.

Noblesville.—The Noblesville public waterworks, owned by the Noblesville Water and Light Company, were first operated in 1892, and the water is drawn from drilled wells, of which the company owns 17. Of the two that penetrate limestone, one was drilled for gas but is now used for its water supply, while the other, 390 feet deep, entered rock at about 80 feet. The two rock wells will yield 750,000 gallons per day. Of the other 15 wells, of which only 9 are now in use, all enter gravel at 60 to 85 feet. The record of the materials penetrated by one of these wells is as follows:

Log of well drilled for Noblesville Water and Light Company.

	Feet.
Soil and clay	4½
Dry gravel	13
Blue clay (hardpan)	20
Water, sand, and gravel	9
Yellow and blue hardpan	6
Water gravel	8
Fine packed sand	12½
	73

Analyses of the water from the gravel wells in 1906 and early in 1907 showed indications of surface pollution. Steps have now been taken to prevent the entrance of surface drainage by cementing around the joints of the pipes.

The rock wells are pumped by an air lift into a 50,000-gallon reservoir, and the water from this reservoir and from the gravel wells is pumped into the mains by direct pressure. There are 750 taps supplied by 13 miles of mains, and more than one-third of the people use this supply. The average daily consumption of water from this source is 480,000 gallons.

About 65 per cent of the people in Noblesville are supplied from privately owned wells, the greater number of which are drilled. The wells have considerable range in depth, determined in part by the depth to the rock, which is from 33 to 175 feet below the surface. Most wells are in gravel, though some obtain rock waters. At the Model mill a well was drilled through the following materials:

Log of well at Model mill, Noblesville.

	Feet.
Gravel	44
Clay	18
Sand	3
Clay	4
Sand	8
Coarse water-bearing gravel	7
Fine water-bearing sand	7
Clay	4
Sand	8
Limestone	6
	108

A deep gas well, the Banner well, had the following section:[a]

Log of Banner gas well, Noblesville.

	Feet.
Drift	73
Niagara limestone and shale	265
Clinton (?) limestone	30
Hudson River and Utica	476
Trenton limestone	9
	853

Sheridan.—In Sheridan the waterworks system, owned by G. H. Farmer, supplies about 25 services. The water is drawn from two driven wells, 150 and 135 feet deep, and pumped to a tank 65 feet high, which has a capacity of 300 barrels. From the tank it is distributed by gravity. About 300 barrels per day are used. Both wells are driven to gravel beds, and the water is fairly soft.

Most of the wells in Sheridan are driven or dug. The dug wells which procure water from a gravel bed at a depth of 30 feet or less are unsafe and should be abandoned, for they receive surface drainage as well as gravel water and are likely to be polluted. The driven wells that enter deeper gravels are much safer. The rock here lies 200 feet beneath the surface, and the expense of sinking drilled rock wells for domestic supplies is often prohibitive.

Cicero.—At Cicero, which lies on a flat plain, the till is 160 feet thick, and few wells enter rock. The private wells, of which there are a large number, are dug and drilled and obtain water from the till and from the inclosed gravel beds. The dug wells range in depth from 10 to 40 feet, and their water is all drawn from gravel or sand beds in the till. In the lowlands along the creek there are many good springs and some flowing wells. (See Pl. IV, No. 36.)

Arcadia.—In Arcadia the wells are dug or drilled and range in depth from 10 to 212 feet. The surface deposits are here so thick that few wells reach rock, though a few enter limestone at depths of 130 to 205 feet and yield an admirable supply for most purposes. The common depth for wells is about 20 feet, and the dug wells predominate in spite of the danger from their use. The water obtained from sand and gravel is abundant and even the shallow wells seldom fail.

Atlanta.—Atlanta has no public waterworks, and private wells are relied upon for the water supply. Many shallow wells of the open or dug type and from 10 to 30 feet in depth are used, and although these supply unfailing water their sanitary condition is doubtful. The drilled wells are deeper, and as all the surface waters are cased off they draw their supply only from the well bottom, from 50 to 130 feet below ground. No rock is struck at depths less than 220

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 253.

to 300 feet, and there are no wells in this town supplied by rock waters.

Other communities.—In the following table is a list of other villages in Hamilton County, with particulars of their water supply:

Other village supplies in Hamilton County.

Town.	Population (1900).	Source.	Depth of wells. Least.	Greatest.	Common.	Depth to rock.	Head below surface.	Character of water beds.
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Aroma	110	Wells, dug and drilled.	10	125	50	102	....	Gravel and limestone.
Bakers Corners.	60	Wells, dug, driven, and drilled.	15	140	18	....	....	Gravel.
Boxley	204	Wells, driven and dug.	20	70	50	....	15	Do.
Carmel	498	Wells, dug, driven, and drilled.	30	112	100	100	12	Gravel and limestone.
Clarksville	160	Wells, dug and drilled.	10	75	30	18	8	Limestone.
Deming	154	.....do	10	142	20	....	....	Gravel.
Durbin	22	Wells, driven, dug, and drilled.	15	90	30	....	....	Gravel and limestone.
Eagletown	275	Wells, driven and dug.	16	200	20	200	15	Gravel.
Fishers Switch.	200	Wells, dug, driven, and drilled.	25	100	25	100	....	Gravel and limestone.
Horton	193	.....do	10	125	15	240	....	Gravel.
Jolietville	231	Wells, dug and driven.	20	100	25	....	12	Do.
New Britton	101	Wells, dug, driven, and drilled.	10	110	15	....	....	Do.
Omega	94	Wells, dug and drilled.	10	200	100	280	....	Do.
Strawtown	89	.....do	25	112	75	50	....	Limestone and gravel.
Westfield	670	Wells, dug, driven, and drilled.	20	182	25	200	0-6	Do.

TYPICAL WELLS AND ANALYSES.

The two following tables contain detailed information regarding typical wells in Hamilton County and analyses of their waters. The last column of each table gives numbers referring to identical wells in the other table:

Records of typical wells in Hamilton County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Temperature.	Analysis No.
			Feet.		*Inches.*	*Feet.*	*Feet.*		*Feet.*	*Galls.*	*°F.*	
1	Town well	Arcadia	163	Drilled	4	163	−25	Gravel				1
2	do	do	177	do	4	177	−20	Limestone				2
3	F. F. Noble	2 miles W. of Arcadia	16	Dug		16	+	Sand				
4	do	do	61	Drilled		61	+	Gravel				
5	Charles Harvey	Aroma	80	do		80	+ 4	do		2		
6	Schoolhouse	Atlanta	120	do	4	120	−	do				3
7	A. E. Jessup	4 miles SW. of Carmel	160	do	3	152	+ 7			3	52	
8	O. C. Elliott	3 miles SW. of Carmel	150	do	8	150	+ 2	Limestone				
9	J. A. Newby	do	140	do	2½	130	+ 4	Sand	135	1		
10	Micah Newby	4 miles SW. of Carmel	140	do	3		+ 8	Limestone	135			
11	J. R. Carson	Cicero	86	do			−16	Gravel				5
12	Geo. Foulke	5 miles W. of Cicero		do			+ 4	Limestone	169	10	51½	7
13	Charles H. Dole	Cicero	42	Dug		42		Sand and gravel.				6
14	E. P. Whisman	6 miles NE. of Cicero		Drilled	8		+ 9	Limestone		20		
15	C. B. Sherer	½ mile NW. of Cicero	1,584	do	8⅝	486	+ 3½	do	90	60		
16	A. L. West	Fishers Switch	95	do	3	95	−30	Gravel				
17	Charles Randall	½ mile N. of Fishers Switch	92	do	3	90		do				
18	Noblesville Water and Light Co.	Noblesville	345	do	8	350	−25	Limestone	− 80			9
19	do	do	60–85	do	8		−25	Gravel				8
20	Excelsior Laundry	do	178	do	4	174	−27	Limestone	172			
21	Nordyke & Marmon	do	108	do	6	75		Gravel				
22	Martha F. Hair	4 miles E. of Noblesville	115	do	8	115	+ 4	Limestone	40			
23	Schoolhouse	Sheridan	150	Driven	2	150		Gravel				11
24	W. W. Morris	Strawtown	112	Drilled	3			Limestone				12
25	Frank Hussey	5 miles E. of Zionsville	153	do	3	152	+ 8	do	147	4		

Mineral analyses of waters in Hamilton County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	Public well	Arcadia	Drilled well, 163 ft. by 4 in.	H. E. Barnard	Nov., 1907	Gravel	...	0.12	80	24	...	...	0.0	272	15	6.0	0.50	0.000	9	350	1
2	....do	....do	Drilled well, 212 ft. by 4 in.	....do	..do	Limestone	...	.40	80	25	...	...	.0	280	20	4.0	.25	.001	19	384	2
3	Schoolhouse well	Atlanta	Drilled well, 120 ft. by 4 in.	....do	Oct., 1907	Gravel	...	.40	81	65	...	...	.0	323	97	60	.30	.000	0.0	370	6
4	Stockyards well	Cicero	Well, 110 ft. by 4 in.	Lake Shore and Michigan Southern R. R.	Dec., 1904	...	...	...	81	29	17		194	...	5.9	22	...	...	...	...	...
5	Dr. J. R. Carson	....do	Drilled well, 86 ft.	H. E. Barnard	Nov., 1907	Gravel	...	.80	170	25	...	...	.0	344	20	12	.001	1.2	23	362	11
6	Charles H. Dole	....do	Open well, 17 ft.	....do	..do	....do	...	.00	256	71	...	...	.0	416	665	140	.05	.000	22	1,284	13
7	George Foulke	5 miles W. of Cicero.	Drilled well, 169 ft.	....do	..do	Limestone	...	1.4	79	27	...	...	.0	260	15	18	.20	.000	19	442	12
8	Public supply	Noblesville	Drilled wells, 60 to 85 ft.	R. B. Dole	Aug., 1907	Gravel	20	2.0	84	31	19		.0	352	32	16	2.8	...	...	376	19
9	....do	....do	Drilled well, 345 ft.	....do	..do	Limestone	21	3.0	82	30	18		.0	372	22	17	.04	...	...	375	18
10	Taylor & Sons	....do	Well, 27 ft.	Lake Erie and Western R. R.	...	...	...	...	112	35	17		188	...	70	25	39	...	...	...	...
11	Schoolhouse	Sheridan	Driven well, 150 ft. by 2 in.	Chase Palmer.	Aug., 1907	Gravel	21	1.8	61	27	47		Tr.	431	5.6	1.5	4.0	...	...	396	23
12	W. W. Morris	Strawtown	Drilled well, 112 ft. by 3 in.	H. E. Barnard	Nov., 1907	Limestone	...	3.0	94	10	...	...	.0	278	9 1	7	1.10	.000	13	438	24

HANCOCK COUNTY.

SURFACE FEATURES AND DRAINAGE.

Hancock County occupies the extreme southeast corner of the area covered in this report. It is irregular in outline and has an area of 290 square miles. As the population in 1900 was 19,189, there was an average of 66 inhabitants to the square mile.

This is essentially an upland county and is more uniformly a high plateau than any other portion of north-central Indiana. In the neighborhood of Wilkinson the surface, though of mild relief, lies more than 1,000 feet above sea level; the extreme northwest corner has an elevation of 800 feet. This plateau is composed of glacial deposits. The north and northwest portions are a till plain, but a low moraine belt covers the south and southeast parts of the county, which lies on the divide between White River on the west and Blue River on the east. The form of the underlying rock surface has had no influence on the present relief of the county. No outcrops occur, and the glacial deposits range from 100 to 300 feet in thickness.

Stream cutting has played a comparatively unimportant part in shaping the surface of this high plain. The only important valley is that of Big Blue River, which crosses the southeast corner of the county. Its valley is about 50 feet below the bordering uplands and contains a wide flood plain. Next in size is Sugar Creek, which crosses the county from northeast to southwest, with a valley which varies from only a few feet in depth at the upper end to 30 or 40 feet below New Palestine. The river flat has nowhere been greatly widened. The only other noteworthy stream is Brandywine Creek, which flows south through Greenfield. The creek lies from 20 to 30 feet below the plain and its flood plain is narrow.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

As will be seen from an inspection of Plate I, the surface deposits of Hancock County are almost equally divided between plains of pebbly till and morainal drift. Alluvial beds of sufficient extent to show on a map of this scale occur only in the valley of Big Blue River. Plate II shows the thickness of the surface deposits throughout the county. As they are nowhere less than 90 feet thick, it follows that by far the greater number of wells procure their supply from the glacial drift above the rock.

The alluvium in the valley of Big Blue River consists of flood-plain and terrace deposits of gravels, sands, and silts. During the retreat of the last great glacier from this region, the Blue River valley afforded one of the important channels of escape for the abundant waters of the melting ice, and along it there were deposited extensive beds of fluvio-glacial débris. The valley is much larger than the present stream would have developed, and the alluvial deposits are more extensive than those left by the postglacial streams of similar size. The thickness of the valley deposits varies but generally falls between 20 and 40 feet. Along Sugar and Brandywine creeks the alluvial beds are more restricted in area and are commonly 15 to 25 feet thick. The valley gravels carry abundant water obtained from the rainfall and from the seepage of the surrounding uplands. Wells are easily obtained, the simplest and most common type being the driven well, 10 to 30 feet in depth. These wells give large yields if ended in coarse gravels, and the water, though hard, is softer than that either from the till or the limestones. There are many wells in alluvium along the Blue River valley and in the flats of Brandywine, Sugar, and the smaller creeks.

The southeast half of this county is moraine covered, the surface consisting of low, rolling hills, 20 or 30 feet high, with many scattered bowlders. There are no sharply defined ridges or areas of strong relief, and in this the moraine differs greatly from the great moraine belts in the northern part of the State. The surface deposits reach great thickness wherever the moraines lie on top of the till, and at Cleveland a well was drilled 240 feet deep before it entered rock. The water supplies of the moraine are much like those of the till, as the materials are nearly identical. Dug wells predominate, but driven and drilled wells are numerous.

In the northern till-covered half of the county the surface is plainlike and rises gradually from the west to the east edge. The thickness of the till seems to be fairly uniform from west to east, the rock surface below rising at about the same slope as the till surface. The stream valleys are all very shallow, and the topography is remarkably uniform and featureless. The clayey till itself furnishes water to a large number of shallow dug wells, the water entering through the loose-curbed walls as it seeps out slowly from the clay. An increase in the amount of gravel in the clay increases the supply of water, and distinct beds of gravel almost everywhere yield rather abundant supplies. Deep driven or drilled wells generally reach some such gravel beds, and few of them enter the underlying rock. Good sanitary protection is given to the deeper gravels by the overlying clays.

CONSOLIDATED MATERIALS.

The "Niagara" limestone outcrops beneath the drift in northeast Hancock County, though it is everywhere deeply covered by the surface deposits. It has been reached by the drill at Fortville, Melners Corners, Wilkinson, and Willow, and its character is evidently much the same as in the area to the north, where it comes to the surface.

Deep drillings throughout the entire county pass through the "Niagara," though in the south, central, and west portions it is overlain by the Devonian beds. All wells entering the "Niagara" obtain abundant water, usually in the upper portion of the formation.

Little is known of the character of the Devonian limestones, which are the uppermost rocks in the south and west portions of the county (Pl. III). The records of drillers commonly class them with the "Niagara." The Devonian beds are reliable water producers, no failure to obtain abundant water in the limestones having been recorded. The water occurs in the fractured and somewhat weathered upper portion of the rock or in the deeper joints or bedding planes.

ARTESIAN AREAS.

One artesian area (Pl. IV, No. 37) includes the lowlands along Brandywine Creek near Greenfield, where there are a number of flowing wells, all of which are drilled into limestone. Two are old gas wells, one on the property of W. S. Freeze (No. 6, p. 142) and one in the flat of Brandywine Creek. It is not known at what depth the flowing water was encountered, except that it is from the limestone, which is here about 150 feet below the surface. The only other flowing wells in this area, eight in number, are at the Greenfield city waterworks. When these wells are pumped the head is lowered below the surface of the ground. The wells are "in sympathy" with the flowing well at the creek bottom, which ceases to flow when the city wells are being pumped. Although the water is found in the Devonian limestone, the head is probably from waters in the underlying "Niagara" limestone. The "Niagara" beds rise toward the east, the direction of the Cincinnati arch, and the flowing waters probably come down this structural slope.

A number of other flowing wells from abandoned gas borings are reported to occur along the Brandywine south of Greenfield.

There are two flowing wells at New Palestine, both on the property of Mr. Max Herrlick. The records of the wells are lost, but they are reported to have entered rock at 285 feet and to be 1,000 feet deep. The flowing water is said to have been encountered at a depth of 200 feet. The water rises 15 feet above the surface, and is carried to a hydraulic ram which pumps 13,000 gallons per day. The water is used for the public supply. Other flowing wells could certainly be obtained in the near-by lowlands if carried to sufficient depth.

One mile north of Melners Corners, in the valley of Sugar Creek, there is a flowing well on the farm of W. A. Collingwood. (Pl. IV, No. 39.) The water is obtained from gravel at a depth of 20 feet, and the flow fills a 1¼-inch pipe. The conditions for flow are local, but wells in the creek valley near by would also probably strike flowing waters.

CITY AND VILLAGE SUPPLIES.

Greenfield.—The city of Greenfield owns and operates waterworks, which were established in 1894 at the east edge of the town. The water, drawn from eight flowing wells (Pl. IV, No. 37), is from the limestone and is pumped directly into the mains from the wells, a domestic pressure of 45 pounds being maintained, while for fire protection the pressure is increased to about 100 pounds. There are over 8 miles of mains and 900 taps, and about 75 per cent of the people use this water. About 300,000 gallons per day are pumped.

In Greenfield there are still large numbers of private wells in use. The dug wells formerly were more numerous, but they are gradually being abandoned and their places taken by driven wells. In the north and northeast parts of the town water-bearing gravels are found at about 45 feet below the surface, while in the south part of town it is necessary to sink wells to a little over 100 feet before good supplies are obtained. Before the city supply was installed many dug wells were used, and typhoid fever was prevalent. No case of this disease has been reported from families which use only the city water.

New Palestine.—The public supply of New Palestine is owned by Max Herrlick. The water flows from the artesian wells already described (Pl. IV, No. 38), and a part of the flow is pumped by hydraulic ram to a tank 86 feet above the wells, which has a capacity of 6,000 gallons. From the tank the water is distributed by gravity to about 2 miles of 2-inch iron mains, and 35 taps are supplied. There are no connections with this system for fire protection.

The private wells are dug and driven. The dug wells range in depth from 14 to 24 feet, and the driven wells from 30 to 125 feet. The common depth for driven wells is 65 feet, and a good bed of water-bearing gravel can almost everywhere be found at that depth.

Fortville.—In Fortville all the open wells have been abandoned, and drilled or driven wells are used altogether. In the town there are perhaps six or eight wells which reach rock, and they all have abundant water. An analysis of water from the limestone, which here lies at a depth of about 165 feet, is No. 3 in the table on page 143. The driven wells are sunk either to first or second gravel, first gravel being reached at 10 to 35 feet, and second gravel at 70 to 80 feet below the surface. Most wells obtain water of good quality from second gravel at an average depth of 70 feet.

Charlottesville.—Charlottesville has no public supply, and each home has a private well from which its water is drawn. Dug wells were formerly numerous, but these are being abandoned and driven or drilled wells substituted. Gravel, encountered at depths of 30 to 85 feet, furnishes safe and abundant waters, which rise within 15 feet of the surface. In the town rock lies 170 feet below the glacial beds, and no rock waters are used.

Other communities.—The following table contains a list of other villages in Hancock County, with details regarding their water supply:

Other village supplies in Hancock County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Cleveland	125	Wells, dug and drilled.	12	240	200	240		Sand and gravel.
Eden	100	do	20	30	20			Gravel.
Gem	80	do	20	150	130			Sand and gravel.
Maxwell	300	Wells, driven and drilled.	40	278		276		Gravel and limestone.
McCordsville	301	Wells, dug and drilled.	14	132	15	100	6	Gravel.
Melners Corners		Wells, driven and drilled.	9	100	20	100	3-10	Do.
Mohawk	162	Wells driven	20	35	30		15	Do.
Mount Comfort	134	do	20	40	30			Do.
Philadelphia	182	Wells, dug and driven.	25	80	75			Sand and gravel.
Shirley	381	Wells, drilled, bored, and dug.	40	138	50	170		Gravel.
Warrington	200	Wells, dug and driven.	10	30	25			Do.
Wilkinson	208	Wells, drilled, driven, and dug.	30	180				Gravel and limestone.
Willow	127	Wells, dug and driven.	20	80		180	5-10	Sand and gravel.

TYPICAL WELLS AND ANALYSES.

The two following tables contain detailed information regarding typical wells in Hancock County and analyses of their waters. The last column of each table gives numbers referring to identical wells in the other table.

Records of typical wells in Hancock County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Analysis No.
			Feet.		*In.*	*Ft.*	*Feet.*		*Ft.*	*Gals.*	
1	C. Vannlaningham	Fortville	175	Drilled	2½		−33	Limestone	165		3
2	L. F. Denney	do	35½	do	2½		−10	Gravel			1
3	E. F. Cahen	do	140	do	2½		−30	do			2
4	City waterworks	Greenfield	170	do	8	170	+	Limestone	170		4
5	County jail	do	200	do	6	200	−30	do	170		
6	W. S. Freeze	do		do	6		+ 3	do		2	
7	J. A. Corbin	1½ miles N. of Greenfield.	171	do	4	171	−30	Gravel			
8	Thomas Rash	Maxwell	105	do	4	105	−25	do			
9	Cleveland, Cincinnati, Chicago and St. Louis R. R.	do	278	do	8	276		Limestone	276		
10	E. L. Dobbins	2 miles SW. of Maxwell.	181	do	4	181	−55	Gravel			
11	McCordsville Natural Gas Co.	McCordsville	910	do		80		Limestone			
12	S. Morrison	½ mile N. of McCordsville.	100	do	3	100	−30	Gravel			
13	W. A. Collingswood.	½ mile N. of Melners Corners.	20	Driven	1¼	20	+ 6	do			
14	Frank Welling	3 miles SW. of Mount Comfort.	147	Drilled	2	147	−37	do			
15	Max Herrlick	New Palestine	1,000	do	6	700	+15	Limestone		75	
16	J. M. Evans	3 miles S. of Oaklandon.	90	do	2½	90	−20	do			
17	Doctor Chateau	Shirley	138	do	4	138	−30	Gravel			
18	J. Masters	Warrington	200	do	1¼	150	−15	do	200		
19	Doctor Titus	Wilkinson	187	do	3	180	−20	Limestone	165		
20	George Condo	do	180	do	3	180	−20	do	165		
21	J. W. Walker	Willow	80	Driven	1¼	80		Sand			

Mineral analyses of waters in Hancock County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.
1	L. F. Denney.........	Fortville....	Drilled well, 35 ft. by 2½ in.	H.E. Barnard.	Oct., 1907	Gravel.
2	E. F. Cahen..........	.....do......	Drilled well, 140 ft.	.....do........	...do......	Do.
3	C. Vannlaningham....	.....do......	Drilled well, 175 ft. by 2½ in.	.....do........	...do......	Limestone.
4	City supply...........	Greenfield...	Drilled wells, 170 ft. by 8 in.	Chase Palmer.	July, 1907	Do.

No.	Silica (SiO_2.)	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	......	0.60	100	21	......	......	0.0	172	65	1.0	0.00	0.0	15	280	2
2	......	.80	74	21	......	......	.0	324	26	2.0	.30	.0	0	370	3
3	......	1.2	73	24	......	......	.0	266	23	2.0	.20	.002	2	348	1
4	28	1.2	48	30	23		.0	344	6.2	7.0	1.5	......	......	326	4

HENDRICKS COUNTY.

SURFACE FEATURES AND DRAINAGE.

Hendricks County, which lies at the southwest corner of the area covered by this report, is about 19 miles wide and 20 miles long from north to south, though there is a projection which extends 2 miles farther south than the rest of the county. The total area is 408 square miles, and in 1900 the population was 21,292. Danville, the county seat, lies 20 miles west of Indianapolis.

This county occupies a part of the broad plateau between White and Wabash rivers, and most of the drainage belongs to the former stream. The plateau slopes as an inclined plane from the northwest to the southeast corner of the county, and this slope is due more to the preglacial surface as left by the ice than to the influence of post-glacial erosion. The largest valley is that of White Lick Creek, and the lowest point of the county, in this valley, is less than 700 feet above sea level, while the highest, in the northwest portion (Pl. I), reaches a height of over 960 feet, giving the county a total range in elevation of about 275 feet. Most of the surface consists of a level plain, and is, in general, little cut by streams. There is, however, a broad belt of moraine which has a north-south trend and lies somewhat west of the center of the county (Pl. I).

White Lick Creek is the dominating stream, and with Little White Lick and its other smaller tributaries its basin includes almost half of the surface. The valley is much deeper than is common for streams of this volume, the excessive development being due to the fact that it discharges into the deep valley of White River, and therefore has the low outlet and steep gradient that are favorable to rapid erosion. The only other streams of importance are Walnut Creek, in the northwest corner, and Mill Creek, in the southwest corner, both of which flow, by way of Eel River, into White River at Worthington.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

The principal alluvial beds of the county are found in the valleys of Big and Little White Lick creeks, and to a lesser extent in the valleys of the other streams. Wherever the alluvium attains a thickness of 15 feet or more it is almost certain to furnish plenty of water to dug or driven wells. From the nature of the materials, however, such shallow wells will receive in a short time any sewage which may enter the ground in the vicinity, so that pollution must always be guarded against. The danger is especially great in towns or in the neighborhood of dwellings or barns; hence water for domestic purposes should not be taken from shallow wells so situated. The deeper alluvium, if covered by beds of rather impervious clay, may yield a first-class water supply.

As stated above, a single moraine belt crosses the county from northwest to southeast (Pl. I). North of Danville the surface is rather irregular and rolling, but south of this city the relief becomes milder.

As in the till plains, the open wells predominate. The greater abundance of gravels has favored the construction of driven or drilled wells, and these are constantly increasing in popular favor. The depth varies with the distance to the gravel beds, but it is rarely necessary to sink wells more than 60 or 70 feet.

As shown in Plate I, till plains occupy most of the county surface. The thickness of the material varies greatly, for in the southwest corner the drift is generally less than 75 feet thick, but the depth to rock increases to the north and east until it reaches more than 200 feet in the deepest places. The majority of the wells in the till-plain areas are open or dug and range from 15 to 40 feet deep. The water enters slowly from the till, but in sufficient quantity for ordinary domestic uses. Wells of this type may be obtained almost anywhere, and in the rural districts offer a fairly safe supply if located at safe distances from outhouse and barnyard drainage. In towns they are not safe. Drilled and driven wells have proved very satisfactory, and have demonstrated that gravel beds may be entered anywhere if the wells are continued 75 feet or more. Locally they are found much nearer the surface.

CONSOLIDATED MATERIALS.

The distribution of the rock formations below the glacial drift is shown approximately in Plate III. The exact line of contact between the Devonian and Mississippian beds in this county can not be determined, because very few wells have penetrated through the drift to them.

The New Albany shale, the uppermost of the Devonian beds, is the oldest rock of the county. Little is known here of the character of its water supply, although in the counties to the east and north it is made up of tight, close-grained beds, which yield little or no water to wells. In Hendricks County the drift above has everywhere yielded sufficient water before the shale is reached.

The "Knobstone" group, of Mississippian age, lies immediately below the drift in all but the northeast portion of this county (Pl. III). These rocks furnish few wells with water in the lower and more shaly portion of the formation. In the southwest half the sandstone of the "Knobstone" comes within 6 or 8 feet of the surface at some places, and wells drilled into it have found plenty of water in the well-defined joints of the rock.

ARTESIAN AREAS.

A flowing-well area lies in the valley of Little White Lick Creek for some distance above and below Danville. (Pl. IV, No. 40.) The best flows have been obtained by the Danville waterworks, where six wells furnish the entire town supply (Pl. VI, *B*). The water is obtained from a gravel bed below till at a depth of 100 to 112 feet, and rises 12 to 22 feet above the surface with an enormous volume. The record of one of these wells is as follows:

Log of well at Danville waterworks.

	Feet.
Sand and gravel	14
Hardpan	5
Blue clay	53
Gravel	40
	112

The gravel beds which yield the flowing waters are of uncertain extent. One well drilled by the Cleveland, Cincinnati, Chicago and St. Louis Railway, one-fourth mile southeast of the Danville pumping station, penetrated hardpan and found no water in or below it. Flowing wells from the drift have also been obtained near Cartersburg in this same artesian area. The Cartersburg Mineral Springs have been described by W. S. Blatchley.[a]

[a] Mineral waters of Indiana: Twenty-sixth Ann. Rept. Indiana Dept. Geology and Nat. Res., 1901.

There is an artesian area in the vicinity of Tilden (Pl. IV, No. 41) where two wells flow at the surface, and where in many wells the water rises within a few feet of the well mouth. The waters are in every well obtained from gravel beds below till, and the wells range from 26 to 114 feet in depth. The record of one of these is No. 14, in the table on page 148.

In artesian area No. 42 (Pl. IV), near New Winchester, a number of flowing wells occur, but by no means all the wells flow. None of the wells are in deep valleys, and many are only 2 or 3 feet below the level of the plain. The water is obtained from the sandstone of the "Knobstone" group, which is entered at 30 to 90 feet below the surface, the overlying till preventing the escape of the waters, and the head may come from the higher part of the formation, a few miles to the north, or from the overlying drift. As no outcrops occur at the surface, the water must reach the rock through gravelly portions of the drift.

An artesian area (Pl. IV, No. 43) at North Salem has a single flowing well, drilled about fifteen years ago in the hope of obtaining oil or gas. The well is 800 feet deep, and the flow is reported to come from a depth of 400 feet, probably from the Devonian limestones. The well flows with a $1\frac{1}{4}$-inch stream.

CITY AND VILLAGE SUPPLIES.

Danville.—The Danville public water system is owned by the city, and the supply is obtained from six drilled wells in the river valley. There are two 2-inch, two 3-inch, and two 4-inch wells, and each is about 112 feet deep. They have been described above, as in artesian area 40. From the wells, which have a head of 22 feet above ground, the water is pumped to a standpipe with an elevation of 100 feet above the town and 200 feet above the wells, and is distributed from this by gravity. The system has 5 miles of mains and 600 consumers, or about 95 per cent of the total population of the town. About 450,000 gallons per day are pumped. An analysis of this water is No. 4 in the table on page 149. The supply is an excellent one, and it is appreciated by the people, as is shown by the large proportion of users of the city water.

There are very few private wells in Danville. A small number of dug and driven wells are used and some water is obtained from springs along the creek valley.

Plainfield.—Plainfield has no waterworks, and all the water is drawn from private wells. These are dug and driven, are 20 to 25 feet deep, and obtain their water from a bed of gravel. Such a supply is likely to become polluted at any time from the drainage of the outhouses and stables of the town. Deep driven and drilled wells are the only safe source of underground waters in such thickly settled communities.

At the Indiana Boys' School, across the creek from the town, the water is obtained from two sources. A fine spring which issues from the side of a gravel terrace supplies the drinking water and a deep well the water used for other purposes. The record of this well was given as follows:

Log of well at Indiana Boys' School, Plainfield.

	Feet.
Soil and brown sandstone	12
Bluestone	58
Bluestone	160
Red shale	18
Brown limestone	52
Limestone	300
White stone	$3\frac{1}{2}$
	$603\frac{1}{2}$

Pittsboro.—Pittsboro is situated on the till plain about 8 miles northeast of Danville, and has no public water supply. The private wells, whose waters are obtained from gravel beds, are dug and driven, and although they range in depth between 15 and 100 feet as extremes, the common depth is only 20 feet. Such a shallow well supply should be abandoned in favor of deeper tubular wells.

Brownsburg.—The wells of Brownsburg are dug and driven, the former ranging from 15 to 30 feet, and the latter from 30 to 150 feet in depth. The common depth for dug wells is 20 feet and for driven wells 40 feet, and the water, which comes from the till and from gravel beds, rises within 10 or 15 feet of the surface. The driven wells 40 feet or more in depth are probably safe from pollution. The dug wells are open to the same objections stated for wells of this class at Plainfield and Pittsboro, and their waters endanger the health of the community.

Coatsville.—The people of Coatsville depend for their water almost wholly upon dug wells from 18 to 30 feet deep, in which the head of water varies with the seasons. Gravel is entered at about 25 feet. Great care should be exercised to locate wells as far as possible from sources of contamination, and driven or drilled wells are much to be preferred.

North Salem.—The wells of North Salem are dug and driven, and from 15 to 75 feet deep. There is one very deep flowing well, which was described as in artesian area 43 (p. 146). The town is on a till plain, and the only reliable source of supply is the gravel beds in the till. The deep driven wells yield a much safer and more satisfactory water than that obtained from the dug wells, which are likely to be contaminated.

Other communities.—The following table contains a list of other villages in Hendricks County, with particulars as to their water supply:

Other village supplies in Hendricks County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Amo	325	Wells, dug and driven.	12	30	20			Gravel.
Belleville	268	Wells, dug and drilled.	10	150	40			Do.
Cartersburg	253	Wells, driven and drilled.	40	110	65		20	Do.
Center Valley	92	Wells, dug, driven and drilled.	18	70	30	15	10	Gravel and rock.
Clayton	478	Wells, dug and drilled.	9	140	50	9-60	0-10	Gravel and shale.
Friendswood	110	do	14	175	70		5	Gravel.
Hadley	68	do	14	140	30			Do.
Hazelwood	100	do	10	100	20	20	10	Sand and gravel.
Joppa	40	Wells, dug, drilled, and driven.	15	50				Gravel.
Lizton	347	Wells, dug and driven.	10	150	11-50		2-8	Sand and gravel.
Maplewood	32	Wells, dug	7	30	10		1-5	Gravel.
Mount Clair		do	10	45	30			Sand and gravel.
New Winchester	116	Wells, dug and drilled.	20	80	25	20-50		Gravel and rock.
Pecksburg	72	Wells, dug	12	30	14			Gravel.
Raintown	50	do	15	30	20			Do.
Reno	73	do	12	30	20			Gravel and clay.
Stilesville	357	Wells, dug and drilled.	9	245	20		4-16	Gravel and sandstone.
Tilden	63	Wells, dug and driven.	15	150	20		15	Gravel.

TYPICAL WELLS AND ANALYSES.

The following tables contain detailed information regarding typical wells of Hendricks County and analyses of their waters. The last column in either table gives numbers referring to identical wells in the other table.

Records of typical wells in Hendricks County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Analysis No.
			Ft.		*Ins.*	*Ft.*	*Feet.*		*Ft.*	*Galls.*	
1	Schoolhouse	Amo	225	Drilled	6			Shale	60		
2	M. T. Hunter	Brownsburg	110	Driven	$1\frac{1}{4}$	110	−20	Gravel			2
3	Public well	do	22	Dug		20	−18	do			1
4	W. W. Quinn	Cartersburg	93	Drilled	2	93	−40	do			
5	John Tarleton	do	90	do				do			
6	L. C. Vanarsdell	Clayton	56	do	6	40		Shale	6		3
7	Vandalia R. R.	$\frac{3}{4}$ mile W. of Clayton	50	do	6		+	Sandstone.	6		
8	Davis & Johnson	Coatsville	205	do	6	140	− 2	do	65		
9	Public supply	Danville	112	do	2, 3, 4	107	+22	Gravel		200	4
10	Charles McLain	2 miles N. of Hadley	68	do			+	Sandstone.	47		
11	Public well	Jamestown	96	do	$1\frac{1}{4}$	96	− 9	Limestone.	40		5
12	J. N. Lockhart	North Salem	800	do	8	400	+ 8	do			6
13	Public well	Pittsboro	15	Dug		14	−12	Gravel			7
14	M. H. Arbuckle	$\frac{3}{4}$ mile NE. of Tilden	$26\frac{1}{2}$	Drilled	2	26	+ 3	do		3	
15	Nathan Underwood	S. of New Winchester	57	do	2		+ $3\frac{1}{2}$	Sandstone.	40		
16	Frank Stinson	2 miles E. of Winchester.	96	do			+	do	70		

Mineral analyses of waters in Hendricks County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	Public well	Brownsburg	Open well, 22 ft.	H. E. Barnard	1907	Gravel	...	0.10	...	165	53	...	...	0.0	438	242	118	5.0	.001	4	1,066	3
2	M. T. Hunter	...do...	Driven well, 110 ft. by 1¼ in.	Chase Palmer	Nov., 1907	...do...	19	1.8	...	62	27	37		Tr.	348	2.8	27	.7	...	...	405	2
3	Vanarsdell Bros.	Clayton	Drilled well, 56 ft. by 6 in.	H. E. Barnard	Sept., 1907	Shale	...	.00	...	355	25	...	...	.0	331	67	20	.000	.000	2	408	6
4	City supply	Danville	Drilled wells, 112 ft.	Chase Palmer	July, 1907	Gravel	16	2.1	...	32	26	58		.0	360	4.3	3.2	9.0	...	...	349	9
5	Public well	Jamestown	Drilled well, 96 ft. by 1¼ in.	H. E. Barnard	1907	Limestone	...	.20	...	46	28	...	...	.0	378	0.0	38	.20	.001	4	548	11
6	J. N. Lockhart	North Salem	Drilled well, 800 ft. by 8 in.[a]	...do...	1907	...do...	...	2.4	...	59	27	...	...	.0	434	0.0	24	.05	.001	4	404	12
7	Public well	Pittsboro	Open well, 15 ft.	...do...	1907	Gravel	...	.10	...	156	58	...	...	.0	419	173	172	12.0	.001	0	1,244	13

[a] Water from 400 feet depth.

HOWARD COUNTY.

SURFACE FEATURES AND DRAINAGE.

Howard County is in the central north-south tier of the group of counties included in this report, somewhat south of its geographic center, and has an area of 295 square miles. Kokomo, the county seat, is 50 miles due north of Indianapolis. The population of the county in 1900 was 28,575.

The county is a part of the high plain between the valleys of White and Wabash rivers, and aside from the valley depression of Wild Cat Creek the surface is monotonously level and featureless. Wild Cat Creek enters the county from the south near the southeast corner and flows northeast and then northwest to Greentown, whence its course is westward through Kokomo to the west county line. The course of the stream in this county is over 40 miles long and the valley is much better developed at the lower than at the upper end. At Burlington, Carroll County, the valley is about 70 feet deep. At Greentown it is less than 30 feet deep, and above it is still shallower. Wild Cat Creek drains all of the south half of the county, and a narrow strip of the plain to the north. From the south it is fed by Honey, Little Wild Cat, and Kokomo creeks. From the north it has no important tributaries.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

The important alluvial deposits of Howard County are all confined to the valley bottom of Wild Cat Creek, though there are small areas of alluvium along the courses of its larger tributaries. The valley ranges in width from over one-half mile in the west to a small fraction of this distance at its upper end, and the alluvium varies much in thickness. At Kokomo wells in the bottom lands enter rock after penetrating 20 to 30 feet of gravels and sands. Farther west the thickness increases. In the alluvial bottom lands underground waters are easily obtained. The water table in these areas stands within a few feet of the surface, and the coarse sand and gravel beds furnish large quantities of water. Driven wells, 10 to 30 feet in depth, are commonly used to procure the alluvial waters. The waters are potable and safe in rural districts where the wells are sufficiently removed from outhouses or stables, but in towns the chances are great for pollution by the penetration of sewage into the unprotected gravels, and in such situations the shallower alluvial waters should be avoided.

The moraines of this county are low and inconspicuous, though their somewhat irregular surfaces stand in contrast with the very level aspect of the surrounding till plains. One belt of morainal drift extends from Greentown northwest into Miami and Cass counties, and Russiaville lies on another small isolated patch.

In the gravelly portions of the morainal drift the ground waters are abundant and may be obtained by dug, driven, or drilled wells. The gravel or sand beds between beds of till furnish the best waters, and the relatively impervious till is effective in keeping out objectionable drainage from the surface.

From its wide surface distribution (Pl. I) the till must be depended upon to furnish the domestic supplies of water throughout most of the county, and the usual method of obtaining water from it is by means of loosely curbed dug wells. The water thus obtained may, under exceptional conditions, be unfailing and pure; but many such wells fail in dry seasons and all are to some extent subject to the dangers of pollution either from the well mouth or from seepage through the ground. If dug wells are to be used, great caution should be exercised to locate them at as great a distance as possible from cesspools or other sources of contamination.

CONSOLIDATED MATERIALS.

The surface deposits of all of Howard County are immediately underlain by limestones. In the eastern portion the "Niagara" limestone is the uppermost formation. At Kokomo, where the rocks outcrop at the surface, the beds are of the Kokomo limestone ("water lime"), next younger than the Niagara. At Russiaville and in the extreme southwest portion of the county the Devonian limestones underlie the drift. The approximate distribution of these formations is shown in Plate III. The various limestone formations have gained the reputation among drillers of being sure water-bearing beds. A great many borings throughout the county have entered limestone, and almost without exception the wells have obtained satisfactory supplies of water.

Chemical analyses (p. 157) seem to show no great difference in composition between the waters from the limestone and those from gravel.

ARTESIAN AREAS.

Scattered throughout the county there are eight areas in which flowing wells occur. These are all in the lowlands, usually along the valleys of the larger streams. The outlines of the areas, as shown in Plate IV, are made to include the districts where flows are at present known. The boundaries are necessarily only approximate. The lack of an accurate topographic base map is one of the causes that have made it difficult, in the short time spent in each portion of the county, to map the flowing-well areas in detail and accurately.

There is an area along the lowlands of Wild Cat and Kokomo creeks, near Kokomo (Pl. IV, No. 44), in which the limestone waters are under artesian pressure. The head of the waters is only a few feet above the level of the creeks, but at favorable spots flowing waters have been obtained. The best known of these areas is at the city park. The rock here lies only 18 feet below the surface, though the flowing wells, three in number, range from 49 to 106 feet in depth. The record of the strongest of the wells is No. 9 in the table on page 156. The wells at the city waterworks, farther upstream, are also reported to flow when not pumped. As they are all in use it was impossible to obtain the amount of flow or the head. On the property of Thomas J. Dye, 2½ miles south of Kokomo, gas borings have encountered flowing waters in the limestone at a depth of about 150 feet, one well in the lowlands of Kokomo Creek being estimated to flow 15 gallons per minute (No. 17, p. 156). There is reason to believe that other wells near the level of the creeks would give artesian flows.

Rock wells along Little Wild Cat Creek, near West Middleton, have obtained flowing waters from the limestone. (Pl. IV, No. 45.) The waters along this valley are under just enough pressure to rise to the surface, and the flows are small. Farther from the stream the waters in rock wells rise somewhat above the level of the creek but do not flow.

The west edge of Russiaville borders on West Honey Creek, in the valley of which there are flowing wells. (Pl. IV, No. 46.) Artesian waters are found in both the first and second gravels but none in rock. The deepest of these wells penetrated 35 feet of white sand and 62 feet of blue till to gravel at 97 feet and was cased only through the sand to the till.

A well one-half mile west of Fairfield (Pl. IV, No. 47) is reported[a] to have obtained a flow of 5,000 barrels per day from the limestone at a depth of 110 feet. The water rises 6 feet above the surface, which at this point is 25 feet lower than at the Fairfield railroad station.

About 1 mile west of Fairfield a small branch of Little Wild Cat Creek has a shallow valley in which there are two flowing wells (Pl. IV, No. 48), both of which are abandoned gas wells, the waters coming from the limestone. It is highly probable that rock wells in the valley bottom between this area and the flowing wells near West Middleton would also obtain flows.

In the valleys of Wildcat and Prairie creeks above Greentown there are at least three flowing wells, the flowing waters coming from the "Niagara" limestone, which here lies 50 to 75 feet below the surface. One well has a temperature of 51° F. and flows about 20 gallons per minute. There is reason to believe that wells which penetrate deep

[a] Leverett, Frank, Wells of northern Indiana: Water-Supply Paper U. S. Geol. Survey No. 21, 1899.

into the limestone are likely to obtain flows anywhere in this county along the valley of Wild Cat Creek.

Area 13 (Pl. IV), which lies along a branch of Deer Creek, and which has been described in part as in Cass County (p. 90), contains three flowing wells in Howard County. One was drilled for gas and the other two for water. The gas well and the deeper of the water wells obtained the artesian flows from limestone. The shallower well secured a flow in gravel at a depth of 65 feet. The records of these wells are Nos. 14, 15, and 16 in the table on page 156.

Area 10, described in part on page 81, extends across the county line from Carroll into Howard County, where it contains one flowing well. This well (No. 1, p. 156) is about 35 feet above the level of Wild Cat Creek. The water is obtained within 6 inches below the top of the limestone, which was struck at a depth of 103½ feet. The materials passed through by this boring were as follows:

Log of well on farm of Richard Fisher, 1½ miles east of Burlington.

	Feet.
Gravel	9
Blue clay	30
Hardpan	50
Red clay	14½
Limestone	½
	104

CITY AND VILLAGE SUPPLIES.

Kokomo.—The Kokomo public waterworks are owned and operated by the American Water Works and Guarantee Company of Pittsburg, Pa., and the pumping station is situated at the east edge of the city near Wild Cat Creek. The water is drawn from 13 drilled wells scattered for over a mile along the creek bottom lands, and all enter the limestone, which here lies 15 to 30 feet below the surface. Some of the wells, which are 6, 8, and 10 inches in diameter, and range from 160 to 500 feet in depth, are said to flow at the surface when not pumped. At present they are all connected, and are drained by syphon into a large cistern at the pumping station. The water is pumped from this well to the mains, and direct pressure from the pumps is maintained. There are 30 miles of mains, 4 to 12 inches in diameter, and 2,500 taps. About 75 per cent of the people use this water, and require an average of 2,000,000 gallons per day.

When the pressure in the mains is increased for fire protection, a red sediment which accumulates in the mains is loosened and gives the water an objectionable reddish color. Proper flushing of the mains would do much to remedy this evil. The supply is otherwise very good and the danger of pollution is slight.

Many private wells are still in use in Kokomo, and these usually obtain water in gravel just above the limestone, or in the limestone itself. The surface deposits vary in depth from 40 to 50 feet at the north edge of the city to only a few feet near the river. The most common type of well is the drilled well, which is sunk to a depth of about 75 feet and finds water in the limestone. The record of an old gas boring gives the following section:[a]

Log of gas boring at Kokomo.

	Feet.
Drift	61
Waterlime and Niagara	359
Hudson River limestone and shale	265
Utica shale	251
Trenton limestone	22
	958

Greentown.—The public supply of Greentown is owned by Delon & Davis, a private company. The water is taken from a single 4-inch drilled well, 95 feet deep, which penetrated 17 feet into limestone. The water rises within about 25 feet of the surface, and the head varies only 3 feet from this level in the driest seasons. A gasoline engine is used to pump the water to a tank 65 feet high, which holds 10,000 gallons and from which it is distributed by gravity. There is about 1 mile of mains, and 95 taps supply one-fourth of the population. The amount pumped varies from 5,000 gallons a day in winter to 20,000 a day in the dry seasons. The water is good and affords a very satisfactory supply.

The private wells in this town are dug, driven, or drilled and are from 20 to 150 feet in depth. Gravel beds are encountered at about 25, 45, and 95 feet, and these waters are much used. The overlying till beds afford to the deeper gravels a good protection from contamination, and the limestone waters are especially safe and abundant. The shallow dug wells are much more dangerous and should be abandoned.

Russiaville.—The water wells of Russiaville are mostly drilled or driven, but a few dug wells are still used. Most of the wells are shallow and obtain water in sand or gravel beds at depths of 15 to 40 feet. In parts of the town the surface deposits are very sandy, and water is difficult to obtain.

Other communities.—The following table contains a list of other villages, with particulars as to their water supply:

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 249.

Village supplies in Howard County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Cassville	66	Wells, dug and drilled	10	110	25	100	....	Gravel, sand, and limestone.
Center	279	Wells, drilled, driven, and dug.	15	135	60	70–100	....	Limestone and gravel.
Fairfield	....	Wells, dug and drilled	12	110	100	60	10	Gravel and limestone.
Hemlock	104	.....do	18	115	20	85	10	Do.
Jerome	....	Wells, dug, driven, and drilled.	20	125	......	70–100	....	Clay, gravel, and limestone.
Kappa	24	Wells, drilled and dug	18	150	115	90	10	Gravel and limestone.
New London	177	Wells, dug and driven	18	40	30	....	....	Gravel.
Phlox	51	Wells, drilled and dug	15	80	60	60	10	Gravel and limestone.
Plevna	57	.....do	18	120	100	65	....	Do.
Ridgeway	18	.....do	20	150	100	80	20	Do.
Sycamore	271	.....do	25	125	100	60	8	Do.
Vermont	....	.....do	25	142	30	142	....	Do.
West Liberty	60	.....do	15	85	60	50–80	12	Sand and limestone.
West Middleton.	202	.....do	15	108	20	100	....	Gravel and limestone.

TYPICAL WELLS AND ANALYSES.

In the following tables are given detailed information as to typical wells in Howard County, and analyses of their waters. In the last column of each table the numbers refer to identical wells in the other table.

Records of typical wells in Howard County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Temperature.	Analysis No.
			Feet.		*Inches.*	*Feet.*	*Feet.*		*Feet.*	*Galls.*	*°F.*	
1	Richard Fisher	1½ miles E. of Burlington	104	Drilled	2		+17½	Limestone	103	6	53	
2	J. P. Rauchert	Cassville	110	do	4	110	+ 8	do			52½	
3	Simpson estate	Center	135	do	4			do				1
4	Jacob Jessepp	2 miles E. of Center	280	do	4			do	80			
5	Everett Scott	Greentown	124	do	4		−22	do	118			
6	Delon & Davis	do	95	do	4	95	−26	do	78			
7	Samuel Ingalls	Hemlock	109	do	4			do	90			2
8	Public supply	Kokomo	160	do	6		+	do	26			4, 5
9	City park	do	106	do	6	50	+	do	18	10		3, 6
10	Kokomo Rubber Works	do	125	do	6		− 8	do	11			
11	Henry C. Wright Hoop Co	do	114	do	4		− 6	do	49			
12	Pittsburg Plate Glass Co	do	350	do	5⅝			do	22			
13	J. M. Leach	do	250	do	10	75	−14	do	16			
14	Jane D. Toubey	5½ miles NE. of Kokomo	65	Driven	2	65	+ 6	Gravel				
15	A. J. Hutson	do	900	Drilled	8		+12	Limestone				
16	Mary T. Smith	5 miles NE. of Kokomo	117	do	3½	117	+ 5	do	70			
17	Thomas J. Dye	2½ miles S. of Kokomo	1,000	do		150	+	do	20	15		
18	F. M. Baker	New London	30	Dug				Gravel				9
19	C. W. Hollingsworth	Russiaville	40	Drilled	2	40	−15	do				10
20	M. B. Jordan	do	97	Driven	2½	97	+ 5	do		5	52	11
21	Thomas E. Pickett	Sycamore	110	Drilled	4	110		Limestone	70			
22	Schoolhouse	Vermont	156	do	4			do	142			
23	Thomas E. Pickett	1 mile S. of West Liberty		do			+	do	140			
24	Marion Curless	½ mile SE. of West Liberty		do	8		+ 3	do			51	12
25	Public well	West Middleton	95	do	4	95	− 8	Gravel	95			13

Mineral analyses of waters in Howard County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	Simpson estate	Center	Drilled well, 35 ft. by 4 in.	H. E. Barnard.	Nov., 1907.	Limestone		1.0		46	30			0.0	288	0.0	5.0	0.10	0.001	2	532	3
2	Samuel Ingalls	Hemlock	Drilled well, 109 ft. by 4 in.	do	do	do		2.0		61	27			.0	360	27	4.0	.00	.000	5	462	7
3	City park	Kokomo	Drilled well,[a] 106 ft. by 6 in.	do	Oct., 1907.	do		.10		60	32			.0	310		37	.00	.32	9		9
4	City supply	do	Drilled wells, 160 ft. by 6 in.	J. H. Brewster.	Apr., 1907.	do		1.0		94	31			168		75(?)	7.5				317	8
5	Do	do	Drilled well, 500 ft. by 10 in.	L. S. & M. S. R. R.	Feb., 1904.			1.9		87	32	12		176		67	9.7					8
6	City park	do	Drilled well, 106 ft. by 6 in.	Chase Palmer.	Aug., 1907.	Limestone	20	.4		63	32	25		.0	357	12	32	.0			372	9
7	Kneer Paper Co.	do	Drilled well, 450 ft. by 8 in.	L. S. & M. S. R. R.	Aug., 1903.			2.3		122	45	34		223		114	52	1.4				
8		do	Wild Cat Creek[b]	do	Sept., 1904.					65	23	8.7		145		23	6.0	4.4				
9	F. M. Baker	New London	Open well, 30 ft.	H. E. Barnard.	Nov., 1907.	Gravel		.10		71	36			.0	272	240	41	4.0	.00	8	636	18
10	C. M. Hollingsworth.	Russiaville	Drilled well, 40 ft. by 2 in.	do	do	do		.60		29	29			.0	255	81	10	.05	.00	1	378	19
11	M. B. Jordan	do	Driven well, 97 ft. by 2½ in.	do	do	do		.80		70	31			.0	298	.0	98	.70	.001	12	360	20
12	Marion Curless	½ mile SE. of West Liberty.	Drilled—old gas well.	do	do	Limestone		.80		83	27			.0	304	58	7.0	.05	.00	2	466	24
13	Public well	West Middleton.	Drilled well, 95 ft. by 4 in.	do	do	Gravel		.01		93	33			.0	326	.0	13	.100	.001	10	400	25

[a] Water at 50 feet.

[b] Normal stage.

KOSCIUSKO COUNTY.

SURFACE FEATURES AND DRAINAGE.

Kosciusko County lies in the eastern tier of counties in the area covered by this report and in the second tier from the north edge of the State. It is the largest county in this region, having an area of 521 square miles. The 1900 census showed a population of 29,109, or an average of about 56 persons to the square mile.

The surface of this county is high, and the drainage is divided between the tributaries of Tippecanoe, Eel, Elkhart, and Yellow rivers, although within the county none of these streams is large. The moraines of the south and east parts are prominent and give considerable relief to the surface, but the northwest quarter of the county is flat and poorly drained.

The surface deposits are of extraordinary thickness, so that little is known about the shape of the rock surface. The present topography is entirely due to the form of the glacial deposits and to the subsequent slight erosion of their surface. Only one boring in the county has penetrated to rock, which lies at a depth of 245 feet at Warsaw. In Noble County, to the east, depths of 375 and 485 feet have been reached before rock was encountered.

Tippecanoe River receives most of the drainage from the county, including the overflow from a large number of lakes. All its tributaries are small, and the Tippecanoe itself is not a large stream in this region of its headwaters. Eel River crosses the southeast corner; but its valley here is not large and its tributaries all of which are unimportant, reach back into only the southern tier of townships.

Turkey Creek, a branch of Elkhart River, heads south into the area near Wawasee Lake and drains most of Van Buren and Turkey Creek townships. Scott and Jefferson townships had naturally very poor drainage, and much of the land was formerly useless for cultivation on account of its marshy character. Artificial drainage ditches have now been constructed to Yellow River, and much of the land has been reclaimed.

Kosciusko County has an exceptionally large number of lakes and ponds—more than any other county in this region. These range in size from Wawasee, or Turkey Lake, which has an area of about 6 square miles and is the largest lake in the State, to small ponds only a fraction of a square mile in area. All the lakes occupy depressions in the morainic material, and many of them have been partly filled by silt and by vegetable growths and are marshy.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

There are no important areas of valley alluvium in the county. Narrow flood plains occur along Tippecanoe and Eel rivers, and occasionally small benches of alluvium are found locally in the smaller valleys; but they are nowhere of sufficient extent to be important sources of water supply.

The outwash plain northwest of Warsaw has considerable gravel and sand mixed with clayey materials and is alluvial in its nature. At Leesburg and at Menoquet the outwash deposits are thick enough to furnish important water supplies to driven wells of shallow depth. Farther northwest the outwash becomes thinner and most wells pass through it into the underlying till for their water.

A great morainic belt covers much of this county (Pl. I), with its surface diversified by rolling hills and hummocks and many of the intervening depressions occupied by lakes. The morainic belt is broad, and although it forms a sharp ridge in few places it reaches heights of about 100 feet above the bordering plains. Water for wells of moderate depth is particularly abundant in the moraines. Most of the wells are driven and find plenty of water at 30 feet or less, but in the more clayey portions wells of greater depth are locally necessary. In the lowlands, near streams or lakes, the gravel beds in places contain water under sufficient head to flow at the surface; but these conditions are strictly local. The water in such cases is derived from the uplands at no great distance from the wells.

As shown in Plate I, the till covers a relatively small portion of the surface of the county. Its importance is greater, however, than its surface distribution would indicate, for throughout the entire county the other surface deposits are underlain by a layer of till which will probably average 200 feet in thickness. Its character is the same as in other parts of this area. In the moraines and the area of heaviest outwash water is commonly obtained above the till; but in those places where the till comes to the surface or where the outwash is thin deep driven or drilled wells penetrate into the till to some gravel or sand bed. Such open beds bear abundant waters which are hard but uncontaminated.

CONSOLIDATED MATERIALS.

As a result of the very heavy mantle of glacial beds, the underlying rocks are nowhere at the surface in Kosciusko County, and only one well was found which had penetrated rock. No attempt has been made to map the distribution of the rock formations; but a well at Warsaw entered limestone, which is presumably of "Niagara" age, and it may be that later formations overlie the "Niagara" at the north edge of the county. This well, which was drilled for oil or gas, may be the only well at Warsaw that receives its water supply from the rock. The water is under artesian pressure and discharges a small stream 4 feet above the surface. (No. 17, p. 164.) An analysis of this water is No. 18 in the table on page 165.

ARTESIAN AREAS.

There are about half a dozen flowing wells in Warsaw (Pl. IV, No. 50), all but one of which obtain the water from gravel beds in the moraine upon which the town is situated. The depth to the flowing water differs in different parts of the town, and the conclusion is that different beds of gravel are drawn upon and that the beds are irregular in shape and distribution. At the waterworks plant a number of small flows were obtained from a depth of 135 feet. At the chair factory of A. Wilder & Co. a well 18 feet deep struck water that rises to the surface. Other flowing wells have been obtained at depths of 78 and 85 feet, but they are in the lower parts of town, and the head is sufficient to give flows only in the lowlands. A complete analysis of one of these waters is No. 17 in the table on page 165.

A single well in Warsaw (No. 17, p. 164) is said to obtain water from a rock bed, which is probably of "Niagara" age. This well is reported to be cased to a depth of 400 feet, so that the water, which flows as a small stream 2 feet above the surface, must come from below this depth if the casing is still intact. An analysis of the water is No. 18 in the table on page 165. The very remarkable similarity between this water and that from a shallow well in the drift (No. 17, p. 164) indicates strongly that the water from both wells is from the same depth or at least that both are drift waters.

Area 51 (Pl. IV) includes the village of Kalorama, a summer resort on the northeast shore of Tippecanoe Lake, which lies in a depression in the great interlobate moraine. The conditions are favorable for artesian wells, and a number of these have been obtained and are now flowing. All are driven wells, sunk through pebbly clay into gravel at 60 to 75 feet below the surface. The source of the flowing water is in the moraine to the north, and the intake of the water is probably not more than a mile, at most, from the point of emergence. Flows are to be expected only in the lowlands.

A single flowing well is reported from northwest of Wauwàs Lake, on the property of the Indiana Portland Cement Company. (Pl. IV, No. 52.) This is said to be a driven well and to flow in a 2-inch stream. The well is at the foot of a moraine ridge, and the waters are probably supplied to the well by a gravel bed which outcrops somewhere in the higher moraine to the east.

A flowing well is reported from the farm of Samuel Kile, three-fourths of a mile north of Wooster. (Pl. IV, No. 53.) It occurs in the lowlands and the water is obtained in gravel. The well is said to flow in a small stream.

There is a single flowing well between Claypool and Burket, near a small creek which flows into Palestine Lake. (Pl. IV, No. 54.) The well extends 60 feet into gravel, and the water rises 3 feet above ground and discharges several gallons per minute. The head is doubtless from the moraine ridge to the southeast.

On the property of Lucinda Hazen, 2 miles northeast of Etna Green, a flowing well has been obtained on low ground. (Pl. IV, No. 55.) The well is driven 82 feet to a gravel bed, and at 3 feet above the surface flows in a 1-inch stream. Other flows may probably be obtained in the neighborhood on equally low ground.

CITY AND VILLAGE SUPPLIES.

Warsaw.—The public supply at Warsaw is owned and operated by the Winona Water and Light Company and the water is drawn from Center Lake, a small body of water at the edge of the town. Sanitary analyses have so far shown this water to be free from colon bacilli, but it is heavily charged with organic matter of other kinds. A marsh at the edge of town which has been used as a dumping ground for all sorts of refuse drains into this lake. In flood seasons Tippecanoe River, into which the sewage from Warsaw drains, backs up through a canal into Center Lake. At times the water has a decided smell and taste of decayed organic matter. By the installation of a good filtration system much of the objectionable matter could be removed and the supply could be made a very desirable one.

At one time the water company drilled 14 wells, which obtained flowing waters in gravel at a depth of about 135 feet. These wells were all "in sympathy" with one another and with other flowing wells in town. The supply from them was insufficient for the demands of the public, and they have been abandoned in favor of the lake water.

The water for city consumption is pumped to a standpipe 125 feet high, from which it is distributed by gravity. There are 7 to 8 miles of mains, 10, 8, 6, and 4 inches in diameter, and 800 taps are in use. About two-thirds of the people use the city water supply, and 1,000,000 gallons a day are pumped.

The people of Warsaw realize that the public water supply is unsafe, and almost every family owns a well for drinking water. These are driven or dug and range from 12 to 150 feet in depth. All terminate in gravel or sand, for the limestone here lies about 250 feet below the surface. In favored localities the wells flow, and even on higher ground the waters commonly rise within a few feet of the surface. The following materials were penetrated by a deep boring for oil in this town:[a]

[a] Twenty-sixth Ann. Rept. Indiana Dept. Geology and Nat. Res., p. 265.

Log of boring for oil at Warsaw.

	Feet.
Drift	248
Niagara limestone	652
Hudson River and Utica	478
Trenton limestone	77
	1,464

Syracuse.—Syracuse is situated on the west shore of a lake of the same name, and lies partly on the flat and partly on a well-developed morainic ridge. The public waterworks are owned by the city, and the water is taken from the lake and carried through an open mill race for about a mile through the town. Along the race there are houses, barns, and cesspools, and the chances for pollution are abundant. The water is pumped by water power developed at the end of the race and is forced to a standpipe on the hill. The standpipe has a capacity of 32,000 gallons. The water is distributed by gravity and is used by about 20 per cent of the people. From 5,000 to 30,000 gallons per day are used.

About four-fifths of the people of Syracuse rely upon private wells for their water supply, and most of these wells are driven. On the hill the wells range in depth from 35 to 130 feet, while on lower ground the deepest wells are only 35 and the shallowest only 12 feet deep. Gravel was found by all wells, and the water is everywhere abundant.

Milford.—The town of Milford is situated on an outwash gravel plain in the north-central part of the county. The town owns its own water system, which has been in operation since 1892. The water is taken from four drilled wells, each 40 feet deep, situated near the grist mill by which the pumping is done. The water is forced to an 83,000-gallon standpipe, 110 feet high, and is distributed by gravity. There are 2½ miles of mains, and 71 taps are in use, supplying 33 per cent of the population. An average of about 20,000 gallons of water a day is pumped.

The private supply of Milford is almost all from driven wells, which range in depth from 40 to 60 feet. The material penetrated is all gravel and sand, and the water is very abundant and rises within 6 or 8 feet of the surface. Milford has no sewage system, and all the drainage from dug privy vaults, kitchen slops, stables, and other sources can readily enter the loose soil and become a part of the underground water supply. For this reason it is advisable to drive the wells deeply into the gravel and to draw water only from the lower and purer beds.

Pierceton.—The town of Pierceton installed its own water works in 1897, and a single drilled well furnishes the entire supply. The well is 8 inches in diameter and 210 feet deep, and the water is supplied by a gravel bed 10 feet above the bottom of the well, and rises within

50 feet of the well mouth. An analysis is No. 8 in the table on page 165. A deep-well pump lifts the water to a wooden tank of 15,000 gallons capacity, and from the tank it is pumped by direct pressure into the mains, which are 6 and 4 inches in diameter and between 1½ and 2 miles long. About 200 taps are supplied and 20,000 gallons per day are needed to supply 50 per cent of the people. The water is of fine quality, and the supply a very satisfactory one. There has been some complaint because the wooden reservoir becomes slimy at times, but reasonable care could prevent this.

Mentone.—In Mentone, which has no public supply, the wells are all privately owned, and are driven, dug, or bored. The town lies on a till plain, and the wells all pass through this material into gravel, which is generally encountered at depths of 30 and 80 feet. Some of the waters from dug and bored wells are evidently bad, and the chances of contamination in such wells are many times greater than in the wells from the deeper beds. An analysis of water from a depth of 90 feet is No. 6 in the table on page 165.

Other communities.—A tabulated list of other villages, with the conditions of their water supply, is given below:

Other village supplies in Kosciusko County.

Town.	Population (1900).	Source.	Depth of wells.			Head above (+) or below (−) surface.	Character of water beds.
			Least.	Greatest.	Common.		
			Feet.	*Feet.*	*Feet.*	*Feet.*	
Atwood	278	Wells, drilled and driven	20	60	45	−30	Gravel.
Burket	286	do	10	80	15		Do.
Claypool	399	Wells, dug and drilled	10	110	70	−20 to −50	Gravel and sand.
Clunette	91	Wells, driven	20	35	30	−28	Sand.
Etna Green	420	Wells, driven and drilled	14	100	25	−12	Gravel
Gravelton	28	Wells, driven and dug	20	100	90		Do.
Hastings	16	Wells, driven	35	100	50		Do.
Kalorama		do	30	70	60	+6 to −5	Do.
Kinzie	67	Wells, dug and driven	20	65	25	−20	Do.
Leesburg	390	Wells, driven	15	30	20	−15	Do.
Menoquet		do	14	60	20	−15	Do.
Milford Junction.		Wells, driven and drilled	16	44	18	−16	Do.
North Webster	300	Wells, driven	18	30	22	− 8	Do.
Oswego	61	do	15	125	20	−15	Do.
Packerton	213	Wells, driven, drilled, and dug.	20	120	80		Do.
Palestine	126	Wells, driven and drilled	30	65	30	−30	Do.
Sevastopol	105	Wells, driven and dug	15	100	60		Do.
Sidney	300	do	20	140	50	−15	Do.
Vawters Park	25	Wells, driven	12	60	25		Do.
Wawasee	22	do	20	40	25		Do.
Winona Lake	156	Wells, drilled and driven	20	100	95	+4 to −10	Do.
Wooster	72	Wells, driven	20	100	26		Do.

TYPICAL WELLS AND ANALYSES.

The following tables give detailed information regarding typical wells in Kosciusko County and analyses of their waters. The last column of each table contains numbers referring to identical wells in the other table.

Records of typical wells in Kosciusko County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Flow per minute.	Temperature.	Analysis No.
			Feet.		*In.*	*Feet.*	*Feet.*		*Galls.*	°*F.*	
1	Public well	Burket	18	Driven	1¼	16	− 10	Gravel			1
2	...do	Claypool	68	Drilled	2	65	− 30	...do			2
3	...do	Etna Green	95	Driven	1¼	90	− 12	...do			4
4	Peter Newcomb	...do	55	...do	2	50	− 40	...do			3
5	Lucinda Hazen	2 miles northeast of Etna Green.	82	...do	1¼	82	+ 3	...do			
6	Public well at bank	Leesburg	18	...do	1¼	18	− 18	...do			5
7	Public supply	Milford	40	Drilled	4		− 8	...do			7
8	...do	Pierceton	210	...do	8	200	− 50	...do			8
9	Mrs. A. Personet	Sevastopol	99	...do	1½	95	− 30	...do			9
10	J. L. Warvel	Sidney	45	Driven	2	45	− 15	...do			10
11	S. N. Hawley	...do	143	...do	2	140	−100	...do			11
12	Public well	Silver Lake	26	Dug		26		...do			12
13	Public well at post-office.	Syracuse	42	Driven	2	42		...do			13
14	Winona Light and Water Co.	Warsaw	150	Drilled	8	135	+ 2½	...do			
15	A. Wilder & Co.	...do	18	Driven	1	18	+ 0	...do			
16	Henry Shane	...do	78	Drilled	2	78	+ 2	Sand	1	52	17
17	Mrs. A. Oldfather	...do	+400	...do	8		+ 4	Gravel	1½	53	18
18	Winona Lake assembly.	Winona Lake	95	...do	3	85	+ 1	...do			
19	...do	Power plant, Winona Lake.	96	...do		96	+ 4	...do			14
20	...do	Winona Lake	63	...do	2	63	+ 8	...do			

Mineral analyses of waters in Kosciusko County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	Public well	Burket	Driven well, 18 ft. by 1¼ in.	H. E. Barnard	Sept., 1907	Gravel	....	0.60	....	118	27	....	....	0.0	240	41	55	2.50	0.002	2	566	1
2	do	Claypool	Drilled well, 68 ft. by 2 in.	do	do	do	....	1.2	....	108	28	....	....	.0	293	32	9.0	.10	....	2	370	2
3	Peter Newcomb	Etna Green	Driven well, 55 ft. by 2 in.	do	do	do	....	1.60	....	94	26	....	....	.0	241	64	26	4.0	.001	9	400	4
4	Public well	do	Driven well, 95 ft. by 1¼ in.	do	do	do	....	1.6	....	83	27	....	....	.0	302	10.7	1	.20	.001	42	342	3
5	do	Leesburg	Driven well, 18 ft. by 1¼ in.	do	1907	do	....	.01	....	112	26	....	....	.0	304	99	31	6.0	.00	4	532	6
6	do	Mentone	Well, 90 ft. by 2 in.	do	do	....	....	.20	....	64	20	....	....	.0	243	64	11	.40	.00	4	534	....
7	Waterworks wells.	Milford	Drilled wells, 40 ft. by 4 in.	do	do	Gravel	....	.01	....	68	23	....	....	.0	224	160	15	2.0	.00	2	312	7
8	do	Pierceton	Drilled well, 210 ft. by 8 in.	do	Sept., 1907	do	....	.15	....	53	30	....	....	.0	294	1.2	1	.40	.001	19	344	8
9	Mrs. A. Personet	Sevastopol	Drilled well, 99 ft. by 1¼ in.	do	do	do	....	.10	....	106	26	....	....	.0	294	7	9	.00	.00	4	322	9
10	J. L. Warvel	Sidney	Driven well, 45 ft. by 2 in.	do	do	do	....	1.2	....	....	....	....	....	....	....	.0	34	.05	.001	42	464	10
11	S. N. Hawley	do	Driven well, 143 ft. by 2 in.	do	do	do	....	1.4	....	66	30	....	....	.0	303	93	1.0	0.3	.001	13	416	11
12	Public well	Silverlake	Open well, 26 ft.	do	do	do	....	.04	....	138	36	....	....	.0	378	52	76	8	.001	9	696	12
13	do	Syracuse	Driven well, 42 ft. by 2 in.	do	do	do	....	.60	....	86	35	....	....	.0	342	140	17	.10	.00	4	404	13
14	Winona Water and Light Co.	Winona Lake.	Drilled wells, 96 ft.	do	do	do	....	.3	....	87	25	....	....	.0	292	9	2	.30	.001	9	282	19
15	Winona Lake Assembly.	Assembly grounds.	Grotto Spring	A. B. Prescott	....	....	13	.70	0.48	84	24	4.3	0.45	....	323	48	3.9	.44	....	...	339	....
16	....	Warsaw	Center Lake	Pennsylvania R. R.	....	....	9.9	4.1		88	8.1	9.5		109	....	66	14	....	....	...	321	....
17	Henry Shane	do	Drilled well, 78 ft by 2 in.	R. B. Dole	Sept., 1907	Sand	27	1.06	....	62	26	25.		.0	339	8.6	.2	1.2	....	...	304	16
18	Mrs. Anna Oldfather.	do	Drilled well, 400 ft.	do	do	Gravel	27	1.3	....	62	26	23.		.0	345	4.8	.2	1.5	....	...	305	17

MADISON COUNTY.

SURFACE FEATURES AND DRAINAGE.

Madison County, which lies on the east edge of this area and in the second tier of counties from the south edge, is rectangular in outline and about twice as long as broad. Anderson, the county seat, is 32 miles northeast of Indianapolis. The county has an area of about 460 square miles, and had in 1900 a population of 70,470, or an average of 153 to the square mile. This population is due in part to the fertility of the farm lands, but is to a greater extent the result of the finds of natural gas in this and adjoining counties. At the present time, however, the supply of natural gas has decreased noticeably, many wells have been abandoned, and many factories whose existence depended on this cheap fuel have shut down.

The maximum relief of this county is a little more than 100 feet, but a large portion of its surface lies between 850 and 900 feet above sea level (Pl. I). The surface is a nearly level plain, interrupted only by the valleys of the larger streams.

The entire surface drainage of the county is received by White River and its tributaries. This river, which crosses the county from east to west somewhat south of the center, has a valley in most places much less than 90 feet deep, and commonly not more than one-half mile wide. Fall Creek, the largest tributary, crosses the south edge of the county. Near Emporia its valley is about 40 feet below the till plain, and becomes deeper westward. Pipe Creek, the most important tributary from the north, flows from the northeast corner to join White River a mile below Perkinsville. Each of these three large streams has a number of less important tributaries, but most of the valleys are mere grooves in the plain, and the uplands are flat and uneroded.

As moraines are lacking in the county, there are no natural lakes. The level plains offer no undrained depressions to form lake basins, and there is no evidence that lakes have ever existed here.

The only noteworthy area in which marshes occur is in the northwest corner, between the headwaters of Pipe Creek and Mississinewa River. Here a very flat area was formerly marshy, but by means of artificial surface ditches and by tiling the wet fields much of this land has been reclaimed.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

Important alluvial beds are found only along the bottoms of White River and Fall and Pipe creeks (Pl. I). These range in width from a few feet to about one-half mile, and their width along a single valley varies within short distances. Wells that penetrate the alluvium almost invariably reach abundant water at no great depth.

Pebbly clay or till occupies almost all of the surface except the narrow belts of valley alluvium, and is continuous below most of the alluvial beds (Pl. I). The thickness of the till throughout the county is shown in Plate II. At a few points in the deep valleys the bed rock outcrops and the till is absent, but at other places it is very thick. North of Halford is a narrow belt that is doubtless a part of the valley of a preglacial stream, in which the till is from 300 to 500 feet thick (Pl. II). It is possible that this buried valley extends to the northeast and connects with the valley that crosses Grant County, though the course it follows is not clear. Throughout the county as a whole the thickness of the till averages about 100 feet.

In most of that part of the county which lies south of Alexandria the drift is so deep that the ordinary wells do not go through it but obtain supplies of water from the drift itself. Many loosely curbed dug wells are in use, and some of them fail to reach gravel beds, but are supplied by slow seepage from the pebbly clay. Drilled wells are now becoming more popular, and experience has shown that few of these fail to find a water-bearing gravel bed somewhere above the limestone. The drift waters are all very hard, and, though good for household and farm purposes if not polluted, they are poor for steaming.

CONSOLIDATED MATERIALS.

The "Niagara" limestone, the youngest rock formation in this county, is everywhere the first bed rock found beneath the till. It outcrops in the valley of Fall Creek near Pendleton and in the White River valley near Anderson, but is elsewhere covered by glacial deposits of various thickness. The discovery of natural gas in this region has brought about the drilling of many deep wells, and by compiling the records of these it has been possible to determine approximately the depth to rock throughout the county (Pl. II). The "Niagara" limestone has proved to be a reliable source of supply for drilled wells. This fact became generally known when it was found that all gas borings had to be cased through the "Niagara" to keep the "Niagara" waters out of the lower part of the well. The waters are under artesian pressure and will flow at the surface in many lowland areas. Large numbers of abandoned gas wells are used for their water supply, and many rock wells have been drilled for the purpose of obtaining water, especially in those localities where the surface deposits are of moderate thickness. The waters are hard, but the overlying till protects them from contamination and the sanitary condition is usually excellent.

ARTESIAN AREAS.

Flowing wells have been obtained in an area along the bottom of Pipe Creek valley extending from below Frankton above Alexandria and including the lower ends of some of the larger tributary valleys. (Pl. IV, No. 56.) All these wells are on very low ground near the stream, and almost all are old gas wells, the water coming from the "Niagara" limestone. The largest flow is from a well 2 miles northeast of Frankton, which yields about 90 gallons per minute, and most of the flows are much less. It seems probable that wells in the valley below Frankton, as far down as the mouth, would find flowing waters. Records of flowing wells in this area are Nos. 16 and 17 in the table on page 174.

Area 57 (Pl. IV) includes the valley of White River for some distance above and below Anderson. In this area are several flowing wells, all of which procure water from the "Niagara" limestone. The source of the waters may be from the southeast toward Richmond, for in this direction the limestone is higher than in Madison County and in the intervening area the drift covering is thick. It is probable, however, that the water supply of this limestone is at least in part from the overlying till, and the artesian head may be from the till rather than from distant outcrops of this formation. This area may possibly be continuous downstream with area 56, by way of the lower valley of Pipe Creek.

In area 58 (Pl. IV) the conditions are very similar to those already described for areas 56 and 57. It includes the valley of Fall Creek entirely across the county, and the valley of Lick Creek to a point above Ingalls. Almost every gas well in the valley bottom between Pendleton and Middleton in Henry County yields flowing water. As in areas 56 and 57, the waters are from the "Niagara" limestone and the head is from the southeast. Further drilling will be likely to extend this area westward, as the valley becomes lower in that direction, and flows may be found along Fall Creek in Hamilton County.

A single flowing well is reported from the farm of Mr. John Fisher, 2½ miles southeast of Pendleton, in the valley of a small stream. (Pl. IV, No. 59.) This well was bored for gas, and the limestone was entered 60 feet below the surface. The "Niagara" is here 203 feet thick, and the flowing water comes from it.

In area 60 (Pl. IV), comprising a low, flat portion of the till plain south of Markleville, in the southeast corner of the county, there are a dozen or more flowing wells, all from gas borings. The water comes from the "Niagara," and the surface in this area is low enough to permit the water to flow.

A number of flowing wells are reported from an area between Ingalls and Lapel. (Pl. IV, No. 61.) These differ from the flowing wells described above in that the water is obtained from gravel in the till and the rock is not penetrated. Some of the wells flow in good volume, which shows no signs of diminishing.

There are several flowing wells in the neighborhood of Lapel (Pl. IV, No. 62), the flows being obtained from the "Niagara" limestone. One is estimated to yield 48 gallons per minute and another (No. 21, p. 174), attached to a hydraulic ram, pumps sufficient water for a house and barn. The least depth at which flowing waters have been reached is 55 feet, at the north edge of Lapel. The limestone was here reached at 35 feet below the surface.

CITY AND VILLAGE SUPPLIES.

Anderson.—The city of Anderson owns its own water supply, and the water is taken from White River, which flows through the city. Although no sewage enters the river for 3 or 4 miles above the waterworks, large quantities of it enter the river at Muncie, about 20 miles above, as well as at Winchester and at half a dozen villages between. Daily bacteria counts are made by the local health officer, and the number ranges from 800 to 400,000 per cubic centimeter in the raw river water. The number increases greatly after a rain. Within recent years a system for the filtration of the water has been installed, and is now being operated very successfully. The water is pumped from the river into coagulating basins, and to it are added from 1½ to 2 grains of sulphate of alumina to each gallon of water. This acts as a coagulant. The water is then run by gravity into filter tanks. The filter consists of 4 feet of fine sand overlying 1 foot of gravel. From the filter beds the water is run into a clear tank holding 500,000 gallons, and from this it is pumped by direct pressure into the mains. There are now in use 32½ miles of mains from 20 to 4 inches in diameter, and 2,200 taps are supplied. About one-third of the people use the city water, and the average daily pump is 1,500,000 gallons. Bacterial counts of the filtered and unfiltered waters show that the present process removes 96 to 98½ per cent of the bacteria, and the appearance is changed from that of a very muddy and unpleasant to a clear and sparkling water.

Many privately owned wells are still in use at Anderson, and almost all the drinking water is obtained from them. The water wells are dug, driven, and drilled and range in depth from 18 to 350 feet. In the city the rock is commonly reached about 120 feet below the surface. Wells shallower than this get water from gravel beds, and these are the most common, while rock wells are few in number. There are good springs along the sides of the river valley. A deep gas boring at Anderson gave the following section:[a]

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 236.

Log of gas well at Anderson.

	Feet.
Drift	114
Niagara limestone and shale	186
Clinton(?)	20
Hudson River and Utica	494
Trenton limestone	24
	838

Elwood.—The public supply of Elwood, owned by the Elwood Water Company, a private concern, is drawn from 14 drilled wells, located near the pumping station. Of these, 10 are 150 feet deep and 4 are 400 feet deep, all are 8 inches in diameter, and all obtain their water from the "Niagara" limestone. The water rises within 20 feet of the surface—that is, 40 feet above the limestone. The water is pumped directly from the wells into the mains.

There are two surface reservoirs which together hold 1,500,000 gallons for a reserve supply in case of fire, but otherwise these are not used. There are 14 miles of mains and 1,100 taps, and on an average 650,000 gallons per day are needed to supply about 40 per cent of the population. An analysis of this water is No. 16 in the table on page 175.

Most of the private wells in Elwood are dug, and range from 15 to 20 feet in depth. The water is found in clay or sand, but is too near the surface to be safe from pollution, especially where the wells are located among dwellings, barns, and other buildings. The water from the deeper wells or city supply is much safer. Some drilled wells have found abundant water in limestone at 60 to 150 feet below the surface, and this supply is highly recommended.

Alexandria.—The town of Alexandria owns a public supply obtained from seven drilled wells. Of these five were drilled for water and are located at the pumping station. They are 10 inches in diameter and 350 feet deep, all except the upper 15 or 20 feet being in the "Niagara" limestone. The chief water supply was reached at a depth of 110 feet. The pumps are also connected with two old gas borings, one 500 and the other 1,800 feet south of the pumping station. The water is pumped to a standpipe 100 feet high and holding 235,000 gallons, and is distributed by gravity. There are 10 miles of mains and 500 taps in use, and somewhat over 50 per cent of the people are supplied. About 300,000 gallons of water are used each day. Mineral analyses of the city water are Nos. 4 and 5 in the table on page 175.

Most of the private wells in Alexandria are drilled, and water from both the gravels and the underlying rock is used. Most of the wells that are 60 to 70 feet deep obtain an unfailing supply of water from the rock, although the head is said to be 25 feet lower than it was ten years ago. The geologic section at Alexandria, as shown by a gas boring, is as follows:[a]

Log of gas well at Alexandria.

	Feet.
Drift	20
Niagara limestone	261
Hudson River and Utica shale	611
Trenton limestone	5
	897

Frankton.—The Frankton public supply was installed in 1899 and is owned by the town. The water is drawn from a dug well 20 feet deep and 20 feet in diameter. This well is located 30 feet from Pipe Creek and only 10 feet above it, and in flood times the creek water can run into the top of the well. During even the normal stages of the creek the water is poor, though clear, and is used largely for sprinkling. There are 4 miles of mains and the water is used by about 40 per cent of the people. About 25,000 gallons per day are consumed.

Nearly every family in Frankton owns a well, most of the wells being dug and from 15 to 20 feet deep. In the south and east parts of the town are some drilled wells that go into limestone at a depth of about 130 feet. The shallow wells are in great danger of pollution by the penetration downward, from the surface and from dug cesspools, of sewage and organic matter of various sorts. Where it is possible the deeper drilled wells should be used, as they are much safer.

Summitville.—The Summitville water system, which is owned by the town and was installed in 1902, is supplied by a single drilled well 8 inches in diameter and 347½ feet deep. The well was drilled through the bottom of the "Niagara" limestone, which is here 100 feet below the surface. No reservoir is used, and the pressure is maintained directly from the pumps. There are 2½ miles of 8 and 4 inch mains and 130 taps, by which somewhat less than half the people are supplied. The well furnishes sufficient water for the ordinary city demand, but the pumping works are connected with a pond from which water can be drawn in case of fire.

In Summitville the private wells are dug, driven, or drilled, the dug wells 13 to 30 feet, and the driven wells 60 to 100 feet deep. The common depth to which wells are sunk is 60 feet, and gravel beds supply most of the water. Mineral analyses of wells of the dug type and of drilled wells in the limestone are Nos. 29, 30, and 31 in the table on page 176.

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 235.

The geologic section at Summitville is given below, as determined by a gas-well boring.

Log of gas well at Summitville.[a]

	Feet.
Drift	100
Niagara limestone	236
Hudson River limestone and shale	300
Utica shale	292
Trenton limestone	50
	978

Pendleton.—Pendleton is on the banks of Fall Creek, the valley of which is here cut 50 feet below the till plain. The "Niagara" limestone outcrops along the creek above and below town, and the drift in the lowlands is nowhere more than 18 feet thick. All the wells are drilled into rock and range in depth from 28 to 140 feet, the common depth being about 35 feet. The water is plentiful and excellent, and rises within 9 to 25 feet of the surface. There are some good springs along the valley sides. Flowing waters are found deep in the limestone by gas borings, but the ordinary water wells do not reach sufficient depths to procure water from this source.

Lapel.—Lapel, situated on Stony Creek near the west edge of the county, has a few shallow wells which obtain water from the till, but most of them are drilled into the limestone. The drift is here 30 to 70 feet deep, and the limestone waters are pure and in little danger of pollution. The common rock wells are only 30 to 59 feet deep. A few of the deeper limestone wells have obtained flowing waters, described above as in artesian area 62 (p. 169), but most of the wells do not flow.

Orestes.—Orestes has no waterworks system, and the supply is all from private wells. Most of the wells are dug and penetrate only 15 to 25 feet into the surface deposits, in which plenty of water is found; but this water is very easily polluted and is a source of great danger where used. Many drilled wells go into limestone, which is here within 50 to 60 feet of the surface, and the waters obtained are both abundant and pure. The drilled wells average about 70 feet in depth.

Ingalls.—Ingalls lies between Lick and Fall creeks in the southwest corner of the county and has a few dug wells, though the driven and drilled wells are more in favor. There are, perhaps, a dozen wells which reach the limestone, which is found at depths of 80 to 100 feet. The rock here seems to be unusually free from openings, and some of the rock wells can be pumped dry, though many yield large volumes of water. A few old gas wells have obtained flowing waters from the limestone. Driven wells 40 feet in average depth

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 260.

are most used, and the water, which comes from a gravel bed in the till, is plentiful and good.

Other communities.—The following table contains a list of other villages in Madison County, with particulars regarding their water supply:

Other village supplies in Madison County.

Town.	Population (1900).	Source.	Depth to rock.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Alliance	....	Wells, dug and drilled.	26	130	26	....	....	Gravel.
Chesterfield	164	Wells, driven and drilled.	20	400	22	110	0–30	Gravel and limestone.
Dundee	175	Wells, drilled and dug.	18	100	75	18–50	10–20	Do.
Emporia	61	Wells, driven and dug.	12	80	60	110	10–30	Gravel.
Fishersburg	250	Wells, drilled and driven.	35	140	75	30–70	....	Gravel and limestone.
Florida	98	Wells, driven and dug.	25	65	35	....	....	Gravel.
Gilman	400	.....do.	13	60	45	64	10	Do.
Leisure	100	Wells, dug and drilled.	20	55	25	25	9	Limestone or gravel.
Linwood	100	Wells, dug and driven.	18	89	25	....	....	Gravel.
Markleville	225	Wells, dug and drilled.	14	115	20	100	....	Gravel and limestone.
New Columbus	....	Wells, dug and drilled; springs.	32	120	33	140	3	Gravel.
Perkinsville	318	Wells, drilled and driven.	20	130	......	80–100	....	Gravel and limestone.

TYPICAL WELLS AND ANALYSES.

The two following tables contain detailed information regarding typical wells in Madison County and analyses of their waters. The last column in each table gives numbers referring to identical wells in the other table

Records of typical wells in Madison County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Temperature.	Analysis No.
			Feet.		*Inches.*	*Feet.*	*Feet.*		*Feet.*	*Gallons.*	*° F.*	
1	Public supply	Alexandria	350	Drilled	10	110		Limestone				4
2	W. B. Leeson	do	42	do	3	42		do	28		50	8
3	Joseph White	do	98	do	3			do	28			7
4	Alexandria Paper Co.	do		do	8		+2	do		20		
5	Perry Heritage	1½ miles NE. of Alexandria		do	8		+3	do	125	20		
6	Norton Brewing Co.	Anderson	275	do	8	270	−22	do				9
7	Harry Bevan	do	180	do	3	180	−40	do	60			
8	Hill Machine Co.	do	32	Driven	6	26	−24	Gravel				
9	Grand Hotel	do	60	Drilled		58		do				12
10	Union Building	do	250	do	6		−20	Limestone				10
11	J. B. Hook	Dundee	93	do	3			do	55			
12	Elwood Water Co.	Elwood	150	do	8		−20	do	60			} 16
13	do	do	400	do	8		−20	do	60			
14	American Sheet and Tin Plate Co.	do	350	do	4			do	40–60			15
15	American Shovel and Tool Co.	do	180	do	8			do	60			14
16	Charles T. Gooding	2¾ miles NE. of Frankton	39½	do	3	39½	+1½	do	9			
17	Daniel Abbott	2 miles NE. of Frankton	365	do	8	70	+10	do	4	90		
18	Odd Fellows	Gilman	45	Driven				Gravel				18
19	J. W. Higgs	Ingalls	90					Limestone				19
20	Cleveland, Cincinnati, Chicago, and St. Louis R. R.	do	40	Drilled	1½		−15	Gravel				20
21	Earl Woodward	Lapel	107	do	2	107	−20	Limestone	80			
22	David Conrad	do	50	do	2	50	−12	do	48			21
23	Robert Wilson	do	900	do	8	125	+4	do	35	45		
24	Paris Wisler	Leisure	50	do	2	50	−10	do				22
25	Jacob Capps	New Columbus	900	do	8		+3	do		5		24
26	E. S. Plackard	Orestes	107	do	3½	100	−5	do	50			
27	William Revis	do	18	Dug		16	−8	Gravel				25
28	Frank Detraz	Pendleton	140	Drilled	4			Limestone	20			26
29	J. P. Jones	do	30	do	4			do	3			27
30	F. W. Egelus	Perkinsville	130	do	3	130	−10	do	80			28
31	Public supply	Summitville	347	do	8		−0	do	100			29
32	R. B. Carll	do	30	Dug		30		Gravel				30
33	E. Homer Howard	do	60	Drilled		60		do				31

Mineral analyses of waters in Madison County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	J. Moody	Alexandria	Well, 72 ft.	Lake Erie and Western R. R.	Nov., 1902			3.5		152	72	29		201		109	103					
2	Mr. Booth	do	Well, 67 ft. by 2 in.	do				2.5		142	50	22		263		76	63					
3		do	Well, 1,000 ft. by 8 in.	do	Sept., 1904					83	29	5.9		186		15	6.8					
4	City supply	do	Drilled wells	do		Limestone	35	16		26	8.3	43		40		77	33				370	1
5	do	do	do	Dearborn Drug and Chemical Co.	Aug., 1900	do	17	2.5		71	32	17		168		44	17				344	
6		do	Pipe Creek	do			14	2.2		119	49	214		265		55	327				1,052	
7	Joseph White	do	Drilled well, 98 ft. by 3 in.	H. E. Barnard	Oct., 1907	Limestone		.40		22	53			.0	335	190	62	5.0	0.001	2	805	3
8	W. B. Leeson	do	Drilled well, 42 ft. by 3 in.	do	do	do		.40		134	33			.0	342	158	44	3.00	.002	0	704	2
9	T. M. Norton Brewing Co.	Anderson	Drilled well, 275 ft. by 8 in.	Wahl & Henius.	Oct., 1900	do				75	34	1.4(?)				12	7	.0			385	6
10	Union Building.	do	Drilled well, 250 ft. by 6 in.	Chase Palmer	July, 1907	do	22	2.6		56	35	13		.0	273	58	12	.07			347	10
11		South Anderson	Well, 60 ft.	Lake Erie and Western R. R.			5.6	8.4		104	14	24		190		36	12				401	
12	Grand Hotel	Anderson	Drilled well, 60 ft.	H. E. Barnard	Sept., 1907	Gravel	.0			140	24			.0	316	134	23	2.50	.004	0	566	9
13	American Shovel and Tool Co.	Elwood	Old gas well, drilled.	(?)		Limestone	1.2	6.8		77	30	6.7		173		30	10				344	
14	do	do	Drilled well, 180 ft. by 8 in.	(?)		do	11	.77		121	38	4.3		160		176	6.7				523	15
15	American Tin Plate Co.	do	Drilled well, 350 ft. by 8 in.	(?)		do	16	5.5		82	37	13		179		59	19				440	14
16	Elwood Water Co.	do	Drilled wells, 150 and 400 ft.	H. E. Smith		do		2.4		84	33	16		213		16	4.8	.0				12, 13
17	City supply	Frankton	Well, 20 ft.	H. E. Barnard	Sept., 1907			.0		111	.0			.0	305	148	23	2.50	.020	2	650	
18	Odd Fellows	Gilman	Driven well, 45 ft.	do	Oct., 1907	Gravel		1.4		25	42			.0	413	37	17	.100	.001	4	488	18

Mineral analyses of waters in Madison County—Continued.

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorate (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
19	J. W. Higgs	Ingalls	Drilled well, 90 ft.	H. E. Barnard	Oct., 1907	Limestone	....	0.8	....	83	29	....	...	0.0	306	7	2	0.100	0.000	0	360	19
20	Cleveland, Cincinnati, Chicago and St. Louis R. R.	do	Well, 40 ft. by 1¼ in.	do	do	....	....	1.2	....	103	28	....	...	.0	241	61	112	.000	.001	4	738	20
21	David Conrad	Lapel	Drilled well, 50 ft. by 2 in.	do	Sept., 1907	Limestone	....	.01	....	115	0.0	....	...	.0	360	141	35	.000	.000	0	468	22
22	Paris Wisler	Leisure	Drilled well, 50 ft. by 3½ in.	do	Oct., 1907	do	....	.10	....	110	0.0	....	...	.0	362	88	22	.100	.000	0	482	24
23	....	Mounds Park	Spring	do	do	....	....	.80	....	71	28	....	...	.0	305	51	7	.100	.001	0	332	.....
24	Jacob Capps	New Columbus.	Old gas well	do	do	Limestone	....	1.00	....	57	25	....	...	.0	326	28	6	.000	.000	33	394	25
25	Wm. Revis	Orestes	Open well, 18 ft.	do	Sept., 1907	Gravel	....	.00	....	97	33	....	...	.0	324	237	89	10	.001	2	1,024	27
26	F. Detraz	Pendleton	Drilled well, 140 ft. by 4 in.	do	Oct., 1907	Limestone	....	.0	....	69	32	....	...	.0	271	63	8.5	4.00	.001	5	580	28
27	J. P. Jones	do	Drilled well, 30 ft. by 4 in.	do	do	do	....	.0	....	14	33	....	...	.0	303	197	1.0	1.50	.000	9	494	29
28	F. W. Egelus	Perkinsville	Drilled well, 130 ft. by 3 in.	do	Sept., 1907	do	....	.14	....	76	5	....	...	.0	307	86	44	.000	.080	0	412	30
29	City supply	Summitville	Drilled well, 347 ft. by 8 in.	Dearborn Drug and Chemical Co.	Mar., 1903	do	17	3.9	....	93	28	17	...	209	....	16	14	......	......	..	402	31
30	R. B. Carll	do	Open well, 30 ft.	H. E. Barnard	Oct., 1907	Gravel	....	.0	....	45	72	....	...	.0	340	271	168	2.00	.005	0	1,192	32
31	E. Homer Howard.	do	Drilled well, 60 ft.	do	do	Limestone	....	1.4	....	42	36	....	...	.0	214	21	14	.200	.000	0	488	33

MARION COUNTY.

SURFACE FEATURES AND DRAINAGE.

Marion County is at the south edge of the area here under discussion, and in the middle north-south tier of counties. It has a total area of 400 square miles and is about 20 miles in each dimension, the only irregularity in outline being a slight eastward projection of the northeast corner. Indianapolis, the county seat, is also the state capital, and is by far the largest city in Indiana.

The surface of the county is a dissected plateau with the highest portions in the northwest and southwest corners. The range of elevation is from about 660 feet, at the lowest point in the White River valley, to somewhat more than 850 feet at Lawrence, and at the point where Marion, Hamilton, and Boone counties meet. (See Pl. I.)

White River crosses the county from north to south, and with its tributaries drains almost its entire area. The depth of the valley varies in different parts of the county as the elevations of the adjacent uplands vary, but is generally deeper in its lower course. At Riverside Park the morainic bluffs rise about 75 feet above the stream. The flood plain is broad, though generally less than a mile in width, but 10 to 25 feet above it there is along the entire river course within the county a broad gravel terrace, at many points 2 or 3 miles wide, though narrower at some places. Indianapolis lies on this terrace.

The largest tributary of White River is Fall Creek, joining it from the northeast. In this county the courses of these two streams are roughly parallel. Eagle Creek, which comes in from the northwest and joins the White below Indianapolis, has throughout its course a well-developed flood plain and valley. Near Traders Point the stream flows more than 50 feet below the uplands.

Buck Creek flows south along the southeast edge of the county and drains about 45 square miles of surface into East Fork of White River. All these streams have many small tributaries which drain the surface very thoroughly. There are no natural lakes worthy of mention.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

Alluvial materials occupy the bottoms of all the larger valleys, and vary in importance with the size of the streams. Another class of alluvial beds of much importance in this county comprises the stratified gravels which lie above the present flood plain of White River and form the great flat terrace, averaging perhaps 2 miles in width,[a] upon which Indianapolis is situated. The alluvial beds

[a] Leverett, Frank, Wells of southern Indiana: Water-Supply Paper U. S. Geol. Survey No. 26, p. 26.

furnish enormous quantities of water to wells wherever they occur. It has been estimated that in Indianapolis alone there are 25,000 wells, and all but a small part of this number are in the alluvium. The wells yield sufficient water for domestic uses, and many of the gravel wells produce large quantities of water for industrial purposes. Open gravel beds may be encountered at various depths, but those near the surface should be avoided as much as possible unless the wells are situated at some distance from possible sources of pollution.

As shown in Plate I, about half the surface of the county is covered with glacial moraine, occurring in three separate areas. East of White River the moraine surface is characteristic, consisting of low undulating hills, which, however, in few places stand more than 50 feet above their surroundings. West of this river the morainic character of the surface is less strongly shown, though in many places it is unmistakable. The conditions for obtaining wells in the moraines are very irregular, and the depth of wells at any given place depends to a great extent upon the amount and thickness of the gravel beds in the drift. For driven or drilled wells, gravels or sands must be penetrated, and the depth ranges from 10 or 15 to 200 feet, depths of 50 or 60 feet being common. Open or dug wells are used to a considerable extent, and these are supplied by seep waters from the clayey drift.

The relative area of surface covered by till is less important here than in any other county of this region south of Wabash River (Pl. I). Nevertheless, the till has been encountered by all borings that have gone through the surface deposits, and is probably continuous, over the rock, throughout the county. As in the moraines, dug wells supplied by the slow-moving waters of the clay are very common. Within recent years it has become generally understood that drilled wells are almost certain to find gravel beds from which more plentiful and better water can be had, and most new wells are of this type. The water table in the till fluctuates noticeably with the seasons, and for unfailing open wells it is necessary to dig below the permanent water level. Deep drilled or driven wells are unaffected by dry spells.

CONSOLIDATED MATERIALS.

The "Niagara" limestone in Marion County is everywhere overlain by younger rocks. Deep borings and our general knowledge of the structure of the rocks indicate that it extends continuously below the entire county and is 200 to 275 feet thick. It is of much the same character as it is farther to the north and east where surface outcrops occur. All wells in the "Niagara" encounter abundant waters which enter from well-defined openings. In Indianapolis many wells are supplied by these waters, but there the "Niagara" is overlain by the Devonian limestones and the wells are cased only to the top of the Devonian. Consequently, the waters obtained represent a mixture from the two formations, and it was difficult to get unmixed samples from either horizon.

East of Indianapolis the Devonian limestones are the youngest rocks. The records of drillers commonly class all limestones above the "Niagara" as "Corniferous," and this term will be used in the well logs. The limestone, from 40 to 50 feet thick, is very porous and open, and is sometimes spoken of as "honeycomb limestone."

The Devonian limestones yield good supplies of water, but they are drilled easily, and most drilled wells go through them to procure additional waters from the underlying "Niagara." No unmixed samples of water from these rocks could be obtained, but a number of analyses of waters from both the "Niagara" and "Corniferous" are given in the table on pages 185–186.

The New Albany shale underlies the drift in most of the south and west portions of the county. The shale is a very poor water producer, and wells which reach it have little chance of obtaining good water supplies unless the boring is continued through to the limestone below. At Bridgeport, near the top of this formation, the shale is 124 feet thick.

The "Knobstone" group, consisting of shales and sandstones, is thought to underlie the extreme southwest corner of the county. No wells were found which have penetrated these beds.

ARTESIAN AREAS.

There is a single district in Marion County in which flowing wells have been procured. This area lies west of Traders Point, along the creek bottom and on the slopes near by. (Pl. IV, No. 63.) Although a number of flowing wells have been obtained, one, much better than the others (No. 20 in the table on p. 184), is 87 feet deep and penetrated a gravel bed in the moraine. The water will rise 16 feet above the surface, and the flow at 2 feet above the surface is about 8 gallons per minute.

CITY AND VILLAGE SUPPLIES.

Indianapolis.—The Indianapolis water supply system, owned by the Indianapolis Water Company, a private corporation, was installed in 1870, a part of the water being taken from White River, and part from deep drilled wells. The river water is drawn from the lake formed by a dam at Broad Ripple Park, and carried by canal to filter beds near the Riverside pumping station. The filtration removes most of the matter in suspension, and materially reduces the number of bacteria present. About 60 per cent of the city water is supplied from the river. The remainder is obtained from wells at the Riverside pumping station, where the company owns 254 acres of carefully guarded land, on which the sanitary conditions are excellent. There are 33 drilled wells, most of which are situated along two lines, though a few of them are scattered. All are drilled into limestone, which is entered at 60 to 90 feet below the surface, and the depths range from 273 to 364 feet. The wells will yield about 16,000,000 gallons per day. When first drilled, in 1896, the water in the wells stood 8 feet above the low-water level of the river, but has now dropped to 32 feet below low-water level.

In August, 1898, a number of the wells were tested, and 25 delivered a normal yield of 18,694,583 gallons daily. In the same month, of three wells tested with a 90-foot air lift, No. 1 yielded 1,297,344 gallons per day, No. 2 yielded 1,323,195 gallons, and No. 3 yielded 1,263,805 gallons. The water from all the wells is pumped by air lift to the surface; but both the well and the filtered water is pumped by direct pressure into the mains. There are 282 miles of mains from 4 to 36 inches in diameter, and 18,863 services are in use, with 2,291 fire hydrants. About 140,000 people are supplied, and the average daily pump of both well and river water is 17,883,800 gallons.

Altogether the supply is a very satisfactory one. The health of the city is good, and there has been much less trouble with typhoid fever than there was when private wells furnished the supply.

Indianapolis has long been known as a city especially favored by the abundance of the underground water supply. Before the installation of the public water system every family owned a private well, and it is estimated that there are still 25,000 wells in use. Most of these are drilled or driven and obtain water from gravel beds which occur at various depths, all being good water bearers. In that part of the city which lies east of the river there are two distinct water zones in gravel, the upper, at 45 to 60 feet in depth, called the first gravel, and another at 70 to 80 feet, known as the second gravel. In the flat west of the river the first-gravel water is found at 12 to 20 feet below the surface, and the second gravel at about 50 feet. In almost all wells the first-gravel waters are polluted, for in all thickly settled areas it is inevitable that much organic matter and sewage should enter the ground, and some of this enters the shallow wells. A great deal of sickness is without question due to the use of wells of this class. The second-gravel waters are much safer, as they are protected above by a layer of clayey till, but many sanitary analyses indicate that even these wells contain organic matter. Many of them, however, supply an abundance of good water. The following is the log of a second-gravel well, the analysis of whose water is No. 8 in the table on page 185.

Log of Parry Manufacturing Company's well at Indianapolis.

	Feet.
Gravel	60
Blue clay	4
Gravel	11
	75

A number of other well logs are given by Leverett [a] in his report on the wells of southern Indiana.

Another and much superior class of water is that supplied by deep-drilled wells from the limestone. In Indianapolis the rock lies from 80 to 120 feet below the surface, and does not outcrop at the surface within many miles of the city. It is protected from contamination from above by a considerable thickness of till, and the chances of pollution from the surface are remote. There are, perhaps, 300 rock wells in the city, most of them used by manufacturing establishments or by office buildings. Two rock divisions may be entered, the "Corniferous" limestone, to a thickness of about 50 feet, and next below it the "Niagara" limestone. A number of analyses of rock waters in Indianapolis are given in the table on pages 185–186. These waters are all drawn from both formations, as the wells are cased only to the surface of the "Corniferous," while the borings go into the "Niagara." A well at the Deaf and Dumb Asylum is reported to have penetrated the following materials:

Log of well at the Deaf and Dumb Asylum.

	Ft.	in.
Depth of dry well	20	10
Gravel, clay, etc	78	8
Shale	3	6
Limestone	172	
Porous blue rock (water)	35	10
Hard rock	3	..
	313	10

The analysis of this water is to be found on page 185, No. 13.

No records of strata in deep borings at Indianapolis could be obtained, but the following logs are from gas borings at Broad Ripple, 7 miles north of the statehouse, and at Bridgeport, 9 miles southwest:

Section of well at Broad Ripple.[b]

	Feet.
Drift	55
Corniferous limestone	48
Niagara limestone	257
Hudson River and Utica	504
Trenton limestone	24
	888

[a] Op. cit., p. 28.

[b] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 237.

Section of well at Bridgeport.[a]

	Feet.
Drift	140
Devonian shale	124
Corniferous limestone	40
Niagara limestone	200
Hudson River limestone and shale	475
Trenton limestone	74
	1,108

Brightwood.—Brightwood is a part of Indianapolis, but is supplied by a separate water system, owned by the city. The water is obtained from two drilled wells 130 feet deep, and one well 380 feet deep, and is pumped to an underground reservoir holding 40,000 gallons. Direct pressure is used, and the system has 31,500 feet of mains. There are 400 consumers and about 93,000 gallons per day are used. The present supply is adequate for ordinary uses, but it gives insufficient fire protection.

Fort Benjamin Harrison.—Fort Benjamin Harrison, situated a few miles northeast of Indianapolis, was completed in 1907, and has its own water system. In 1907 there were four deep wells, of which three were drilled for water, and the fourth was an old gas well, plugged at 318 feet. The rock here lies at a depth of 195 feet, and the water is all taken from the limestone. Elaborate tests of the capacity of these wells have been made, and the four pumped together will yield about 120 gallons per minute. The log of one well is as follows:

Log of well at Fort Benjamin Harrison.

	Feet.
Soil	20
Hard gray sandy clay	40
Same with some gravel	40
Hardpan	40
White quartz sand (water-bearing)	35
Quicksand	3
Brown limestone (?)	7
Gray gravel, sand, and clay	10
Disintegrated limestone (water-bearing)	15
Brown sandy limestone	45
Gray limestone (plentiful water)	120
Shale	20
Hard limestone	7
	417

The water is pumped to two standpipes, and distributed by gravity, and the supply is expected to be sufficient for the demands of the fort.

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 237.

OTHER COMMUNITIES.

The following table contains a list of other villages in Marion County, with the conditions of their water supply:

Village supplies in Marion County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head above (+) or below (−) surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Acton	460	Wells, dug and driven.	22	40	35			Gravel.
Ben Davis	100	Wells, dug and drilled.	15	125	20 100			Sand and gravel.
Bridgeport	375	Wells, dug, driven, and drilled.	10	80	60			Do.
Broad Ripple	487	Wells, drilled and dug.	20	150	60	40–90		Sand, gravel, and limestone.
Castleton	199	do	6	112	20		− 8	Gravel.
Clermont	276	do	14	200	20		−15	Do.
Cumberland	310	do	15	240	140	240		Sand, gravel, and limestone.
Flackville	27	Wells, dug and driven.	15	50	30			Sand and gravel.
Glens Valley	52	do	30	60	50			Gravel.
Howland Station	100	Wells, driven	25	50	40			Do.
Lawrence	385	Wells, dug	10	30	20	200		Gravel and till.
New Augusta	215	Wells, drilled and dug.	14	110	90		− 3	Gravel.
New Bethel		Wells, driven, drilled, and dug.	20	118	60			Do.
Nora	70	Wells, driven and dug.	12	100	95	80		Gravel and limestone.
Oaklandon	300	Wells, dug and drilled.	11	150	20.	160	− 8	Gravel.
Southport	285	Wells, dug and driven.	10	40	35			Sand and gravel.
Traders' Point	50	Wells, dug and drilled.	20	87	25		+16 − 5	Do.
Valley Mills	145	do	15	135	20			Gravel.
West Newton	300	do	15	215	55	184		Do.

TYPICAL WELLS AND ANALYSES.

The following tables give detailed information regarding typical wells in Marion County and analyses of their waters. The last column in each table gives the numbers of identical wells in the other table.

Records of typical wells in Marion County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Analysis No.
			Feet.		*In.*	*Ft.*	*Ft.*		*Ft.*	*Gall.*	
1	C. W. Heady & Son	Broad Ripple	43	Drilled	3	42	− 8	Gravel	43	......	1
2	N. Morris Simons	Carmel	156	...do	2	150	−40	Limestone	120	......	....
3	W. C. Rush	Flackville	32	Driven	....	32	....	Gravel	....	......	2
4	Deaf and Dumb Asylum.	Indianapolis	313	Drilled	8	310	−30	Limestone	99	......	13
5	National Starch Co	.....do	380	...do	8	370	−18	.....do	98	......	12
6	Indiana Abattoir Co	.....do	300	...do	8	....	−15	.....do	....	......	....
7	Majestic Office Building.	.....do	217	...do	8	200	−45	.....do	....	......	15
8	Pope Motor Car Co	.....do	80	...do	4	80	−16	Gravel	....	......	....
9	Western Cold Storage and Ice Co.	.....do	354	...do	8	190	−30	Limestone	100	......	14
10	Home Brewing Co	.....do	365	...do	8	....	−60	.....do	....	......	7
11	Indianapolis Brewing Co.	.....do	300	...do	6	....	−70	.....do	....	......	16
12	Noelke-Richards Iron Works.	.....do	300	...do	8	230	−70	.....do	....	......	6
13	Indianapolis Cold Storage Co.	.....do	376	...do	10	....	−46	.....do	100	......	....
14	Indianapolis Light and Heat Co.	.....do	350	...do	10	325	−20	.....do	100	......	....
15	Interior Hardwood Co.	.....do	405	...do	4	370	−18	.....do	124	......	....
16	Capital Rattan Co	.....do	400	...do	6	110	−19	.....do	100	......	23
17	Advance Veneer and Lumber Co.	.....do	303	...do	6	185	−60	.....do	85	......	25
18	Soldiers and Sailors Monument.	.....do	270, 160	...do	8	....	−42	....	....	......	24
19	Augustus Bowen	Nora	77	...do	3	70	−28	Gravel	78	......	....
20	Everet Mavel	Traders Point	87	...do	2	87	+16	.....do	....	8	....

Mineral analyses of waters in Marion County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	C. W. Heady & Son.	Broad Ripple	Drilled well, 43 ft. by 3 in.	H. E. Barnard.	Sept., 1907	Gravel	....	0.80	....	117	26	....	....	0.0	315	69	33	0.00	.001	2	488	1
2	W. C. Rush	Flackville	Driven well, 70 ft.	do		do	....	.20	....	84	16	....	....	.0	267	57	40	.00	.001	0	308	3
3	L. S. Ayres & Co.	Indianapolis	Well, 300 ft.	T. W. Smith.	Sept., 1906		22	39		120	44	85		199	....	138	130	....	....	...	793	....
4	United States Encaustic Tile Co.	do	Well, 60 ft. by 6 in.	Dearborn Drug and Chemical Co.	Jan., 1903		7.2	2.0	....	123	31	26	....	207	....	112	21	....	....	...	539	....
5	Merchants' Light and Heat Co.	do	Well, 274 ft. by 10 in.	do			13	1.4	....	142	45	46	....	248	....	147	51	....	....	...	697	....
6	Noelke-Richards Iron Works.	do	Drilled well, 300 ft. by 8 in.[a]	do	Apr., 1906	Limestone	32	118	....	76	34	28	....	216	....	19	6.7	....	....	...	....	12
7	Home Brewing Co.	do	Drilled well, 365 ft. by 8 in.	do		do	12	7.7	....	130	42	34	....	233		107	51	....	....	...	....	10
8	Parry Manufacturing Co.	do	Well, 75 ft. by 8 in.	do	1905.	Gravel	11	2.1	....	106	31	11	....	163	....	111	17	....	....	...	460	....
9	State Life Building.	do	Drilled well, 188 ft.	do		Limestone	10	2.2	....	127	46	83	....	187	....	230	99	....	....	...	793	....
10	American Brewing Co.	do	Drilled wells, 205 ft.		April, 1907	do	15	.0	.0	143	46	41	....	....	....	113	99	.00	....	...	747	....
11	Central Power Co.	do	Drilled well, 240 ft. by 8 in.			do	1.4	3.9	....	63	34	32	....	210	....	3.2	10	....	....	...	366	....
12	National Starch Co.	do	Drilled well, 380 ft. by 8 in.	C. S. Miner		do	7.4	2.0	....	127	47	....	....	....	....	96(?)	50	....	....	...	792	5
13	Deaf and Dumb Asylum.	do	Drilled well, 313 ft. by 8 in.		Feb., 1905.	do	19	Tr.	....	96	35	11	....	223	....	19	10	....	....	...	414	4
14	Western Cold Storage and Ice Co.	do	Drilled well, 354 ft. by 8 in.[b]			do	7.2	11	....	119	44	21	....	227	....	100	31	....	....	...	....	9
15	Majestic Office Building.	do	Drilled well, 217 ft. by 8 in.	E. Martin		do	....	32	....	43	23	....	....	....	....	34	Tr.	Tr.	....	...	360	7

[a] Water from 230 feet.

[b] Water from 190 feet.

Mineral analyses of waters in Marion County—Continued.

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2)	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_3).	Color.	Total solids.	No. in record of wells.
16	Indianapolis Brewing Co.	Indianapolis	Drilled well, 175 ft. by 6 in.		1906.	Limestone	28	14	....	175	52	....	....	620(?)	....	91	78	Tr.	....	....	537	11
17		do	Pogues Run [a]	Lake Shore and Michigan Southern R. R.			....	3.2		86	30	24		147	....	100	27	0.0	....	....	....	....
18		do	do.[b]	do			....	....	....	91	32	27		171	....	96	25	....	....	....	....	....
19		do	White River [c]	do	Feb., 1904.		....	2.7		68	24	5.5		129	....	42	8.5	11	....	....	....	....
20	City supply	do	City drilled wells.	do	Dec., 1907.		....	....	....	85	31	31		169	....	54	48	....	....	....	....	....
21	Columbia Conserve Co.	do	Well, 315 ft.	No Scale Co.			9.6	3.4	....	70	46	7.9	....	205	....	24	12	....	....	....	....	....
22	Do.	do	Well, 180 ft.	do			14	2.2	....	78	44	7.9	....	205	....	38	12	....	....	....	401	....
23	Capital Rattan Co.	do	Drilled well, 400 ft.[d]	Chase Palmer.	July, 1907.	Limestone	14	.3	....	60	36	60		.0	344	95	18	2.5	....	....	466	16
24	Soldiers and Sailors' Monument.	do	Drilled wells, 270 and 160 ft.	do	do	do	18	Tr.	....	104	48	60		.0	310	186	80	21	....	....	726	18
25	Advance Veneer and Lumber Co.	do	Drilled well, 303 ft. by 6 in.[e]	do	do	do	16	.2	....	64	27	30		.0	406	5.6	5.2	2.7	....	....	365	17
26	Frank Fox	New Augusta.	Well, 143 ft.	H. E. Barnard.	Sept., 1907		....	.00	....	95	18	....	....	.0	299	124	10	.30	.000	2	328	....

[a] Average of four analyses. [b] High stage. [c] Normal stage. [d] Water from 110 feet. [e] Water from 185 feet.

MARSHALL COUNTY.

SURFACE FEATURES AND DRAINAGE.

Marshall County lies along the west edge of the area here under discussion and is in the second tier of counties south of the Michigan-Indiana line. It measures about 22 miles from east to west and 21 miles from north to south, and is therefore almost square. The total area is 440 square miles, and as the population in 1900 was 25,119, there were 57 inhabitants to the square mile. Plymouth, the county seat, is 108 miles north of Indianapolis and 75 miles southeast of Chicago.

The county is essentially plateau-like. The total range in elevation is but little more than 100 feet. The lowest point is in the Tippecanoe Valley in the southeast corner; several points on the west and north edge are more than 850 feet above sea level (Pl. I). The east half of the county is a monotonous plain, varied only by a few small areas of low moraine; the west half is largely occupied by the Maxinkuckee moraine, which extends southward from St. Joseph River through St. Joseph and Marshall counties and into Fulton County. This moraine, though of characteristic topography, is not of great relief, and in few places stands more than 50 feet above the bordering plains.

Along the west edge of the county is an irregular belt of flat surface, which is part of the bed of the glacial Lake Kankakee, and this abandoned basin is now a sandy plain.

Yellow River enters the county near its northeast corner and flows southwest in a zigzag course, draining almost three-fourths of the surface. In its course across the Maxinkuckee moraine the valley is in some places 40 to 50 feet below the bordering uplands, but in the till plain near Bremen it is much shallower. The flood plain does not generally exceed one-fourth mile in width.

Tippecanoe River crosses the southwest corner of the county through the till plain, and is fed by a number of small tributaries with shallow valleys.

A branch of Kankakee River heads in the moraine in the northwest corner of the county, and with its tributaries drains an area of about 40 square miles. The stream valleys are all small and shallow.

There are many lakes in Marshall County, all of which occupy basins in the moraine itself or in bordering areas where the drainage has been obstructed by the moraines. Most of the lakes are small, but the largest, Lake Maxinkuckee, in the southwest corner of the county, is about 2 square miles in area, and has a maximum depth of 76 feet. The lake, which is fed by springs and the drainage from a small area of the surrounding hilly moraine, has become popular as a summer resort, on account of its excellent boating, bathing, and fishing, and, besides the villages of Culver and Maxinkuckee, a considerable part of the shore line is occupied by residences and hotels. The other lakes are all much smaller, and most of them are shallow.

The northeast portion of the county was originally very poorly drained and largely occupied by marshes, and although there is still some wet ground, surface ditches and tiling have helped to bring much of the land under cultivation. Locally there are small marshes in poorly drained depressions in the moraine.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

Valley alluvium occurs to some extent along the banks of Yellow and Tippecanoe rivers. In the Yellow River valley the deposits range in width from one-fourth mile to almost nothing in the vicinity of Bremen. Along the west edge of the county there is a sand plain which was formerly the bed of a lake. Locally small dunes of wind-blown sand occur in the moraine near the old lake bed, and the sand in some places is still moving.

The surface of the entire eastern half of the county has more or less stratified gravel and sand. This covers the till and is so intermingled with it that the area has been classified by Mr. Leverett (Pl. I) as gravelly till and will be described under this heading.

All the types of alluvium mentioned are found either on flat plains of incomplete or sluggish drainage or in the valley lowlands. In either situation wells are easily obtained. Driven wells, 10 to 25 feet deep, are common, and the yield is abundant for ordinary domestic or farm uses. Such a well can often be sunk in a few hours and at a very small cost.

Morainal drift covers much of the west half of the county, and small areas in the east half. For successful driven or drilled wells in the moraine it is necessary to sink to open beds of gravel or coarse sand, and as these occur irregularly, they may be near the surface or considerably below it. As a rule the water table in the moraine is farther from the surface than on the plains, owing to the greater relief, and thus requires wells of greater depths. Where open beds are struck, however, the waters are abundant and pure. Artesian wells occur at many points in the moraine and are described below.

The till plains are found in the east half and the northwest corner of the county. A few deep borings have shown over 200 feet of till, and this is probably about the average thickness, exclusive of the overlying deposits. The till extends uninterruptedly below the moraines and the alluvial beds. Near the surface an unusual amount of gravel and sand is incorporated with and overlies the till, and this condition holds throughout the county.

The till plains of this county are particularly favored by the abundance and availability of their underground waters. Wells range from 15 to 40 feet in depth and generally pass through thin layers of sand and till into gravel. Driven wells are commonly used and are very satisfactory, affording good protection from surface pollution.

ARTESIAN AREAS.

Area 64 (Pl. IV) includes the valley of Yellow River for some distance above and below Plymouth, and although the valley is here scarcely more than one-eighth of a mile in width, twenty or thirty flowing wells have been obtained in it. All the flowing waters have been reached in gravels, but below the valley alluvium, for it is necessary to go through till to reach artesian waters. Flows have been obtained at various depths. At the old grist mill a gravel bed at a depth of only 28 feet yields strong flows. The wells at the waterworks procured artesian waters at depths of 50 to 60 feet and between 125 and 200 feet, and the volume of flow varies greatly from season to season. The head of the waters is from the surrounding moraine and the source can not be more than a few miles from the wells. Analyses of the waters from several wells in Plymouth are given in the table on pages 194–195.

Area 65 (Pl. IV) forms a narrow belt along the north and east shores of Lake Maxinkuckee. The flows all occur along the lowlands not more than 25 feet above the level of the lake, and as the moraine rises rather abruptly from the shores, the artesian belt is of small extent. Perhaps the best flows have been obtained at Culver Military Academy, just north of the town of Culver. There are about a dozen flowing wells on the grounds, each of which discharges 10 to 50 gallons or more per minute. The wells are 10 to 50 feet deep and the head is about 6 feet above the surface. The artesian waters are obtained in gravel underlying clayey drift.

In other places within this artesian area the flows are obtained at depths of 15 to 200 feet, and all have about the same head. The gravel beds in which the waters are under pressure probably come to the surface somewhere in the higher parts of the moraine, and the water that enters there acquires sufficient head in moving downward toward the lake to flow from wells that penetrate to it. No flows can be expected on ground more than 20 to 25 feet above lake level.

Area 66 (Pl. IV) includes a narrow belt of land running south and east from Donaldson along the foot of the moraine area. Several flowing wells have been obtained in gravel below pebbly clay at depths of 30 to 75 feet. The flows are rather weak, and yield only a few gallons per minute.

Area 67 (Pl. IV) has a situation similar to that of area 66, and these two may prove to be continuous. The conditions of flow are furnished by gravel beds in the moraine, which dip to the west below impervious clay beds. In the vicinity of Teegarden these gravel beds extend out beneath the gravelly plain, and nearly every household in that village has a flowing well. The head is commonly only a foot or two above ground, and some wells will flow only in the cellars below the level of the surface. The strongest well in the village (No. 19 in the table, p. 193) has a head 8 feet above ground and flows about 6 gallons per minute at that height. The common depth for wells is 30 to 50 feet, although some are deeper. A continuation of this flowing-well area extends westward from Teegarden along Yellowbank Creek, and along this valley flows have been obtained from gravel below till, at depths of 50 to 100 feet.

The valley of Yellow River near Bremen and for several miles below it (Pl. IV, No. 68) has furnished a number of flowing wells. At Bremen the water in a few wells rises to the surface and flows a little in wet seasons, and other wells to the southwest flow constantly, though none yield a large volume. The water is found in gravel below glacial clay at depths of 50 to 75 feet.

Several flowing wells are reported from the lowlands between Argos and Tippecanoe (Pl. IV, No. 69), the water being obtained from gravel beds beneath till. It is probable that the head of the waters is from the moraine to the east. The pressure is sufficient to cause flows only in favored localities.

CITY AND VILLAGE SUPPLIES.

Plymouth.—The city of Plymouth owns its excellent water supply, taken from flowing wells. The first three wells were drilled about 1888, and are still in use, and in 1895 nine additional wells were drilled. The water from all these is flowing for at least a part of the year, and in wet seasons the natural yield is sufficient to supply the demands. In dry seasons the yield is less and the requirements are greater, so the wells are then pumped by air lift. The early wells were from 126 to 196 feet deep, but wells of the later series are all less than 60 feet deep. In 1907 it was decided to put in an additional deep well, which was sunk in August of that year. It was learned at a later date that this well had entered shale, into which it was bored for some distance. No adequate supply of water was obtained from this material. At the time the town was visited (August 16, 1907) this well was reported to have penetrated the following materials:

Log of well at city waterworks, Plymouth.

	Feet.
Clay	9
Sand and gravel	180
Clay	23
Limestone	2
Shale	107
Limestone.	

From the wells the water flows or is pumped by air lift to an underground reservoir 24 feet in diameter and 14 feet deep. From this it is pumped by direct pressure into 8, 6, and 4 inch mains, of which 7¾ miles are now in use. There are about 430 service taps and 52 fire hydrants, and almost half of the people avail themselves of this supply. Records of the city wells are Nos. 15 and 16 in the table on page 193, and analyses of the waters are Nos. 16, 17, and 18 in the table on pages 194–195.

There are very few dug wells in Plymouth. Most of the private wells are drilled or driven, and 50 feet is the usual depth. Along the river valley there are many flowing wells, already described as in area 64 (p. 189). In the higher parts of town the same waters may be obtained, and they are also under artesian pressure, the water standing at about the same level as that to which it will rise in the flowing wells. The gravel waters are protected above by the impervious clay bed, and the supply is excellent.

Bremen.—At Bremen the waterworks, built by the city in 1893, are supplied by five driven wells, 4 and 6 inches in diameter, which obtain water from a depth of 60 feet. The water is obtained from gravel after sand, clay, and hardpan have been penetrated, and rises to about the level of the ground. One well was drilled to shale at 180 feet, but less water was found at that depth than at the 60-foot gravel horizon. The water is forced into a standpipe 104 feet high and holding 1,000 barrels, and from this it is distributed by gravity. There are about 7 miles of 6, 4, and 2 inch mains and 320 taps. It is estimated that 600,000 gallons a day are used to supply about 75 per cent of the population.

Most of the private wells in Bremen are driven, and range from 15 to 110 feet in depth, with 50 feet as the common depth. In some of these the water flows at the surface (area 68, p. 190), while in most it stands a short distance below ground. All the water is drawn from gravel below clay, and the supply of the deeper wells is protected from pollution.

Argos.—The Argos water system is owned by the city and was built in 1897. A single well, 120 feet deep and 6 inches in diameter, furnishes the entire supply, which is obtained from a gravel bed beneath glacial clay. The principal water-bearing bed was found at a depth of 80 feet, the water rising within 20 feet of the surface. The water is pumped to an 800-barrel underground reservoir, and from this by direct pressure into the mains. About 86 taps and 27 fire plugs are supplied by 18,800 feet of 6 and 4 inch mains, and 800 barrels of water are used per day. Only one-fifth of the people of the town use this supply.

About 80 per cent of the population of Argos use private wells, almost all of which are driven and from 20 to 100 feet deep, though most of them strike abundant water in gravel at 30 feet, and this water rises within 20 feet of the surface. The driven wells are very satisfactory and never fail unless obstructed in some way.

Bourbon.—The Bourbon waterworks are owned by the Union Water, Light, and Power Company and were installed in 1897. The water is obtained from two drilled wells, 8 inches in diameter and 150 feet deep, which reach a gravel bed after penetrating alternating layers of sand, till, and gravel. Deep-well pumps are used to lift the water into a standpipe 100 feet high and holding 2,100 barrels, and the water is distributed from this by gravity. Connections are so made that direct pressure can be used in case of fire. Only 70 services are supplied by this company, which furnishes water to about one-seventh of the people of the town. The average amount pumped daily is 1,500 barrels.

In Bourbon there are a great many private wells, and practically all are driven from 16 to 60 feet deep, averaging about 20 feet. The head of the water is from 3 to 30 feet below ground.

Culver.—The town of Culver, on Lake Maxinkuckee, installed a public water system in 1907. The stock of the company is owned by the town and by individuals, with the understanding that the town is to buy all of the stock. Three 4-inch wells have been drilled, and the contract has been let for a 6-inch well. The water is obtained from a gravel bed 70 feet below ground and rises within 12 feet of the surface. A pneumatic pressure tank is used and the water is distributed by the expansion of the compressed air in the tank, into which the water is forced by a 20-horsepower gasoline engine. Only 5 taps and 15 fire hydrants had been installed at the time of visit (September 23, 1907).

Drilled wells are the prevailing type in Culver. They are 10 to 135 feet deep, the average depth being about 70 feet. A few wells in the lowlands flow, but most of the town lies on the moraine considerably above the lake level, and the waters in few wells rise nearer than 12 feet to the surface. The waters come from gravel beds in the moraine and are good.

Other communities.—The following table contains a list of other villages in Marshall County, with particulars in regard to their water supply:

Other village supplies in Marshall County.

Town.	Population (1900).	Source.	Depth of wells.			Head above (+) or below (−) surface.	Character of water beds.
			Least.	Greatest.	Common.		
			Feet.	*Feet.*	*Feet.*	*Feet.*	
Ayr	86	Wells, driven	40	100	60		Gravel.
Burr Oak	200	....do	30	90	50		Do.
Donaldson	110	....do	15	80	60	0 to −15	Do.
Harris Station		....do	15	30	20		Do.
Inwood	279	....do	12	85	25		Do.
Lapaz	311	....do	40	50	40		Do.
Maxinkuckee	105	....do	80	140	100	−10 to −20	Do.
Rutland	64	....do	20	50	25	−10 to −15	Do.
Teegarden	150	....do	35	50	40	+ 8 to − 3	Do.
Tippecanoe	304	....do	20	40	30	−10 to −15	Do.
Tyner	167	Wells, driven and dug	17	145	30	−10 to −15	Do.
Walnut	141	Wells, dug	15	20	15	− 4 to −10	Do.

TYPICAL WELLS AND ANALYSES.

The two following tables give detailed information regarding typical wells in Marshall County and analyses of their waters. The last column in each table gives numbers referring to identical wells in the other table.

Records of type wells in Marshall County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Temperature.	Analysis No.
			Feet.		*In.*	*Ft.*	*Ft.*		*Ft.*	*Galls.*	*°F.*	
1	Public supply	Argos	120	Drilled	6	80	−20	Gravel				1
2	....do	Bourbon	150	..do	8	150	−36	..do				2
3	....do	Bremen	60	Driven	4 and 6	60	0	..do				4
4	Amos Friend	Burr Oak	60	..do	2	60	−50	..do				5
5	Public supply	Culver	70	Drilled	4	70	−12	..do				7
6	C. E. Hayes	....do	18	Driven	1¼	18		..do				8
7	Culver Military Academy.	....do	30- 50	..do	2		+ 6	..do		80–100		6
8	Charles Johnston	Donaldson		..do			+	..do		2		9
9	Township well	2 miles E. of Donaldson.	50	..do	2	50	+ 3	..do				
10	Andreas Bros	Hibbard	45	..do	1¼	45		..do				10
11	D. T. Warnacut	Inwood	30	..do	1¼	30		..do				11
12	H. Y. Shirk	Lapaz	45	..do	1¼	45	0	..do				12
13	Marshall County	Marshall County Infirmary.	86	Drilled	4	86	−28	..do				13
14	J. W. Wilson	Maxinkuckee	128	Driven	2	120	−20	..do				14
15	Plymouth waterworks.	Plymouth	126–196	Drilled	6		0	..do				17
16	....do	....do	50- 60	..do	2 and 4	50	+	..do				18
17	Wm. Zehner	....do	28	..do	12	28	+ 4	..do		300		15
18	G. E. Kimmel	Rutland	49	Driven	1½	45	−10	..do				
19	Jacob Hildebrand	Teegarden	45	..do	1¼	45	+ 8	..do		6	51	19
20	J. E. Johnson	Tyner	45	..do	1¼	45	−10	..do				20
21	Plymouth waterworks.	Plymouth	322+	Drilled					213			

Mineral analyses of waters in Marshall County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	Public supply	Argos	Drilled well, 120 ft. by 6 in.	H. E. Barnard	1907	Gravel	...	1.6	...	83	28	...	...	0.0	332	0.0	14	1.0	.020	9	272	1
2	do	Bourbon	Drilled well, 150 ft. by 8 in.	do	1907	do	...	1.6	...	65	26	...	...	.0	306	.0	12	.5	.001	4	354	2
3	J. W. Brougher	Bremen	Driven well, 65 ft. by 2 in.	do	1907	do	...	1.0	...	139	18	...	...	.0	161	16	13	6.00	.00	9	314	...
4	Public supply	do	Driven wells, 60 ft. by 6 in.	do	1907	do	...	.2	...	116	27	...	..	.0	289	42	30	6.00	.00	19	582	3
5	Amos Friend	Burr Oak	Driven well, 60 ft. by 2 in.	do	1907	do	...	.01	...	119	25	...	...	.0	379	103	30	6.0	.001	2	554	4
6	Culver Military Academy.	Culver	Driven well, 50 ft. by 2 in.	do	1907		...	.3	...	113	25	...	...	.0	286	8.6	2.0	.30	.001	52	252	7
7	Public supply	do	Drilled wells, 70 ft. by 4 in.	do	1907	Gravel	...	.1	...	74	28	...	...	.0	268	17	2	.10	.001	33	294	5
8	C. E. Hayes	do	Driven well, 18 ft. by 1¼ in.	do	1907	do	...	.01	...	88	29	...	...	.0	301	20	10	4.00	.001	2	408	6
9	Charles Johnston	Donaldson	Driven well	do	1907	do	...	.20	...	65	25	...	...	.0	245	25	9	.01	.001	9	306	8
10	Andreas Bros	Hibbard	Driven well, 45 ft. by 1¼ in.	do	1907	do	...	.80	...	78	31	...	...	.0	310	70	12	1.00	.00	4	404	10
11	D. T. Warnacut	Inwood	Driven well, 30 ft. by 1¼ in.	do	1907	do	...	.01	...	114	32	...	...	.0	360	37	52	8.0	.001	2	644	11
12	H. Y. Shirk	Lapaz	Driven well, 45 ft. by 1¼ in.	do	1907	do	...	.00	...	89	43	...	...	.0	331	62	33	1.2	.001	0	488	12
13	Marshall County	Marshall County Infirmary.	Drilled well, 86 ft. by 4 in.	do	1907	do	...	.0	...	85	32	...	...	.0	302	36	8	.2	.001	2	396	13
14	J. W. Wilson	Maxinkuckee	Driven well, 128 ft. by 2 in.	do	1907	do	...	.2	...	69	25	...	...	.0	268	6.6	1	.20	.06	19	344	14
15	Wm. Zehner	Plymouth	Drilled well, 28 ft. by 12 in.	do	1907	do	...	.2	...	68	24	...	...	.0	301	21	5	.00	.001	4	278	17
16	City supply	do	Drilled wells, 40 to 200 ft.	Lake Shore and Michigan Southern R. R.	1904	do	...	2	.7	61	27	9	.1	169	....	Tr.	1.3	....	....	...	....	....

17	.....do	.....do	Drilled wells, 126 to 196 ft.	R. B. Dole	1907	...do	21	.4	...	37	23	1	7	.0	242	2.3	1.5	.8	.....	...	207	15
18	.....do	.....do	Drilled wells, 50 to 60 ft.	.....do	1907	...do	18	3.8	...	61	30	7	.4	.0	326	3.6	.2	1.5	.....	...	285	16
19	Jacob Hildebrand	Teegarden	Driven well, 45 ft. by 1¼ in.	H. E. Barnard	1907	...do	...	.0	...	98	41	...	...	.0	398	17	9	.01	.001	0	394	19
20	J. E. Johnson	Tyner	.....do	.....do	1907	...do	...	.0	...	111	35	...	...	.0	336	78	32	18	.00	9	586	20
21	A. Nellans	Walnut	Open well, 14 ft	.....do	1907	...do	...	.01	...	150	41	...	...	.0	418	95	21	3.5	.001	2	720	....

MIAMI COUNTY.

SURFACE FEATURES AND DRAINAGE.

Miami County occupies the geographic center of the area discussed in this report. It is 30 miles long from north to south, and 12 wide, except in the southern portion, where a projection extends 4 miles to the east. The area is 375 square miles, and the population in 1900 was 28,344, or 75 to the square mile. Peru, the county seat, is 68 miles north of Indianapolis.

All of the area which does not lie in the valleys of the larger streams is classed as uplands, though the large streams and their branching tributaries have done much to dissect the plain. The surface slopes from both the north and south portions of the county toward Wabash River, which, at the west county line, is about 640 feet above sea level. The highest point is at the north edge, with an elevation of about 880 feet, making a total range in the county of about 250 feet.

Wabash River, which, with its tributaries, receives all the surface drainage from the county, crosses it centrally from east to west, and has a deep, broad valley, with a wide flood plain. At Peru the valley floor is 1½ miles broad and is more than 100 feet below the divide between Wabash and Eel rivers. There are rock outcrops along the lower valley on the south side of the river, but most of the deepening has been in the unconsolidated deposits.

Eel River, which joins the Wabash at Logansport, crosses the north half of Miami County in a northeast-southwest direction. Its valley is well developed but is neither so deep nor so broad as that of the Wabash.

Mississinewa River enters from the east to join the Wabash above Peru. The valley is narrow and canyon-like, 100 feet deep in places, and rock outcrops along the sides show that the stream has cut its channel 30 feet into the limestone.

Big Pipe Creek and Deer Creek cross the south portion of the county, and, with their tributaries, afford good drainage to the plateau. The valleys are much shallower than those of the three rivers mentioned above.

Miami County is almost devoid of natural lakes or marshes. This is rather remarkable when account is taken of the fact that its north end lies on a great moraine ridge which in the counties farther north and east is dotted with lakes. The well-developed drainage of this moraine by Eel River and its tributaries is, in part, the cause of this absence of poorly drained areas.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

The deposits of valley alluvium are of considerable importance, especially along the Wabash Valley. Here the gravels form not only the present flood plain of the river, but the extensive terraces above it. The city of Peru lies on the lowest terrace, and there are remnants of another terrace 30 feet above this one. On the flood plain at Peru the alluvium is from 15 to 25 feet thick; on the higher terrace it is much deeper, because of both the greater elevation above the stream and the sloping rock surface, which here dips to the north. Wells in the valley east and west of Peru have penetrated 40 to 60 feet of gravel. There are alluvial beds of some importance along the valleys of Eel and Mississinewa rivers and Big Pipe Creek, but they are all of smaller area and in general are thinner than the deposits of the Wabash Valley. The alluvium everywhere yields abundant water, and hundreds of wells are supplied by it. In sparsely settled districts these wells may be good, but in towns the waters from alluvium are liable to pollution, as surface drainage readily enters the porous material. Peru has a great many wells in alluvium, the shallow wells being particularly dangerous. Large numbers of cesspools drain into the gravel, and liquid matter from them finds its way to shallow wells.

That portion of the county which lies north of Eel River is almost entirely occupied by a broad moraine belt (Pl. I). There is also a small strip of this moraine between Wabash and Eel rivers, and another belt extends into the west and southwest part of the county. The topography of the main moraine belt is characteristic, the surface consisting of irregular knolls of sandy or gravelly drift or of the typical pebbly clay. The outlying moraine areas are similar but of a milder type. In the moraines water-bearing gravels or coarse sands are usually encountered at depths of 30 to 60 feet, although in some wells it is necessary to go deeper. The presence of impervious clay above the water-bearing bed is a guaranty against the commoner forms of contamination, and the waters, though hard, are always cool and palatable. Some dug wells obtain less desirable supplies by seepage from the clays near the surface.

The two principal till-plain areas, one of which lies between Wabash and Eel rivers and the other in the east and southeast parts of the county (Pl. I), were continuous before Wabash River cut its valley through them. The till is everywhere less than 100 feet thick south of the Wabash Valley, but is deeper to the north. Many wells 200 feet deep have failed to reach rock, and one well pierced over 300 feet of unconsolidated material.

Most wells in the till are dug and supply small quantities of water. Drilled wells that penetrate to considerable depths are becoming more and more common, and these are sunk to beds of gravel; and in the south half of the county many wells go through the till into the rock below.

CONSOLIDATED MATERIALS.

Throughout this entire county the surface deposits are immediately underlain by limestones of Silurian age. The term "Niagara" is commonly applied to all these limestones, though undoubtedly the younger limestone, the Kokomo ("water lime"), which outcrops at Kokomo, is present in part of the area. Well drillers do not distinguish between the two formations. There are many rock wells south of Peru and a few north of that city, all of which furnish abundant water obtained in the fractured upper portion of the formation or in openings in the body of the rock. Some of the openings are several inches in diameter, as shown by the way in which the drill will drop when openings are struck. Analyses of rock waters from various localities are given in the table on pages 203–204.

ARTESIAN AREAS.

Artesian area 70 (Pl. IV) includes a belt in the north part of Peru, the first terrace above the Wabash River flood plain, where several wells flow in small volume. At the factory of the Peru Canning Company are five drilled wells 67 feet deep, the water bed being a stratum of gravel. The wells flow at the surface when not pumped, but when in use the head of these wells and of all others in the neighborhood is lowered below the surface.

Flowing wells occur along Wabash River a few miles west of Peru. (Pl. IV, No. 71.) The largest of these wells, on the farm of G. M. Tillett, generally known as the "Flowing Well farm," was drilled for gas. The important flow of water is from the "Niagara" limestone and was reached 90 feet below the surface. When drilled the well was cased through this limestone, and salt water from the "Trenton" limestone rose within 4 feet of the well mouth. The casing was later pulled, and an analysis of the water (No. 20, p. 204) shows that the "Trenton" water does not enter into the present flow to a noticeable extent. This well was capped down to 1¼ inches, from which opening the water rises 22 feet above the surface. The force of the water lifted the pipe 14 inches out of the ground in two years, but when the cap was removed, the pipe settled back in two days. It now flows 600 gallons per minute. The drive pipe is 44 feet long and reaches to the limestone. The following materials were penetrated by this well:

Log of flowing well on farm of G. M. Tillett, near Peru.

	Feet.
Clay and gravel	44
Limestone	420
Shale	425
Trenton limestone	12
	901

There are several other flowing wells within a few miles, but none of them approaches this one in volume of flow.

Area 72 (Pl. IV) includes the lowlands in the vicinity of Deedsville. Here there are a few wells that flow continuously and several more that flow only in wet seasons. All the flows have been obtained from gravel beds in the moraine at depths of 30 to 60 feet. An analysis of the water from one of these wells is given in the table on page 203.

Area 73 (Pl. IV) includes the valley of a small creek west of Bunker Hill. The artesian waters come from the limestone, which here lies comparatively close to the surface, and the wells are drilled into the rock. One well flows at 8 feet above ground and yields about 4 gallons per minute. An analysis of the water is No. 1 in the table on page 203.

Flowing wells occur along the valley of Deer Creek and one of its tributaries. (Pl. IV, No. 74.) At Miami the limestone from which the artesian waters come is reached at a depth of 35 to 40 feet but is somewhat deeper in the valley to the east. The best wells are about 100 feet deep, and the water, of good quality, has everywhere a temperature of about 52° F. The wells flow somewhat more copiously in wet seasons than at other times.

Driven wells in the creek bottom south of Santa Fe have obtained flows at shallow depths (Pl. IV, No. 75) from gravel in the till. The yield is small and the conditions for flows are very local.

CITY AND VILLAGE SUPPLIES.

Peru.—The public water system of Peru is owned by the city and was installed in 1878, the water being drawn in part from wells and in part from Wabash River. Fourteen wells, situated on the south side of the river and above the city, are in use; they are 8 inches in diameter and about 350 feet in average depth. The water is drawn from the "Niagara" limestone and is good, though rather high in salt from the intrusion of the salty "Trenton" rock waters from poorly plugged gas wells. The wells furnish about 75 per cent of the water used, the remainder being pumped directly from Wabash River. The river receives sewage from Wabash, Huntington, and other towns above, and this impure water is mixed with the well water and contaminates the whole supply. At the time the city was visited it was having another well drilled, and enough wells are to be sunk in the near future to furnish all the water.

The water from the wells and the river is pumped to a reservoir 93 feet higher than the pumping station and having a capacity of 1,200,000 gallons. It is distributed by gravity to 24 miles of mains and 1,765 taps. About 1,300,000 gallons daily are needed to supply 65 per cent of the inhabitants. For fire protection the river water is pumped by direct pressure into the mains.

Large numbers of private wells, mostly driven or drilled, are in use in Peru. The depth to limestone ranges from 0 to 100 feet, and the wells obtain water from either the rock or the alluvial gravels. Near the river rock wells are common, but the rock surface becomes lower to the north, and the thicker gravels furnish driven wells with plentiful water. The rock waters are good, as are those from the deep gravels, but shallow gravel wells are dangerous and should be abandoned. A deep boring for oil just south of the city limits gives the following section:[a]

Log of deep boring at Peru.

	Feet.
Drift	10
Water lime and Niagara limestone	455
Clinton (?) limestone	15
Hudson River and Utica	449
Trenton limestone	27
	956

Converse.—The town of Converse owns its own public water system, which is supplied by a drilled well 8 inches in diameter and 240 feet deep. The well penetrated 192 feet into the limestone, and the water rises within 10 feet of the surface. An analysis of this water is No. 3 in the table on page 203. From the well the water is pumped by steam to a tank 72 feet high and holding 1,000 barrels, from which it is distributed by gravity. There are about 2 miles of 8, 6, and 4 inch mains, and 60 per cent of the people require 200,000 gallons per day. The water is pure and wholesome.

The private wells of Converse are dug, driven, and drilled, and range from 10 to 200 feet deep, though 60 feet is the average depth. The water stands about 10 feet below the surface, and the wells never fail. Limestone is entered at depths of 45 to 50 feet, and much of the water is obtained from the rock.

Denver.—Denver has no public water supply, and each family has a private well. These are almost all driven wells, from 10 to 60 feet deep, and though the average depth is only about 25 feet the supply is abundant. The driven wells penetrate gravel beds in the glacial deposits, and the limestone that is encountered at 45 to 100 feet below ground has always furnished plentiful supplies of water to the drilled wells that have gone into it.

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 254.

Bunker Hill.—Bunker Hill lies on a belt of low morainal drift. The wells are driven, drilled, or dug, and the common source of supply is the limestone, which is here encountered at 65 to 83 feet below the surface. The driven wells obtain gravel waters from shallow depths and are in constant danger of pollution from the cesspools of the town. The gravel wells are comparatively safe, but the rock wells are best protected from contamination, and the water is of excellent quality.

Other communities.—The following table contains a list of other villages in Miami County, with particulars in regard to their water supply:

Other village supplies in Miami County.

Town.	Population (1900).	Source.	Depth to rock.			Depth to rock.	Head above (+) or below (−) surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Amboy	402	Wells, drilled and dug.	20	45	25	14–45	− 8	Limestone.
Bennetts Switch	133	Wells, dug and drilled.	15	96	20	72		Gravel and limestone.
Chili	245	Wells, drilled and dug.	18	80	65			Gravel.
Courter		do	20	110	80		−15 to −25	Do.
Deedsville	112	Wells, driven, drilled, and dug.	10	65	30		+ 2 to —	Do.
Loree	30	Wells, drilled and dug.	20	120	100	80	−20 to −30	Gravel and limestone.
Macy	314	Wells, drilled, driven, and dug.	20	230	110		−20 to −40	Gravel.
McGrawsville	40	Wells, drilled and dug.	20	110	100		−18	Gravel and limestone.
Miami	244	Wells, driven, dug, and drilled.	8	105	10	36	− 8	Do.
Nead	21	Wells, bored, drilled, and dug.	20	105		85		Do.
North Grove	316	Wells, drilled	80	100	85	70	− 8	Limestone.
Perrysburg	86	Wells, driven, dug, and drilled.	20	156	50			Gravel.
Pettysville	47	Wells, driven	40	75	60		−30	Do.
Reserve	95	Wells, drilled and dug; and springs.	20	205	100	0–60		Limestone.
Santa Fe	92	Wells, drilled and dug.	14	110	100	70–80		Gravel and limestone.
Wagoner	105	Wells, drilled, driven, and dug.	15	170	100			Sand and gravel.
Wawpekong	205	Wells, drilled	100	130	110	79–95	−14	Limestone.
West Peru		Wells, driven and drilled.	10	130	12	20		Gravel and limestone.

TYPICAL WELLS AND ANALYSES.

The two following tables contain detailed information regarding typical wells in Miami County and analyses of their waters. The numbers in the last column of each table refer to identical wells in the other table.

Records of typical wells in Miami County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Temperature.	Analysis No.
			Feet.		*Inches.*	*Feet.*	*Feet.*		*Feet.*	*Gallons.*	*° F.*	
1	A. L. Weckler	Bunker Hill	172	Drilled	4	150	−45	Limestone	85			1
2	Clem Graves	¾ mile NW. of Bunker Hill	140	do	4		+ 8	do	14	4		2
3	Public supply	Converse	240	do	8		−10	do	48			3
4	Oscar Moody	Deedsville	34	Driven	1¼			Gravel				4
5	J. E. Milliron	Denver	35	Dug and driven	1¼	35		do				5
6	Mrs. S. A. Morgan	Macy	230	Drilled	2	230	−40	do				7
7	Public well	do	75	do	2			do				6
8	F. M. Tracy	Mexico	130	do	4							9
9	B. Herrell	Miami	105	do	4		+ 8	Limestone	36	1½	52½	10
10	L. M. Reeder	do	10	Dug			− 8	Gravel				11
11	F. F. Morris	Nead	105	Drilled	4			Limestone	85			8
12	J. W. Eltzroth	North Grove	82	do	2	82	− 8	do	70			12
13	Chas. A. Rannells	Perrysburg	56	Driven	2			Gravel				13
14	Brubaker & Criaer	do	156	Drilled	4		−10	do				
15	Peru Canning Co.	Peru	67	do	5	65	+ 0	do				
16	Peru Ice and Cold Storage Co.	do	214-300	do	4		−15	Limestone	−14			
17	G. M. Tillett	5 miles W. of Peru	901	do	8	90	+22	do	44	600	51½	20
18	J. O. Cole	West Peru	12	Driven	1¼	12	− 0	Gravel				19
19	F. K. Baber	Pettysville	74	do	2	50	−45	do				21
20	David Behney	Reserve	110	Drilled				Limestone	65			22
21	Levi Baker	Wagoner	170	do	2	170		Gravel				23
22	Public supply	Peru	500	do	8							

Mineral analyses of waters in Miami County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	A. L. Weckler	Bunker Hill	Drilled well, 172 ft. by 4 in.	H. E. Barnard	1907	Limestone	...	3.2	...	71	37	....	....	0.0	370	0.0	5	0.05	0.04	4	562	1
2	Clem Graves	3½ miles W. of Bunker Hill.	Drilled well, 140 ft. by 4 in.	do	1907	do	...	.01	...	66	38	....	....	.0	375	8	6	.05	.001	0	428	2
3	Public supply	Converse	Drilled well, 240 ft. by 8 in.	do	Oct., 1907	do	...	.40	...	90	25	....	....	.0	322	97	8	.05	.001	4	456	3
4	Oscar Moody	Deedsville	Driven well, 34 ft. by 1¼ in.	do	Nov., 1907	Gravel	...	2.0	...	120	40	....	....	.0	324	109	38	.10	.00	9	596	4
5	J. E. Milliron	Denver	Dug and driven well, 35 ft.	do	Sept., 1907	do	...	.0	...	86	27	....	....	6.0	218	68	10	.50	.00	0	434	5
6	Public well	Cloud's store, Macy.	Drilled well, 75 ft. by 2 in.	do	do	do	...	4.0	...	119	38	....	....	.0	368	9	18	.05	.001	19	484	7
7	Mrs. S. A. Morgan	Macy	Drilled well, 230 ft. by 2 in.	do	do	do	...	3.2	...	58	.0	....	....	.0	289	.0	3.0	18	.001	19	252	6
8	F. F. Morris	Nead	Drilled well, 105 ft. by 4 in.	do	1907	do	...	.01	...	108	41	....	....	.0	356	23	8.0	.3	.003	9	406	11
9	F. M. Tracy	Mexico	Drilled well, 47 ft. by 4 in.	do	Sept., 1907	do	...	.04	...	86	27	....	....	14	222	23	9.0	2.00	.001	4	394	8
10	B. Herrell	Miami	Drilled well, 105 ft. by 4 in.	do	Nov., 1907	do	...	.10	...	104	34	....	....	.0	297	9.0	3.0	.10	.00	5	352	9
11	L. M. Reeder	do	Open well, 10 ft.	do	do	do	...	.0	...	83	28	....	....	.0	200	145	45	.00	4.0	8	466	10
12	J. W. Eltzroth	North Grove	Drilled well, 82 ft. by 2 in.	do	Oct., 1907	Limestone	...	1.6	...	83	27	....	....	.0	332	98	6	.05	.04	6	422	12
13	C. A. Rannells	Perrysburg	Driven well, 56 ft. by 2 in.	do	Sept., 1907	Gravel	...	.12	...	71	22	....	....	.0	177	47	21	.05	.00	23	322	13
14	....	Peru	Wabash River[a]	Lake Shore and Michigan Southern.	Mar., 1907	....	...	....	...	46	14	44		69	....	38	77	5.4	....	...	....	....
15	....	do	Pipe Creek[b]	do	....	....	...	3.2		69	21	3.2		137	....	28	2.8	6.0	....	...	....	....
16	Public supply	do	Drilled well, 500 ft. by 8 in.	do	Mar., 1907	....	...	....	...	90	30	41		164	....	51	75	6.2	....	...	....	....

[a] High stage.

[b] Average of four samples.

Mineral analyses of waters in Miami County—Continued.

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
17	Peru Canning Co.	Peru	Drilled well, 67 ft. by 5 in.	R. B. Dole	Aug., 1907.	Gravel	23	2.8	...	91	34	9.6		0.0	350	76	2.2	Tr.	.....	...	392	....
18	Peru Ice and Cold Storage Co.	do	Drilled wells, 214 to 300 ft.	do	do	Limestone	18	2.3	0.6	162	52	36	7.4	.0	360	318	48	4.8	.....	...	835	....
19	J. O. Cole	West Peru	Driven well 12 ft. by 1¼ in.	H.E. Barnard	1907	Gravel	...	1.4	...	134	38	....	....	.0	316	53	84	.05	.001	50	360	13
20	G. M. Tillett	5 miles W. of Peru.	Drilled well, 90 ft.[a]	do	1907	Limestone	...	.6	...	101	30	....	....	.0	287	42	12	.1	.001	20	366	17
21	F. K. Baber	Pettysville	Driven well, 74 ft. by 2 in.	do	Sept., 1907.	Gravel	...	.1	...	85	25	....	....	.0	226	24	2	8.00	.001	4	356	19
22	D. Behney	Reserve	Drilled well, 110 ft.	do	1907	Limestone	...	.6	...	119	44	....	....	.0	290	33	35	8.0	.010	4	434	20
23	Levi Baker	Wagoner	Drilled well, 170 ft. by 2 in.	do	Sept., 1907.	Gravel	...	4.0	...	106	31	....	....	.0	336	.0	1.5	.7	.001	60	288	21

[a] Water at 90 feet.

ST. JOSEPH COUNTY.

SURFACE FEATURES AND DRAINAGE.

St. Joseph County is in the extreme northwest corner of the area under consideration, its north boundary being formed by the Indiana-Michigan state line. It has an area of 460 square miles, and had in 1900 a population of 58,881, more than half of which was in South Bend, the county seat. The average population per square mile was 128.

The county has a topography of great diversity, and the uplands, which in most counties include the greater part of the area, are here of small extent as compared with the lowlands, which occupy almost half of the surface. The uplands include only those areas mapped as moraine or till (Pl. I), and are confined to the southeast corner of the county and to scattered areas along the north edge. The small moraine-covered districts north of Kankakee River and east of the St. Joseph and the district extending south and east from South Bend have the rolling, somewhat irregular surface characteristic of moraines, though the till-covered portions are flat. The lower valleys of St. Joseph and Kankakee rivers are less than 700 feet above sea level, but the till plain in the southeast corner rises to more than 850 feet, giving a range in elevation in the county of over 150 feet.

There is a low flat area west of South Bend, on both sides of Kankakee River, that was once the bed of a lake. Much of the former lake bed is marsh, and although artificial drainage has resulted in the reclamation of a part of it, there is still an extensive marsh north of Kankakee River. The valley of St. Joseph River is also a broad belt of lowlands several miles wide.

St. Joseph River, the most important stream of the county, enters from the east, and flowing west to South Bend there turns sharply north into Michigan. The valley is several miles wide, and during the retreat of the last glacier was filled with alluvial gravels. The stream now occupies a narrow valley which it has cut into the gravels. The river has no important tributaries in this county.

Kankakee River heads in the Kankakee marsh within a few miles of the St. Joseph, and the divide between the two drainage systems is a low inconspicuous gravel flat. Kankakee River has a low gradient through its marshy basin.

The plain east of the Maxinkuckee moraine is drained by small streams which are tributary to Yellow River.

In the west half of the county are many small lakes of two distinct types. Those of one type, in the old Lake Kankakee bed, are shallow and bordered by marshes, and the basins were formed by the unequal accumulation of organic deposits in the marsh; those of the other type, in kettles or depressions in the moraine, are surrounded by low hills of glacial drift and are less marshy.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

An important belt of alluvium, 2 miles or more in width, lies along the St. Joseph River valley. The valley is filled with this material to a great depth, and the river has now intrenched itself in its own deposits which lie as broad terraces on either side. The lake-bed deposits of the Kankakee marsh are sands and gravels, but are finer and more perfectly stratified than the stream-laid materials and the sands form a larger proportion of their entire thickness. A third class of alluvium, found as outwash aprons beyond the edges of some of the moraines (Pl. I), overlies till plains or alluvial beds of river origin and is thickest near the moraines and thins out away from them.

All the alluvial beds are good water bearers. Shallow driven wells are much used, and the water, though in places of doubtful sanitary quality, is abundant and well suited for industrial purposes. The wells are easily polluted by drainage from cesspools or from the surface, as there is rarely a protecting bed of clay above.

The distribution of the moraines in the county is shown in Plate I, and the topography is of the irregular hill and hollow type characteristic of such deposits, though the relief is not great. The moraines were deposited on top of till, and their thickness is determined in few places, as well drillers fail to recognize the transition from moraine to the underlying glacial deposits. Many shallow dug wells are in use in the moraines, water being obtained from the clayey drift. Other drilled and driven wells penetrate to water-bearing gravel beds, which are found as deep as 100 feet below the surface. These wells are free from surface drainage and furnish excellent water, but the shallow wells are undesirable on account of the likelihood of contamination.

The till plain which occupies southeastern St. Joseph County is level and featureless. The till is continuous between the other surface deposits and the rock throughout the county, though it covers only one-fourth of the surface. Its thickness has been determined at only a few points, but probably averages about 200 feet. Many dug wells get small supplies of water from the till itself or enter gravel in the till at depths of 30 feet or less. If gravels are found the supply is plentiful, though as readily subject to pollution as the water from other open wells. Deeper gravels can as a rule be found by sinking tubular wells, which shut out the objectionable surface waters. These gravels afford the best available source of water in the till areas.

ARTESIAN AREAS.

Artesian area 76 (Pl. IV) includes the lowlands near St. Joseph River in South Bend and somewhat north of that city. The waters in a wider belt are under artesian pressure, but flows occur only on the low ground close to the stream. The best known of the flowing wells are at the two city pumping stations. The central station has 35 wells, all from 112 to 116 feet deep, and the flowing water comes from a gravel bed below till; at the north station there are 34 flowing wells, the water in which is doubtless from a continuation of the same gravel bed that supplies the wells at the central station, but this bed is only 87 feet below ground. The head of the wells at both stations is sufficient to cause flows when the pumps are idle, but when they are in operation the water stands considerably below the well mouth. At the central station the heavier pumping reduces the head of the waters for some distance in all directions, as shown by other wells supplied from the same gravel bed. The new wells at the plant of the Indiana and Michigan Electric Company, 200 yards from the pumping station and across the river from it, are influenced by the pumping of the city wells, and the head of the waters in them varies from +2 to −2 feet, according to the amount pumped from the wells across the river. The effect on surrounding wells is less marked at the north station, as the natural head of the waters is greater. A well in the park less than 100 yards from the city wells flowed 150 gallons per minute at a height of 8 feet above the ground at a time when the city pumps were at work. Flows have been obtained in the river valley as far north as St. Mary's Academy.

Area 67 (Pl. IV), described in part for Marshall County (p. 189), contains many flowing wells east and southeast of North Liberty. Eight flows are reported from a single farm. The wells are all on low ground, and the flowing waters come from a gravel bed at a depth of 60 to 80 feet, the head being from the moraine to the east.

CITY AND VILLAGE SUPPLIES.

South Bend.—The city of South Bend owns and operates its public waterworks, the water being drawn from about 70 drilled wells (area 76). There are two pumping stations, one of which, the central station, is on the river bank near the center of the city. The wells here are 112 to 116 feet deep and 4 to 10 inches in diameter. The pumping at this station is done either by water power from St. Joseph River or by steam. The north station, near the river at the north edge of the city, is supplied by about 34 drilled wells 6 to 10 inches in diameter and 87 feet deep. These wells also flow when the pumps are not running. Steam pumps are used at this station.

The water from both sets of wells is forced into a standpipe 225 feet high and holding 33,000 gallons. It is distributed from this standpipe by gravity. There are 80 miles of mains 4 to 24 inches in diameter, and 7,000 taps supply about 75 per cent of the people of the city. The average daily pump of the central station is 2,500,000 gallons, and of the north station 2,820,000 gallons. The capacity of the two stations is 14,000,000 gallons per day, but the wells will not furnish this amount of water, and new wells were being drilled at the central station in the fall of 1907. The city has also purchased 5 acres of land near the river, one-half mile below the north station, and it is planned to install an additional pumping station at this place. Analyses of water from the city wells are Nos. 12, 17, and 18 in the table on pages 213–214.

A great many private wells are in use in South Bend, both for domestic and industrial purposes. The town is located on a broad alluvial flat, and abundant water can everywhere be obtained by dug or driven wells at shallow depths. Most wells for family use are driven, averaging about 30 feet deep, and in these the water is abundant, but all analyses show much organic matter, and the presence of sewage in the upper-gravel waters is almost inevitable, as there is no protective covering of clay. The waters should never be used for domestic purposes. For manufacturing uses the waters are very satisfactory, although rather hard. Large quantities are obtained by building large, loosely curbed dug wells. A much safer water may usually be obtained from gravel at depths of 60 to 80 feet, beneath a layer of clay. A combination dug and drilled well at the Studebaker plant gave the following section:

Section of combination well at Studebaker plant, South Bend.

	Feet.
Sand and gravel	32
Coarse gravelly sand	8
Coarse sand, finer than that above	12
Rather fine angular sand	5
Coarse gravelly sand	4
Fine sand	4
Sandy blue clay	11
Fine blue clay	14
Fine quicksand	4
Sandy gravel	9
	103

A deep gas well near that given above penetrated the following materials:

Section of deep gas well, South Bend.[a]

	Feet.
Drift	160
Subcarboniferous and Hamilton shale	220
Corniferous limestone	60
Lower Helderberg limestone	40
Niagara limestone	640
Clinton (?) limestone	60
Hudson River and Utica	420
Trenton limestone	427
	2,027

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 260.

Mishawaka.—Mishawaka lies on the gravel terrace above St. Joseph River, about 4 miles east of South Bend. The waterworks are owned by the city, and the supply taken from St. Joseph River is pumped by direct pressure into 17 miles of mains and 1,550 service taps. About two-thirds of the people use this water and require an average of 2,000,000 gallons per day.

The river water is very badly polluted, and few people use it for drinking. It receives all the sewage from Elkhart, Goshen, and other towns, besides much local pollution, and in its raw state is unfit for a city supply. The water could be greatly improved by the installation of a filter system such as is used at Indianapolis, Anderson, and other cities in this State.

There has been some discussion in Mishawaka as to the possibility of obtaining an artesian water supply such as is used in South Bend. Independent investigations of the underground water resources of this city were undertaken in 1906 by George C. Matson, of this Survey, and by the writer, and the same conclusions were reached by both. It is apparent that the coarse gravel bed which furnishes the water at South Bend becomes more and more sandy to the east, and beneath the terrace south of Mishawaka it is replaced by fine sand. The water in this sand is under sufficient artesian pressure to carry it within 15 or 20 feet of the surface, but the fineness of the material prevents its ready flow into the well, and the yield of wells in it will be small.

A well which was drilled at the brewery of Kamm & Schellinger in 1906 reached a depth of 723 feet without getting a good water supply. Some sulphur water was obtained near the bottom of the well, but this was not satisfactory and the well was abandoned. The following materials were penetrated:

Section of drilled well at Kamm & Schellinger brewery, Mishawaka.

	Feet.
Sand, gravel, and clay; little water, but some at 125 feet	130
Blue shale; no water	240
Limestone; some sulphur water near bottom	353
	723

This company also drilled three test wells in the marsh one-half mile south of the brewery, but obtained little water. South and east of this town deep wells have been more successful. At the Dodge Manufacturing Company's plant there are five 6-inch wells, 45 to 60 feet deep, in a coarse gravel, which will yield 250 gallons per minute each. At the National Veneer Products Company's factory a single 6-inch well, 67 feet deep, will yield 500 gallons per minute. Analyses of both of these waters are Nos. 2 and 4 in the table on page 213.

The best available source of supply for Mishawaka, therefore, is from wells drilled south and east of the town. A large tract of land could be obtained around the wells, and proper precautions taken to prevent contamination of the water from sewage. If enough wells were drilled and they were placed as far apart as possible, there is every reason to believe that an adequate and desirable supply of well water could be obtained for the city.

The private wells of Mishawaka, from which the entire supply of drinking water is drawn, are almost all driven wells, which range in depth from 10 to 90 feet, and most of which end in gravel at a depth of 40 feet. The water rises within 2 to 20 feet of the surface. The wells furnish a somewhat safer and certainly a more palatable water than that furnished by the city system. The shallow wells, however, are almost certain to be more or less polluted when located in a thickly settled district. There is no protective bed of clay above the water-bearing gravel, and objectionable liquid matter of all kinds enters the ground in large quantities and becomes a part of the underground water supply. The deeper-driven wells are much safer than the shallow ones.

Walkerton.—The town of Walkerton built a public water system in 1897, and four drilled wells, 30 feet deep and 6 inches in diameter, furnish the supply. The wells enter gravel at 15 feet, and the yield is sufficient for present demands. A steam pump forces the water to a tank, which is 105 feet above ground and holds 1,700 barrels. Ordinarily the water is distributed by gravity, but in case of fire a higher pressure is obtained by pumping directly into the mains. There are about 3 miles of 6 and 4 inch mains and about half the people use the water, of which 3,000 barrels per day is pumped.

For private supplies driven wells are used in Walkerton to the exclusion of other types. These range in depth from 18 to 45 feet, the most common depth being 30 feet. The wells are in gravel, and the water stands at 15 to 25 feet below the surface. The waters are abundant, but all sewage of the town goes into the ground and the shallow wells are naturally the most easily polluted. It can be said that, in a general way, the deeper a well is the less likely it is to receive sewage from above. There are no impervious clay beds to protect the upper gravel waters.

New Carlisle.—The New Carlisle public water supply is owned by the town, and the water is taken from four drilled wells 118 feet deep and 5 inches in diameter. The town lies on the slopes of a moraine ridge and on the edge of the alluvial plain below, and the wells are near the base of the moraine slope. They penetrate to a gravel bed below blue clay and obtain abundant water of fine quality. A shallow dug well, 20 feet in diameter and 29 feet deep, has been built for use in emergencies, but the deep wells have so far supplied enough water for all purposes. The water is pumped to a tank located 85 feet above the pumps and holding 33,000 gallons, and is distributed by gravity to 2¾ miles of mains. Almost every family south of the railroad uses this water, though no mains have been laid north of it. Analyses of the city water are Nos. 5 and 6 in the table on page 213.

The few private wells in town, almost all of which are in the gravel plain north of the railroad, are of the driven type, and 20 feet is a usual depth. The water is from gravel and is plentiful, but because of the openness of the gravels and the abundance of private cess-pools and other possible sources of contamination the sanitary conditions are unsafe.

North Liberty.—North Liberty has no public supply. The town lies on an alluvial plain, and each family owns a driven well, usually from 35 to 60 feet in depth, in which the water stands within 12 to 15 feet of the surface. The wells enter a gravel bed, and overlying clay beds are thin or altogether wanting. The supply is plentiful, and the deeper wells are good, especially when clay is penetrated above the water-bearing bed. Otherwise sewage is likely to enter, and the shallow wells in this town are not safe.

Other communities.—The following table contains a list of other villages in St. Joseph County, with particulars regarding their water supply:

Other village supplies in St. Joseph County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Crumstown	100	Wells, driven	10	25	20	133	6–10	Gravel.
Granger	67	do	25	50	28		25	Do.
Hamilton		do	10	30	18			Gravel and sand.
Lakeville	350	do	30	85	50		10–20	Gravel.
Lydick	100	do	20	75	40			Do.
Osceola	177	do	25	30	27		22	Do.
Polan Town		do	10	22	18		6	Do.
Terre Coupe		do	10	30	18			Gravel and sand.
Walnut Grove		do	90	113	100		80	Gravel.
Woodland	90	Wells, driven and dug.	20	110	100			Do.
Wyatt	170	do	18	120	100		4–20	Do.

TYPICAL WELLS AND ANALYSES.

The two following tables give detailed information regarding typical wells in St. Joseph County, and analyses of their waters. The numbers in the last column of each table refer to identical wells in the other table.

Records of typical wells in St. Joseph County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Analysis No.
			Feet.		*Inches.*	*Feet.*	*Feet.*		*Ft.*	
1	Alexander Moore	Lakeville......	50	Driven..	2	50	−15	Gravel..	....	1
2	Dodge Manufacturing Co.	Mishawaka....	45-60	....	6	45-60	−10	...do.....	....	2
3	Kamm & Schellinger.	.....do.........	723	Drilled..	6	125	....	Sand....	125	.....
4	Public well......	Mishawaka, corner Main and Second streets.	35	Driven..	1¼	35	....	Gravel..	....	3
5	Mishawaka Woolen Manufacturing Co.	Mishawaka....	176	Drilled..	6	......	....	....	49	.....
6	National Veneer Products Co.	.....do.........	67	Driven..	6	55	− 3	Gravel..	....	4
7	Public supply...	New Carlisle..	118	Drilled..	5	118	−28	...do.....	....	5, 6
8	Robert Jimison.	North Liberty	38	Driven..	1¼	38	−12	...do.....	....	7
9	Notre Dame University.	Notre Dame..	150	Drilled..	8	140	−25	...do.....	....	8
10	St. Mary's Academy.	.....do.........	100	...do.....	8, 6	100	−15 to +3	...do.....	....	.....
11	L. S. Crull......	Osceola.......	27	Driven..	1¼	25	−22	...do.....	....	9
12	Public supply...	South Bend (central station).	112-116	Drilled..	4-10	112	+ 2	...do.....	....	17
13	Do..........	South Bend (north station).	87	...do.....	6-10	85	+ 8	...do.....	....	18
14	Singer Manufacturing Co.	South Bend...	40-100	...do.....	4	40-100	−12	...do.....	....	14
15	Indiana & Michigan Electric Co.	.....do.........	112	...do.....	8	112	+2 to −2	...do.....	....	16
16	Oliver Chilled Plow Works.	.....do.........	30	Dug.....	....	30	− 9½	...do.....	....	15
17	Studebaker Bros	.....do.........	90	Drilled..	10	90	....	...do.....	....	.....
18	Public supply...	Walkerton....	30	...do.....	6	....	−15	...do.....	....	20, 21
19	J. H. Lydick....	Walnut Grove	113	Driven..	2	113	−80	...do.....	....	.....

Mineral analyses of waters in St. Joseph County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	Alexander Moore	Lakeville	Driven well, 50 ft. by 2 in.	H. E. Barnard	1907	Gravel	...	0.03	...	43	36	...	...	0.0	307	48	3.0	0.10	0.001	2	364	1
2	Dodge Manufacturing Co.	Mishawaka	Driven wells, 45 to 60 ft. by 6 in.	?	....	do	14	2.6	...	133	75	7.1	...	184	....	565	8.5	....	....	...	....	2
3	Public well	Main and Second streets, Mishawaka.	Driven well, 35 ft. by 1½ in.	H. E. Barnard	1907	do	...	.20	...	152	44	...	...	.0	317	238	39	4	.001	2	794	4
4	National Veneer Products Co.	Mishawaka	Driven well, 67 ft. by 6 in.	do	1907	do	...	.01	...	71	76	...	...	.0	238	97	4.0	1.20	.001	9	294	6
5	City supply	New Carlisle	Drilled well, 118 ft. by 5 in.	Lake Shore and Michigan Southern R. R.	Sept., 1905	do	...	...	...	68	23	2.3		146	....	23	3.5	....	....	...	....	7
6	do	do	Drilled well, 118 ft. by 5 in.	H. E. Barnard	1907	do	...	.4	...	61	25	...	...	.0	273	41	2	.01	.001	9	326	7
7	Robert Jimison	North Liberty	Driven well, 38 ft. by 1¼ in.	do	1907	do	...	...	...	69	27	...	...	.0	289	112	36	.01	.001	2	462	8
8	Notre Dame University.	Notre Dame	Drilled well, 150 ft. by 8 in.	do	1907	do	...	.0	...	72	26	...	...	.0	243	30	4	.00	.001	2	236	9
9	L. S. Crull	Osceola	Driven well, 27 ft. by 1¼ in.	do	1907	do	...	.10	...	89	24	...	...	.0	213	70	43	1.0	.001	0	450	11
10	Lake Shore and Michigan Southern R. R.	South Bend	Well, 32 ft. by 20 ft.	Lake Shore and Michigan Southern R. R.	May, 1907	do	...	...	...	87	27	16		158	....	40	14	44	....	...	....	....
11	Chicago, Indiana and Southern R. R.	do	Well, 25 ft. by 3 in.	do	do	do	...	...	...	159	58	37		135	....	399	57	.0	....	...	....	....
12	City supply	do	Drilled wells, 87–116 ft. by 6 in.	do	Jan., 1905	do	...	...	...	68	23	6.3		138	....	32	9.7	Tr.	....	...	....	....
13	Studebaker Bros	do	Well 35 ft. by 20 ft.	do	Dec., 1903	do	...	1.0		71	25	4.2		144	....	35	7.8	9.8	....	...	....	....
14	Singer Manufacturing Co.	do	Open well, 35 ft.	Dearborn Chemical Co.	....	do	17	6.5	...	109	33	33	...	213	....	96	18	....	....	...	532	14
15	Oliver Plow Company	do	Open well, 30 ft. by 30 ft.	H. E. Barnard	1907	do	...	.0	...	76	28	...	...	.0	247	39	24	1.5	.001	0	372	16
16	Indiana and Michigan Electric Co.	do	Drilled well, 112 ft. by 8 in.	do	1907	do	...	.0	...	57	34	...	...	.0	218	10	7	.0	.001	4	270	15

Mineral analyses of waters in St. Joseph County—Continued.

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe.)	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
17	City supply (central station).	South Bend...	Drilled wells, 112 to 116 ft.	Chase Palmer.....	Oct., 1907	Gravel..	13	0.4	....	88	29	16		0.0	294	78	18	3.2	.....	...	405	12
18	City supply (north station).	.....do.........	Drilled wells, 87 ft...	.....do............	.....do.....	...do.....	14	3.8	....	45	22	7.7		6.0	210	25	3.2	0.0	.....	...	242	13
19	D. M. Barton..........	Terre Coupe...	Well, 14 ft. by 1½ in.	Lake Shore and Michigan Southern R. R.	Sept., 1905	....	...	....	....	48	12	3.2		86	....	23	5.0	....	.....	...	....	....
20	Public supply.........	Walkerton....	Drilled wells, 30-40 ft. by 6 in.	.....do............	Feb., 1904	Gravel..	...	1.0		95	26	43		139	....	72	67	47	.....	...	....	18
21	.....do................	.....do.........	.....do...............	H. E. Barnard....	1907.......	...do.....	...	....	....	89	30	...	...	.0	254	73	19	4	.0	2	612	18

TIPTON COUNTY.

SURFACE FEATURES AND DRAINAGE.

Tipton County lies in the middle north-south tier of counties in the area under discussion and in the third tier from the south edge. Tipton, the county seat, is 36 miles north of Indianapolis. The county, which is rectangular in outline, is 20 miles long and 13 wide, and has an area of 260 square miles. The population in 1900 was 19,116, or 73 inhabitants to the square mile.

The county, a typical upland area, lies on the divide between White and Wabash rivers, although the watershed is a flat, featureless plain. About three-fourths of the surface lies between 850 and 900 feet above sea level. Only the valley of Duck Creek, in the southwest corner, falls below 850 feet, and in the southwest edge the surface rises somewhat above 900 feet, the total range in elevation being not more than 75 feet.

All of the surface except a small area bordering on Boone and Hamilton counties consists of a flat plain with an entire absence of hills or of deep valleys. In some places, however, it shows slight wavelike undulations, with the crests only 5 or 6 feet above the troughs. The morainic areas (Pl. I) have somewhat greater relief, with low knolls and depressions and scattered bowlders, but even there the crests of knolls are not many feet above the plain.

Tipton County includes a portion of the divide between the White River and the Wabash drainage systems. Cicero Creek, the most important of the tributaries of the White, drains the south-central and southwest portions, and at Atlanta lies 20 to 30 feet below the general level and has a narrow flood plain, but the valley becomes shallower to the north and west until the creek is only a few feet below the plain. Polliwog Creek, another tributary of White River, drains the southeast corner of the county.

North of Tipton the drainage belongs to the Wabash system. Most of the surface water is carried northeast into Howard County by Turkey and Mud creeks, tributaries of Wild Cat Creek, which in turn flows westward into Wabash River. All the valleys of the county are shallow and narrow.

Although the surface everywhere is flat, the drainage is well developed and there are no lakes and marshes. Still, in the districts where the slope is very slight, it has been found advisable to assist the natural drainage by ditches and by underground tilling. As a result, the land is nowhere too wet to permit cultivation.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

Alluvial deposits are of as little extent here as in any other county in the area. They occur only as narrow and shallow flood-plain deposits along the larger streams, and since only the headwaters of even these larger streams are found in the county, it follows that there has been but little stream deposition and that the alluvium is generally unimportant as a source of water. The only valley in which the stream deposits have been penetrated by many wells is that of Cicero Creek, where some driven wells have found plenty of water at shallow depths in the open gravels along the valley floor.

The moraines of the county are all at its western edge. The larger area (Pl. I) is the north end of the long, low ridge that extends northward from the vicinity of Indianapolis. It is here not a very important topographic feature, but has a little more relief and is slightly more rolling than the till plain. There is also a small area of moraine that lies mostly in Howard County but extends into the extreme northwest corner of Tipton County. It is of the same general topographic character as that farther south.

For a long time shallow dug wells only were used to obtain water from the moraine areas, and these were supplied by slow seepage from the clay beds. Of late years the tide of public sentiment has turned strongly toward deep-driven or drilled wells, which are gradually replacing open wells. Many of them penetrate 100 to 200 feet of surface materials, and waters are almost everywhere obtained from layers of gravel interbedded with the clayey drift.

The till occupies the surface over a large proportion of the county and varies in thickness from 40 to 75 feet along the north and east edge to 200 or 300 feet at the south and west edges. The material is similar to that of the till wherever found in this area. Dug wells still predominate in the till, especially in the places where it is exceptionally thick, and many receive their entire supply from the close-grained clay. Such supplies are unsatisfactory, both in regard to quantity and quality, and the proportion of drilled wells is increasing. If the drilled wells fail to find sufficient water in the till they may be continued into the limestone, in which plentiful waters of good quality are to be found.

CONSOLIDATED MATERIALS.

As shown on Plate III, rocks of two periods underlie the surface deposits of Tipton County. The Silurian outcrops are all limestones and consist of the "Niagara" formation and the Kokomo limestone ("water lime"). Above them, and outcropping in the west edge of the county, are the lower Devonian beds. The beds all dip at low angles to the west and have been worn away by erosion to give the present distribution of outcrops below the drift. No rocks appear at the surface in this county.

As stated above, the Kokomo and "Niagara" beds are limestones, the former somewhat less massive than the latter. The Silurian limestones have been penetrated by wells at a number of points at Tipton and eastward. All of these rock wells show large quantities of water, and no record was found of wells which failed to get plenty of water when the rock was entered.

The Devonian limestones occur only in the area of very heavy drift and have been little exploited for their water. Deep gas borings have found good supplies, but these go into the Silurian as well as the Devonian rocks. It is probable, however, that the Devonian limestones are water bearing here as well as in other places where they have been tested, and wells of sufficient depth should be successful in these rocks.

ARTESIAN AREAS.

In contrast to the numerous artesian areas in the counties to the north and south, there are only two areas in Tipton County in which flowing wells are known to occur. This is explained by the position of the county on a high level plain and by the shallowness of the stream valleys. The head of the flowing waters in the neighboring counties is rarely more than 2 or 3 feet above the surface, even in the deeper valleys, and the absence of deep valleys in this county leaves few areas where the surface is below the level to which the artesian waters will rise.

In the valley of Cicero Creek near Tipton and to the south there are a number of flowing wells. (Pl. IV, No. 77.) All are old gas wells which are cased down to rock, so that the flowing waters must come from the Kokomo limestone ("water lime") or the "Niagara" formation. The flows are all small, and some wells which once flowed have now failed. The head of the water is but little above the surface, and seems gradually to be decreasing.

Flowing wells occur along the valley of Mud Creek within a few miles of Sharpsville. (Pl. IV, No. 78.) All are from old gas borings, and the water comes from the Silurian limestones. The strongest of these, on the farm of Mrs. Hannah Davenport, flows in a $1\frac{1}{4}$-inch stream.

CITY AND VILLAGE SUPPLIES.

Tipton.—The Tipton waterworks are the property of the city, and the supply is drawn from fifteen wells, of which five are gravel wells 68 to 114 feet deep. The water-bearing gravels are well protected from pollution from above by a heavy coating of impervious till. The rock wells, 10 in number, are 8 inches in diameter, and the gravel wells 4 and 6 inches. The water from the wells is forced by air lift to an underground cistern, and from this is pumped by direct pressure into the mains. There are 13 miles of mains, 4 to 12 inches in diameter, and 900 consumers are supplied. The daily consumption of water ranges from 300,000 to 400,000 gallons.

Many families in Tipton are still supplied from private wells, nearly all of which are driven into gravel, which is found at 30 to 60 feet below the surface. A common depth for them is 55 feet. The gravel waters are plentiful, and the deeper wells yield an abundance of pure and wholesome water. There are a few water wells that enter the limestone, which here lies 165 feet below the surface. Analyses of these waters are Nos. 1 to 8 in the table on page 220.

Windfall.—Windfall has no public water supply. Each family owns a private well and the town relies upon these wells for its water. There are many dug wells which are sunk 20 to 30 feet into the till, and these are certain to be more or less contaminated, as there is no sewerage system in the town and the open privy vaults are as numerous as the wells. All the liquid sewage enters the ground and some of it ultimately finds its way to the open wells and becomes mixed with the water which the people drink. The objectionable features of the dug wells are avoided by deep drilled or driven wells, which go through clayey till before entering water-bearing gravels or limestone. The till acts as a covering to prevent pollution of the deeper waters by organic matter from above. In Windfall the limestone is reached at a depth of 60 feet, and the pure and abundant rock waters furnish the best well supplies.

Sharpsville.—Sharpsville lies on the till plain near the shallow valley of Mud Creek. It has no public waterworks. The private wells are dug, drilled, or driven, and range in depth from 12 to 100 feet. The shallow dug wells in the clayey till are dangerous for the same reasons as those given for the dug wells at Windfall, and they should be abandoned as rapidly as possible. Driven wells, to be safe, should be sunk through a considerable depth of clay to keep out drainage from the surface. The rock wells furnish a fine quality of water and give the largest supplies. Limestone is entered at depths of 68 to 80 feet, and no wells in this rock have been failures.

Kempton.—The town of Kempton is situated at the west edge of the county on the border of a region of low moraine. The limestone is here 265 feet below the surface and its depth has prevented the utilization of limestone waters as a source of supply for the wells of the town, which are all driven or drilled, and enter gravel beneath pebbly clay. Most of them reach a gravel bed at a depth of about 34 feet. The record of a typical well of this sort is No. 5 in the table on page 219. Other wells enter gravel at 80 feet, and a still deeper gravel bed has been reached at a depth of 200 feet. The coating of till above even the first gravel protects the waters, and all the wells are good.

Other communities.—The following table gives a list of other villages in Tipton County, with particulars regarding their water supply:

Other village supplies in Tipton County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Curtisville	123	Wells, dug and drilled.	20	90	25	90	15	Gravel and lime stone.
Ekin	100	Wells, driven and drilled.	20	60	25	240	8	Gravel.
Goldsmith	227	Wells, dug and drilled.	15	120	80			Do.
Groomsville		Wells, drilled	25	50	40	120		Do.
Hobbs	222	Wells, dug and drilled.	13	65		180	10	Do.
Jackson	72	Wells, dug and driven.	18	160	22	90	10	Gravel and limestone.
Nevada	70	Wells, dug and drilled.	12	130	80	40–50	8–15	Do.
New Lancaster	100	do	20	60	50	50	8	Limestone and gravel.
Normanda	114	Wells, drilled and dug.	12	280	175	300		Gravel.
Tetersburg		do	20	125	100	190		Do.

TYPICAL WELLS AND ANALYSES.

The two following tables give detailed information regarding typical wells in Tipton County and analyses of their waters. The numbers in the last column of each table refer to identical wells in the other table.

Records of typical wells in Tipton County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head below surface.	Water-bearing materials.	Depth to rock.	Analysis No.
			Feet.		*In.*	*Feet.*	*Feet.*		*Ft.*	
1	Schoolhouse	Atlanta	120	Drilled	4	120		Gravel		
2	Lewis Land	Curtisville	80	do	5	80	15	do		
3	R. B. Barr	1½ miles north of Goldsmith.	171	do	2	171	11	do		
4	Sherman Hobbs	Hobbs	68	do	4	68	10	do		
5	Fred Spencer	Kempton	33	Driven	1¼	33	15	do		
6	Lenley Coats	Nevada	132	Drilled	4	132	14	Limestone	70	
7	Public well	Sharpsville	84	do	4	82	8	do	68	
8	Mike Hoffman	do	105	do	4		7	do	73	
9	Carl Harper	½ mile south of Sharpsville.	122	do	4	120		do	70	
10	City supply	Tipton	280	do	6	275	15	do	139	1
11	do	do	62	do	8	62		Gravel		2
12	J. N. Russell	do	212	do	6	200	6–15	Limestone	120	
13	Public well	Windfall		do	2			do	60	9
14	Windfall Canning Co.	do	217	do	4			do	60	

Mineral analyses of waters in Tipton County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	City waterworks	Tipton	Drilled well, 280 ft.	R. B. Dole	1907	Limestone	25	1.7	....	73	15	31		0.0	411	1.3	5.4	4.2	......	....	350	10
2	Do.	do	Drilled well, 62 ft.	do	1907	Gravel	26	4.3	....	76	28	20		.0	402	4.4	7.8	4.0	......	....	349	11
3	Lake Erie and Western Railroad.	do	Well, 184 ft.	Lake Erie and Western Railroad.	Nov., 1903	....	...	9.8		88	25	24		216	....	6.8	5.6	.0	......	....	....	....
4	Do.	do	Well, 225 ft.	do	Aug., 1904	....	...	....	....	69	29	23		202	....	......	6.1	.0	......	....	....	....
5	Do.	do	Well, 56 ft.	do	do	....	...	....	....	93	25	28		210	....	32	7.3	.0	......	....	....	....
6	Do.	do	Well, 168 ft.	do	Sept., 1903	....	...	2.0		70	27	23		195	....	1.0	6.7	.0	......	....	....	....
7	A. H. Pence	do	Well	H. E. Barnard	Oct. 1907	....	...	.6	....	71	25	....	....	.0	348	0.0	8.0	.30	0.001	0.0	372	....
8	A. W. Bowers	do	do	do	do	....	...	.6	....	19	30	....	....	.0	403	21	5.0	.40	.000	9	442	....
9	Public well	Windfall	do	do	do	Limestone	...	1.0	....	83	7.6	....	....	.0	400	51	20	.50	.000	0	464	13

WABASH COUNTY.

SURFACE FEATURES AND DRAINAGE.

Wabash County is situated on the east edge of the area treated in this report and half way between its north and south borders. The county is 27 miles long and 16 wide, and is regular in outline with the exception of a notch in the northeast corner formed by the corner of Whitley County. It has an area of 418 square miles and in 1900 the population was 28,235, or 68 to the square mile. Wabash, the county seat, lies 70 miles north and 18 miles east of Indianapolis.

The county is a broad, rather level plateau, across which Wabash River has cut a deep, broad valley medially from east to west. Two of its principal tributaries have cut valleys diagonally across the county, Eel River from the northeast and Mississinewa River from the southeast. The upland surface is a till plain, overlain in part by morainal deposits. Northwest of Eel River is an area of moraine, and east of the Wabash is another north and south moraine belt (Pl. I). These moraines occupy the highest portions of the surface. The extreme northwest corner reaches an elevation of 900 feet above tide, and the surface of the Mississinewa moraine is generally between 800 and 850 feet in elevation. The lowest point in the Wabash Valley, at the west edge of the county, is about 665 feet above sea level, giving a total range in elevation of about 235 feet.

Wabash River and its tributaries receive all the drainage, its valley being about 100 feet below the surface of the till plain and 150 feet or more lower than the crest of the Mississinewa moraine, through which it has cut its way. The valley is less than 1 mile wide above Wabash, but becomes gradually wider toward the west, and is cut in part into the surface deposits, and in part into the "Niagara" limestone.

Mississinewa River enters from Grant County and crosses the west border to join the Wabash above Peru. At Redbridge its valley is about 100 feet deep and is cut through the surface deposits to the rock, so that occasional outcrops of limestone show at the surface. Its drainage basin includes only a narrow belt at the south edge of the county.

Eel River, crossing the northwest corner of the county, follows roughly the southeast border of a great moraine, and with its tributaries drains nearly half of the surface. The stream valley is not more than 50 feet below the level of the till plain to the south, but the ridgelike crest of the moraine to the northwest reaches heights of nearly 200 feet above the river.

Lakes are found only in the morainic region northwest of Eel River and are of the same origin as those farther north, in Kosciusko County. They occupy basins in the irregular depressions of the moraine surface, which the agencies of erosion have so far failed to drain or fill. The Mississinewa moraine, while of greater area here than in Grant County, is of a more even character and lacks depressions in which the surface waters can collect. There are no marshes worthy of note.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

The only important alluvial deposits, along the bottom of the Wabash Valley, average less than a mile in width, though they are somewhat wider locally. Their thickness varies from place to place, but at Wabash, where they have been most often penetrated, they range up to 60 feet in thickness. Other areas of much smaller extent occur along the valley floors of Eel and Mississinewa rivers, where flood-plain deposits of gravel and sand are of local importance as water bearers. All the valley deposits are found to carry abundant waters, which are easily and cheaply obtained and which rise in the wells nearly to the surface. The water is well adapted for boiler and other industrial uses. For domestic purposes the shallow gravel wells should be avoided unless they are located in the country and well removed from dwellings, outhouses, or barns. The porous nature of the beds permits any sewage at the surface to penetrate readily into the ground, and in the absence of impervious clay beds above the water-bearing gravel the chances of pollution are many.

The distribution of the moraines of Wabash County is shown on Plate I. That area which lies northwest of Eel River is of strong morainic topography with irregular knolls, ridges, and undrained kettles, with many of the larger depressions occupied by lakes. The morainic material is unusually thick, doubtless 100 to 200 feet in the higher portions. The Mississinewa moraine stretches to the northeast and southeast of Wabash River east of Wabash. Its relief is much less than that of the heavy moraine farther northwest, and although the highest points of its surface stand scarcely 50 feet above the bordering till plain, the topography is distinctive and in sharp contrast to the level till-plain surface. There are no large lakes in its depressions.

The underground waters of the moraines must be obtained from the till or from the inclosed gravel or sand beds, and dug wells have been most commonly used to secure supplies from the clayey portions of the moraine. If gravel beds are encountered the supply is more abundant. Within the past ten years it has become generally known that drilled or driven wells are almost certain to strike gravel beds at depths of less than 100 feet, and almost all new wells are of one of these types, the water obtained being more plentiful and much safer than that obtained from dug wells.

Till plains occupy about two-thirds of the surface of Wabash County (Pl. I). The depth of the drift varies from a thin edge at points along the sides of the Wabash and Mississinewa valleys to 200, 300, and even 400 feet in the thickest portions. The surface deposits south of the Wabash are not generally of exceptional thickness, as wells commonly enter limestone at less than 100 feet. The rock surface is irregular, however, and contains deep drift-filled valleys. A boring at La Fontaine penetrated 400 feet of drift, and this old valley has been traced southeast through Grant County and beyond. Its extension northwest of La Fontaine is reported by a well driller, but can as yet be mapped only approximately. North of the Wabash the rock surface dips northward, and at North Manchester in the Eel River valley the drift is 274 feet thick. It is probable that this material is 400 feet thick in the moraine to the northwest. The compact till supplies water by seepage to a large number of dug wells, although many dug wells also enter gravel beds below till at depths of 20 to 40 feet and obtain an abundant supply. South of Wabash some drilled wells find good gravel beds in the till, but many have penetrated the underlying limestone before obtaining sufficient water. North of the Wabash, in the area of very thick drift, water-bearing gravels are found from 20 to 150 feet below the surface.

CONSOLIDATED MATERIALS.

All deep borings which have gone through the drift have next entered the "Niagara" limestone. This limestone, which outcrops at certain points along the deeper valleys, is very uniform in character throughout all the observed localities, and wells are universally successful if drilled deeply into it. South of Wabash River rock wells are common, and water can be obtained almost anywhere at depths of less than 100 feet. North of this river very few wells reach the limestone.

ARTESIAN AREAS.

The best known flowing well area in the county is that from which the city water supply of Wabash is obtained (Pl. IV, No. 79), in the valley of Treaty Creek, three-fourths of a mile from Wabash River and about 60 feet above it. There are now nine flowing wells in use and four more have been abandoned. At this point the drift is gravelly, and the artesian waters were obtained at depths of 40 to 60 feet and at 120 feet, and the nine wells yield, without pumping, about 1,500,000 gallons a day. The record of the materials penetrated by one of these wells is as follows:

Record of flowing well for city supply, Wabash.

	Feet.
Soil	2
Sand	3
Clay	33
White gravel (water-bearing)	60
Clay	19
Gravel (water-bearing)	8
	125

Area 80 (Pl. IV) is in the valley of Treaty Creek about 3 miles above area 79, and has a single flowing well at White Institute. This well was drilled for gas about 1890, and still yields approximately 50 gallons of water per minute. The water is from the "Niagara" limestone and rises 3 feet above the surface.

Area 81 (Pl. IV) includes the valley of a small tributary of Mississinewa River at Somerset. The wells are all drilled into the "Niagara" limestone, and the artesian waters come from this formation. There are four flowing wells and they are dependent on the same source, as the later wells have reduced the flow of the earlier ones. The water has a temperature of 53½° F. The record of one of these wells is No. 12 in the table on page 228, and an analysis of the water is No. 10 in the table on page 229.

In the lowlands of the Eel River valley at North Manchester there are many flowing wells from 55 to 100 feet deep (Pl. IV, No. 82), the artesian waters being procured from gravel beds covered above by tough, impervious till. The water for the city supply is from flowing wells. The artesian pressure was formerly much stronger than it is now, but the wells have been left uncapped, and the continuous drainage of the gravel waters through many openings has greatly endangered this valuable supply. The wells are closely related to one another, and those situated on lower ground have seriously affected other wells higher up on the slope. Some which once flowed copiously have ceased to flow when other wells below have been put in, and neighborhood quarrels have arisen on this account. The remedy for this condition of affairs is obvious. A town ordinance should be passed requiring all flowing wells to be capped and faucets to be put in, so that only such water as is needed shall be drawn. This would restore the head to some extent and the flows of all the wells would be improved and the artesian head preserved. The present rapid diminution of the flows points to a total loss of the artesian head at no remote date.

In the Eel River valley near Liberty Mills there are about half a dozen flowing wells (Pl. IV, No. 83), all in gravel below till and 30 to 70 feet deep. The head is sufficient to raise the water 6 to 8 feet above the surface, and one well that flows about 35 gallons per minute is made to run a small water wheel, which pumps water throughout the dwelling house. The temperature of the wells that were measured was 52° F. The head seems to have been affected by the opening of a drainage ditch in the flat 3 miles east of the town.

Flowing wells are reported to occur at intervals along the Mississinewa Valley west of La Fontaine. All are rock wells, and belong to artesian area 27 (Pl. IV), described under Grant County (p. 120).

CITY AND VILLAGE SUPPLIES.

Wabash.—The Wabash public supply is owned by the Wabash Electric Light and Water Works, a private corporation. The water is from nine flowing wells in the valley of Treaty Creek, described above as in artesian area 79. No water from Wabash River is used. From the wells the water flows by gravity to a covered reservoir at the pumping station, and from this it is forced to a standpipe on the hill, the pressure on the mains being maintained by gravity from the reservoir. There are 26 miles of mains from 6 to 12 inches in diameter, 1,790 taps are used to supply about 75 per cent of the people in Wabash, and 243 fire hydrants are installed for fire protection. About 1,300,000 gallons per day are pumped.

This is a most excellent water supply and is open to criticism only from the fact that sometimes the water becomes slightly turbid from the loosening of growths of iron-stained algæ, which accumulate at the well mouths and in the mains. This trouble could be lessened by proper care in removing this material from the boxes at the wells and by frequently flushing the mains.

Wabash is situated partly on a terrace above Wabash River and partly on the river bluff 70 feet above the terrace. In the lowlands the gravel deposits are in places as much as 60 feet thick and the water is abundant for drilled or driven wells. Many wells are owned by private individuals.

On the edge of the bluff the drift is only 10 to 20 feet thick, its depth increasing to the north, and the water table is very low near the edge of the bluff, so that almost everyone in the higher parts of town uses the public supply. A deep boring at Wabash gave the following section:[a]

Section of deep-well boring at Wabash.

	Feet.
Drift	28
Niagara limestone and shale	525
Hudson River and Utica	325
Trenton limestone	54
	932

North Manchester.—The North Manchester public water system is owned by the city, and the water is obtained from 12 flowing wells, described above as in artesian area 82. The record of the wells is No. 7 in the table on page 228. The water from six of the wells flows into a large cistern, and that from the other six is pumped into it. From the cistern the water is pumped to a standpipe 110 feet high and said to hold 160,000 gallons, and is distributed by gravity from

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 265.

this standpipe. There are about 9 miles of mains and 250 service taps, and the people who use this supply (about one-third) require 130,000 gallons each day.

The privately owned wells of North Manchester are numerous, and are almost all driven or drilled. Fortunately most of the dug wells have been abandoned. The wells range in depth from 25 to 140 feet, with 65 feet as the common depth. The head of the water varies in different wells from several feet above the surface to 20 feet below it. All wells obtain water from gravel, and the supply from the deeper wells is good and pure. An analysis of this water is No. 8 in the table on page 229.

The geologic section in this town, as shown by a deep well drilled for gas, is as follows: [a]

Geologic section at North Manchester, as shown by deep-well record.

	Feet.
Drift	274
Niagara limestone and shale	300
Hudson River limestone and shale	250
Utica shale	306
Trenton limestone	50
	1,180

Roann.—Roann has no public waterworks, and privately owned driven and dug wells furnish the water supply. The wells are from 30 to 85 feet deep, the greater number being supplied by a gravel bed at 40 feet below the surface. The deeper gravel waters, where protected above by clays, are likely to be pure, but dug wells, especially in towns which have no sewage system, are very dangerous, as they are sure to become polluted to some extent. All dug wells in town should be filled up and replaced by deeper drilled or driven wells.

La Fontaine.—La Fontaine is supplied by privately owned wells, which are driven or drilled and are 14 to 100 feet deep. The water is found in gravel beds at various depths in the drift. The town is located over a great preglacial valley, which extends toward the southeast and northwest. Gas-well drillings have found as much as 442 feet of drift, while both to the east and west the limestone outcrops at the surface. This valley is a continuation of the same valley that J. A. Bownocker [b] has traced into Grant County from the southeast. The rock in this town is too far below the surface to have been used as a source for well supplies.

Laketon.—Laketon lies on a rolling till plain near Eel River, and the water supply is all obtained from private wells, there being no public supply. Most of the wells are drilled, but a few are dug, and all

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 253.
[b] Ohio State Acad. Sci., Special Paper No. 3, pp. 32-45.

obtain water from gravel, no well here having penetrated to rock. The wells are from 14 to 65 feet deep, the greatest number entering gravel at 35 feet below the surface. The water generally rises within 10 feet of the well mouth. There are no springs of importance in the neighborhood.

Other communities.—The following table contains a list of other villages in Wabash County, with particulars regarding their water supply:

Other village supplies in Wabash County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Dora	102	Wells, driven and drilled; springs.	30	120	80	0–90		Limestone and gravel.
Lagro	456	Wells drilled	40	100	70	3+	10–30	Limestone.
Liberty Mills		Wells, drilled, driven, and dug.	25	100	30		25	Gravel and sand.
Lincolnville	275	do	20	170	25, 70	60–70	10–30	Gravel and limestone.
Mailtrace	30	Wells, drilled and dug	20	185	140			Gravel.
New Holland	72	do	15	44	30	0–30	15–20	Gravel and limestone.
Redbridge	30	do	10	120	100	0–60		Limestone and gravel.
Rich Valley	132	Wells, driven, drilled, and dug.	18	30	25			Sand and gravel.
Rose Hill	89	Wells, dug and drilled	12	125	80			Gravel.
Servia	288	Wells, drilled, driven, and dug.	20	100	40		15	Do.
Somerset	320	Wells, dug and drilled	11	110	20	65		Gravel and limestone.
Spiker		Wells, drilled	70	90	80			Gravel.
Treaty	147	do	30	70	60			Do.
Urbana	239	Wells, drilled and dug	20	120	70	101	10–35	Gravel and limestone.
Vernon		do	14	120	20	80		Do.

TYPICAL WELLS AND ANALYSES.

The two following tables contain detailed information regarding typical wells in Wabash County and analyses of their waters. The numbers in the last column of each table refer to identical wells in the other table.

Records of typical wells in Wabash County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Analysis.
			Feet.		*In.*	*Ft.*	*Ft.*		*Ft.*	*Galls.*	
1	Dr. R. L. Banister.	La Fontaine....	38	Driven..	1½	....	−20	Gravel.....	.....	......	1
2	Public well........	Lagro..........	72	Drilled..	6	72	− 6	Limestone.	6	......	2
3	.....do............	Laketon.........	37	...do.....	2	37	−16	Gravel.....	.....	......	4
4	Wm. Iholtz........	Liberty Mills....	30	...do.....	2	....	+ 6	.....do......	.....	......	.....
5	Edw. Rittenhouse.	.....do..........	68	...do.....	2	65	+ 8	.....do......	.....	35	5
6	E. A. Kanower....	Mailtrace........	132	...do.....	2	130	−40	.....do......	.....	......	.....
7	Public supply.....	North Manchester.	80-100	...do.....	2	....	+ 3	.....do......	.....	......	7
8	Isaac Lowrey......	.....do..........	55	...do.....	2	98	+ 3	.....do......	.....	6	8
9	North Manchester Creamery.	.....do..........	75	...do.....	2	75	+ 5	.....do......	.....	20	.....
10	Joseph Overman...	Redbridge.......	125	...do.....	4	....	−70	Limestone.	60	......	.....
11	Public well........	Roann..........	40	Dug......	....	38	−35	Gravel.....	.....	......	9
12	Jacob Drook.......	Somerset........	120	Drilled..	3½	120	+ 0	Limestone.	60	......	10
13	Geo. O. Miller.....	Urbana.........	131	...do.....	4	65	− 8	.....do......	101	......	12
14	Daniel E. Spiker..	.....do..........	80	...do.....	2	80	....	Gravel.....	.....	......	11
15	Dr. H. Adee.......	Vernon..........	120	...do.....	2	....	−13	Limestone.	80	......	.....
16	Wabash Electric Light and Water Works.	Wabash.........	45-65	...do.....	8, 6	....	+12	Gravel.....	.....	......	15
17	.....do............	.....do..........	390	...do.....	..6	....	+ 0	Limestone.	100	......	.....
18	.....do............	.....do..........	126	...do.....	6	120	+20	Gravel.....	.....	325	14, 16
19	Pioneer Hat Works	.....do..........	169	...do.....	6	....	−50	Limestone.	60	......	.....
20	White Institute....	4 miles SE. of Wabash.	900	...do.....	8	....	+ 3	.....do......	.....	50	.....

Mineral analyses of waters in Wabash County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	Dr. R. L. Banister..	La Fontaine.	Driven well, 38 ft. by 1½ in.	H. E. Barnard	Nov., 1907	Gravel......	...	1.4	...	102	20	....	...	0.0	244	159	24	0.00	0.002	9	2086	1
2	Public well.........	Lagro.......	Drilled well, 72 ft. by 6 in.	.....do.........	1907	Limestone ..	...	.4	...	119	69	....	...	.0	359	178	54	1.5	.001	4	816	2
3	....	Laketon.....	Round Lake..........	W. B. Landon	May, 1906	....	2.1	1.9		72	19	15		114	....	92	5.3	.....	.....	...	.....	....
4	Public well.........	.....do.......	Drilled well, 37 ft. by 2 in.	H. E. Barnard	Sept., 1907	Gravel......	...	.01	...	162	35	....	...	.0	346	70	59	2.00	.00	2	676	3
5	Edw. Rittenhouse.	Liberty Mills	Well, 68 ft. by 2 in....	.....do.........	....do	....	...	.6	...	86	34	....	...	.0	313	19	3	.001	.008	28	356	5
6	....	North Manchester.	Eel River............	Cleveland, Cincinnati, Chicago and St. Louis Ry.	....	....	11	12		50	14	24		92	....	41	6.1	.....	.....	...	292	....
7	City supply.........	.....do.......	Drilled wells, 80 to 100 ft. by 2 in.	R. B. Dole....	Sept., 1907	Gravel......	21	.94	...	64	25	11		.0	312	13	1.5	0.5	.....	...	284	7
8	Isaac Lowrey.......	.....do.......	Drilled well, 55 ft. by 2 in.	H. E. Barnard	....do	.....do........	...	.8	...	94	4	....	...	.0	262	48	1.6	.001	.001	32	390	8
9	Public well.........	Roann.......	Open well, 40 ft........	.....do.........	....do	.....do........	...	.4	...	146	37	....	...	.0	345	96	34	8.00	.001	2	626	11
10	Jacob Drook........	Somerset....	Drilled well, 120 ft. by 3½ in.	.....do.........	1907	Limestone ..	...	.8	...	96	35	....	...	.0	341	0	34	.05	.001	4	462	12
11	Daniel E. Spiker...	Urbana.....	Drilled well, 80 ft. by 2 in.	.....do.........	Sept., 1907	Gravel......	...	.2	...	69	41	....	...	.0	324	77	3	1.00	.001	19	460	14
12	Geo. O. Miller.......	.....do.......	Drilled well, 131 ft. by 4 in.	.....do.........	....do	Limestone ..	...	.0	...	89	31	....	...	.0	284	87	10	.00	.00	4	466	13
13	Wabash Electric Light and Water Works.	Wabash.....	Well, 13 ft.............	Dearborn Drug & Chemical Co.	....	....	11	5.3	...	83	27	4.7	...	181	....	13	7.3	.....	.....	...	340	....
14	City supply.........	.....do.......	Drilled well, 126 ft. by 6 in.	H. E. Barnard	1907	Gravel......	...	1.2	...	78	30	....	...	.0	329	22	5	.00	.001	4	382	18
15	.....do...............	.....do.......	Wells, 45 to 390 feet....	Cleveland, Cincinnati, Chicago and St. Louis Ry.	....	....	19	3.1		147	42	10		224	....	162	19	.....	.....	...	634	16
16	.....do...............	.....do.......	Drilled well, 126 ft. by 6 in.	R. B. Dole....	Sept., 1907	Gravel......	22	.70	...	53	31	17		.0	278	25	3.8	0.4	.....	...	286	18

CHEMICAL CHARACTER OF THE WATERS OF NORTH-CENTRAL INDIANA.

By R. B. Dole.

INTRODUCTION.

Information regarding the characteristics of individual waters in north-central Indiana is of so local interest and can be so readily obtained from the tables of analyses in the main part of the report that it does not merit space here. The purpose of this paper is rather to suggest standards that may assist intelligent study of the analytical data and may show the broad general relations with respect to quality between the wells and other sources of supply in this and in other regions. The methods of testing the waters are, therefore, briefly outlined, the chief uses of water are reviewed, and the qualities peculiar to each class of waters are discussed. In conclusion some assays giving further information are presented.

METHODS OF ANALYSIS.

Many analyses quoted in the preceding pages were made by industrial chemists chiefly to determine the value of the waters as sources of railroad supply. Such estimates are usually made in accordance with accepted procedure for industrial work and the results are sufficiently accurate for most purposes. These analyses, originally stated in hypothetical combinations in grains per gallon, have been recomputed to ionic form in parts per million in order that they may be compared with analyses from other sources. Though it is probable that normal carbonates are actually present in only a few of these waters, it was impossible to determine this certainly from the hypothetical statements, and therefore it has been necessary to compute combined carbonic acid to the carbonate radicle (CO_3) in nearly all these analyses.

The analyses by Dole, Palmer, and Van Winkle were made in special laboratories of the United States Geological Survey in accordance with the methods outlined in Water-Supply Paper 236, pages 9 to 26, inclusive. The probable accuracy of the methods and their sources of error are discussed in the same publication. The samples of water for these tests were collected in 1-gallon glass-stoppered bottles supplied to the field force from the laboratories, and the waters were examined as soon as practicable after collection.

One-pint samples also were collected by the field men and shipped to Indianapolis, where Dr. H. E. Barnard, chief chemist of the Indiana state board of health, examined them for total solids, iron, calcium, magnesium, carbonates, bicarbonates, sulphates, nitrates, and chlorides. As only a small amount of water was available special procedures had to be used. One hundred cubic centimeters of the sample was titrated with fiftieth normal sulphuric acid in the presence of phenolphthalein indicator to estimate carbonates, after which methyl orange was added and titration with fiftieth normal sulphuric acid was continued until the end point indicated by methyl orange appeared, in order to determine the amount of bicarbonates. To the residue from the bicarbonate determination 5 cubic centimeters of a saturated solution of ammonium chloride was added with sufficient ammonia to make the solution alkaline. After the solution was heated to boiling 10 cubic centimeters of a saturated solution of ammonium oxalate was added and the solution was allowed to cool. The precipitate was removed by filtration, washed with hot water, ignited, and weighed as calcium oxide. To the filtrate from the determination of calcium 10 cubic centimeters of ammonia and 10 cubic centimeters of a saturated solution of sodium ammonium phosphate were added, after which the contents of the dish were stirred vigorously three or four minutes and then allowed to stand three hours. The precipitate removed by filtration was washed with ammonia water (1 to 3) and ignited slowly at first, but with gradually increasing temperature until a white ash was obtained, when the magnesium was weighed as magnesium pyrophosphate. For the determination of chlorine 10 cubic centimeters of the sample was titrated with a solution of silver nitrate containing 4.789 grams $AgNO_3$ in 1 liter of distilled water. For the determination of sulphates 100 cubic centimeters of the sample was acidified with hydrochloric acid, heated to boiling, and the sulphates precipitated with 10 cubic centimeters of a saturated solution of barium chloride. The precipitate, after being removed by filtration in hot solution, was washed with hot water, dried, ignited, and weighed as barium sulphate, from which the amount of the sulphate radicle (SO_4) was computed. For total solids 50 cubic centimeters of the sample was evaporated in a platinum dish on the water bath and the residue weighed. The residue from the determination of total solids was dissolved in 15 cubic centimeters of dilute hydrochloric acid, transferred to a beaker, 3 or 4 drops of nitric acid were added, and the solution was heated for ten minutes on the water bath. It was then transferred to a Nessler tube and 5 cubic centimeters of a 5 per cent solution of potassium sulphocyanide was added. The color developed was compared with that in iron standards prepared from ferrous ammonium sulphate. Nitrates were estimated in a 10 cubic centimeter sample by the phenol-sulphonic acid method.

Field assays made during a short field study of the quality of boiler waters in Wabash Valley are reported in a table at the end of this paper. They were performed in accordance with the methods outlined in Water-Supply Paper 151, and though only a few estimates were made for each water the information throws some additional light on the quality of the waters. The figures in the column headed "probable incrustants" are obtained by adding to bicarbonates computed to $CaCO_3$ the sulphates computed to $CaSO_4$ and finding the average between this sum and the figure representing total hardness, in accordance with the following formula. This computation is necessarily arbitrary and the result is only roughly approximate.

$$\text{Probable incrustants} = \frac{0.82\ HCO_3 + 1.42\ SO_4 + \text{total hardness.}}{2}$$

EXPRESSION OF ANALYTICAL RESULTS.

The results of the analyses in this paper are stated in parts per million, and though the amounts of water for examination were measured by volume the mineral content is usually so low that the figures may be considered to represent parts per million by weight. Simplicity of computations, avoidance of fractions, and certainty of the basic unit make this decimal system especially satisfactory for practical purposes. Expression of the results of water analyses in parts per million has been generally adopted by sanitary and research chemists and by many technical chemists, and the exclusive employment of this unit industrially is delayed only by more or less objectionable precedent.

For the convenience of those who may desire to transform the results to other forms of expression it may be stated that multiplying the number of parts per million by 0.058 gives the equivalent in grains per United States gallon of 231 cubic inches, multiplying it by 0.07 gives the equivalent in grains per imperial gallon, and multiplying it by 0.00833 gives the equivalent in pounds per thousand gallons.

The analytical methods commonly employed in the examination of water permit the estimation of the elements and radicles that are present; they also permit the determination of the total amount of mineral matter in solution and more or less approximate separation of the incrusting from the nonincrusting constituents. Besides these data, however, ordinary chemical tests give little knowledge regarding the chemical composition of mineral waters, and consequently the exact amounts of the different salts in solution are largely matter for conjecture. Though such salts as sodium chloride, potassium carbonate, and magnesium sulphate are probably present, they are not determined as such, and their exact amounts can not be computed from the analytical data. The ionic form of stating the analyses—that is, statement of the radicles present—has been adopted in this report because it gives fact and not opinion. The form is entirely practical and presents the actual results for the consideration and criticism of persons other than those making the tests.

STANDARDS FOR CLASSIFICATION.

MINERAL CONSTITUENTS OF WATER.

All natural waters contain, dissolved or suspended in them, more or less of all materials with which they have come in contact. Such materials are taken up in amounts determined principally by their chemical composition and physical structure, temperature and pressure, the duration of contact, and the condition of substances that have previously been incorporated in the water. To designate such suspended or dissolved matter as "impurities" is hardly correct, because they are introduced normally—in strict accordance with natural conditions and not necessarily by human agency. It has become customary, however, to call such substances impurities when they are detrimental or injurious in some proposed use of a water supply. For purposes of examination the substances that may be present are classified as suspended matter, such as particles of clay or leaves; dissolved matter, either of mineral or organic origin; microscopic animals or plants; and bacteria. The presence or absence of very small animals and plants likely to affect the quality of waters is determined by microscopic examination, and the chance of contracting disease by drinking the water is ascertained by bacteriological processes. The mineral substances in the well waters of north-central Indiana are the most important, however, and consideration is therefore given in the present study chiefly to the suspended and the dissolved mineral matter. The amount and nature of the mineral ingredients are most commonly determined by estimates of total suspended matter, total dissolved matter, total hardness, total alkalinity, silica, iron, aluminum, calcium, magnesium, sodium, potassium, carbonates, bicarbonates, sulphates, nitrates, chlorides, free carbonic acid, and free hydrogen sulphide. These estimates are measure of the materials most commonly present and most likely to affect the value of the waters. Articles describing the methods employed in making these estimates have already been cited under the heading "Methods of analysis" (p. 230).

USES OF WATER.

In judging the value of a water from the data afforded by analysis it is necessary to consider the supply both in relation to the use to which it is to be put and in relation to other available supplies. Besides being used for drinking and for general domestic purposes, water is essential in steam making, paper making, starch manufacture, and many other industrial processes. The medicinal properties of the dissolved minerals are supposed to give many waters special significance. For each of these purposes the relative amounts of certain ingredients in a water determine its value and assist in its classification. For example, considerable iron in a water may be harmful in one industrial process and harmless in another. The value of a water for another process may be directly measurable by the amount of suspended matter present, the amount of dissolved matter not being significant. Furthermore, many waters that are considered of great medicinal value are unfit for boiler use.

To catalogue waters as good or bad, hard or soft, pure or impure, is indefinite and frequently misleading. Absolutely pure water (H_2O) does not exist in nature, and, as stated before, a water should not be called impure when it contains only substances derived by natural means from natural sources. The arithmetical values of terms ordinarily employed to describe the quality of water, like those of many other words, are variable and largely dependent on local usage. In New England, for instance, water to be considered soft must have much less than 100 parts per million of total hardness, and water containing 30 or 40 parts of sulphates would not be used. In northern Indiana, however, it would be difficult to find a well water with total hardness less than 100 parts per million, yet many well waters in that region are called soft, and waters containing 30 to 40 parts of sulphates are often used in boilers without occasioning much comment. This example illustrates the uncertain significance of general descriptive words in classifying waters and emphasizes the advisability of knowing the intended use of a water and the composition of other available supplies before pronouncing judgment on its quality.

WATER FOR DOMESTIC PURPOSES.

CONDITIONS IN NORTH-CENTRAL INDIANA.

The flat topography of north-central Indiana makes highland conserved supplies impossible, and the comparatively few meandering streams of this prairie land are often so turbid or so evidently polluted that the prospect of using them as sources of domestic supply without purification is not inviting. Consequently wells furnish most of the water for drinking and for general domestic purposes.

Of 54 cities and villages having municipal supplies, 48 obtain all or part of their water from underground sources and 44 use well water exclusively. (See pp. 53–54.)

PHYSICAL QUALITIES.

To be entirely acceptable as a domestic supply, water should be free from suspended matter, color, and odor, and fairly cool when it reaches the consumer; it should be free from disease-bearing germs, and it should be low in dissolved mineral ingredients. The nearer a water approaches these conditions the more satisfactory it is for general use. Suspended mineral matter clogs pipes, valves, and faucets, and growths of microscopic plants suspended in water frequently cause stains in clothes and bad odors. The red or reddish-brown masses of suspended matter sometimes occurring in well waters of this region are usually growths of *Crenothrix*, which is described by Whipple[a] as a small filamentous plant having a gelatinous sheath colored by a deposit of ferric oxide. It grows especially in ground waters containing considerable iron, forming tufts or layers in water pipes and well casings and sometimes clogging them. Particles becoming detached escape through faucets, giving the water an unsightly appearance and causing rusty stains on clothes washed in the water. So far as is known, *Crenothrix* in drinking water does not cause disease. Color is usually due to dissolved vegetable matter and is a cause of serious objection only when it exceeds 20 or 30 parts per million. In general the well waters of this area are satisfactory in respect to suspended mineral matter and color. Sometimes finely divided material from quicksands enters driven wells, but such trouble is not nearly so serious here as in other parts of the country. A few of the waters, especially those containing iron, develop a turbidity of 10 to 30 parts per million on exposure to the air, due to precipitation of dissolved matter, and such a condition gives rise to an apparent though not a real color. Most of the color recorded in analyses of these well waters is due to this cause, and true colors are so low as to be insignificant. Odors may be caused by various conditions. An odor like that of rotten eggs, encountered in many waters in the oil belt, is due to free hydrogen sulphide (H_2S). Growths of microscopic organisms in tanks and water mains often have unpleasant odors that make the water objectionable.

BACTERIOLOGICAL QUALITIES.

Before a water is used for domestic purposes there should be reasonable certainty that it is free from disease-bearing organisms. Yet present bacteriological technique does not permit positive

[a] Whipple, G. C., The microscopy of drinking water, New York, 1899, p. 144.

statement regarding the presence or absence of such organisms, and it is advisable, therefore, to guard supplies against all chances of infection. The disease germs most commonly carried by water are those of typhoid fever. The bacilli enter the supply from some spot infected by the discharges of a person sick with this disease, and, though the germs are comparatively short lived in water, they persist in fecal deposits for remarkable lengths of time and retain their power to infect water. Consequently, wells should be so located that their waters are guarded against the entrance of filth of any kind, either over the top or by infiltration, and pumps and piping in the system should also be protected. The types of rural water supplies with reference to pollution in a central-western section of the United States have been discussed by Kellerman and Whittaker.[a] Considered as to bacteriological purity, the well waters of north-central Indiana in general are good. Water from a carefully cased well over 20 or 30 feet deep is acceptable if the well is located after the exercise of reasonable judgment in regard to privies, cesspools, and other sources of pollution. Open dug wells and the pits often constructed as reservoirs around the tops of casings are frequently exposed to fecal contamination from above or through cracks in poorly built side walls. Care should be taken that the casings of deep wells do not become leaky near the surface of the ground so as to allow pollution to enter. As a matter of ordinary precaution the ground should be kept clean and water should not be allowed to become foul or stagnant near any well, no matter how deep it is. If shallow dug wells are necessary, they should be constructed with water-tight casings extending down into the well as far as practicable and also a short distance above ground. The floor, or curbing, should be water-tight, and pumps should be used in preference to buckets for raising the water. Every possible precaution should be taken to prevent feet scrapings and similar dirt from getting into the water by way of the top of the well. Underground water is not only less likely to become contaminated if protected from surface washings, air, and light, but it keeps better and is less likely to develop microscopic plants that give it a bad taste.

CHEMICAL QUALITIES.

Amounts of dissolved substances permissible in a domestic supply depend much on their nature. No more than traces of barium, copper, zinc, or lead should be present, because these substances are poisonous. The occurrence of these elements in measurable amounts in ordinary well waters is so rare that tests for them are not usually made. Any constituent present in sufficient amount to be clearly per-

[a] Kellerman, K. F. and Whittaker, H. A., Farm water supplies of Minnesota: Bull. Bur. Plant Industry No. 154, U. S. Dept. Agr., 1909.

ceptible to the taste is objectionable. Two parts per million of iron is unpalatable to many people, and even this small amount can cause trouble by discoloring washbowls and tubs and by producing rusty stains on clothes. Tea or coffee can not be made satisfactorily with water containing much iron, because an inky black compound is formed. Four or five parts of hydrogen sulphide are unpleasant to the taste, and this dissolved gas is objectionable also because it corrodes well strainers and other metal fittings. Many well waters in this area contain so much free hydrogen sulphide that they are unfit for use. The amounts of silica and aluminum ordinarily present in well waters have no special significance in relation to domestic supply. The alkalies, sodium and potassium, are high in most Indiana waters in which chlorides are high.

Approximately 250 parts of chlorides make a water taste "salty," and much less than that amount causes corrosion. In regions where the chloride content runs as low as 5 or 10 parts in normal waters unaffected by animal pollution the amount of chlorides is frequently taken as a measure of contamination. But such practice in north-central Indiana is out of the question for two reasons: First, the normal chloride content in most of the well waters is so high that the small changes possibly caused by animal pollution are insignificant; second, wells near together and free from contamination may differ 200 or 300 per cent in their content of chlorides, owing to difference in the composition of the materials from which they draw their respective supplies. Therefore the establishment of isochlors, or lines of equal chlorine, in this area would be of no sanitary value whatever.

Calcium and magnesium are chiefly responsible for what is known as the hardness of water. This undesirable quality is indicated by increased soap consumption and by deposition on kettles of scale composed almost entirely of calcium, magnesium, carbonates, and sulphates. Calcium and magnesium unite with soap, forming insoluble curdy compounds with no cleansing value and preventing the formation of a lather until all of these two basic radicles has been precipitated. Hardness is measured by the soap-consuming capacity of a water expressed as an equivalent of calcium carbonate ($CaCO_3$), and it can be computed from the amounts of calcium and magnesium in a water or can be determined by actual testing with standard soap solution. If, as Whipple states,[a] 1 pound of ordinary soap will soften only about 24 gallons of water having a total hardness of 200 parts per million, it can readily be seen that housekeepers and owners of laundries in north-central Indiana are intimately concerned in the hardness of water, which ranges in this region from 150 to 500

[a] Whipple, G. C., The value of pure water, New York, 1907, p. 26.

parts per million and does not in many samples fall below 200 parts. The use of soda ash (sodium carbonate) to "break" such waters, or to precipitate the calcium and magnesium, is common and effects saving in the cost of soap. Some large cities in other States have found it advisable to soften their public water supplies instead of leaving that task to the individual consumer.

WATER FOR BOILER USE.

IMPORTANCE OF MINERAL CONTENT.

The amount of mineral matter in the waters of north-central Indiana is so considerable that the selection of proper supplies for boiler use depends largely on the chemical composition of available waters, and the quantity of water required for locomotives by the network of railroads in this section is so enormous that its quality is a matter of high importance in industrial economy. The chief troubles in boiler-room practice caused by the mineral constituents of natural waters are formation of scale, corrosion, and priming.

FORMATION OF SCALE.

The most common trouble is formation of scale, or deposition of mineral matter within the boiler shell. When water is heated under pressure and concentrated by evaporation, as in a steam boiler, certain substances are thrown out of solution and solidify on the flues and crown sheets or within the tubes. These deposits cause increased fuel consumption because they are poor conductors of heat and increased cost of boiler repairs and attendance because they have to be removed. If the amount of scale is very great or if it is allowed to accumulate the boiler capacity is decreased and disastrous explosions are likely to take place. In two years the inspectors for one insurance company [a] found over 86,000 boilers, or nearly one-fifth of all those examined, to be defective on account of sediment, incrustation, and scale.

The importance of scale formation and of means of reducing or preventing it may be judged by considering the effect of a water such as is shown on page 265 by the average composition of the waters in the fresh-water limestones. If such water were used in a system without condensers under ordinary conditions it would form about 2.6 pounds of scale to 1,000 gallons of water; besides the increased fuel consumption and increased depreciation of the plant caused by this deposit, the scale itself in a 1,000-horsepower system would amount to a ton every seven working days, and this mass would have to be shoveled, scraped, and hammered from the inside of the boiler.

[a] The Locomotive (Hartford), new ser., vol. 21, 1900, p. 29; vol. 22, 1901, p. 21.

In one boiler room in Indianapolis $160 a month has been saved in maintenance charges by treating the water supply.[a]

The scale or incrustation consists of the substances that are insoluble in the feed water or become so within the boiler under conditions of ordinary operation. It includes practically all the suspended matter, or mud; the silica, probably precipitated as silica (SiO_2); the iron and aluminum, appearing in the scale as oxides or hydrated oxides; the calcium, precipitated principally in the form of carbonate and sulphate; and the magnesium, found in the deposits principally as the oxide but partly as the carbonate. The scale conconstituted by these substances is therefore a mixture of compounds, which varies in amount, density, hardness, and composition with different conditions of water supply, steam pressure, type of boiler, and other circumstances. Calcium and magnesium are the principal basic substances in the scale, over 90 per cent of which usually is calcium, magnesium, carbonates, and sulphates. If much organic matter is present part of it is precipitated with the mineral scale, as the organic matter is decomposed by heat or by reaction with other substances. If magnesium and sulphates are comparatively low or if suspended matter is comparatively high the scale is soft and bulky and may be in the form of sludge that can be blown or washed from the boiler. On the other hand, a clear water relatively high in magnesium and sulphates may produce a hard, compact scale that is nearly as dense as porcelain, clings to the tubes, and offers great resistance to the transmission of heat. Therefore the value of a water for boiler use depends not only on the quantity of scale produced by it but also on the physical structure of the scale.

CORROSION.

Corrosion or "pitting" is caused chiefly by the solvent action of acids on the iron of the boiler. Free acids capable of dissolving iron occur in some natural waters, especially in the drainage from coal mines, which usually contains free sulphuric acid. Many ground waters contain free hydrogen sulphide, a gas that readily attacks boilers; dissolved oxygen and free carbon dioxide also are corrosive in their action. Organic matter is probably a source of acids, for it is well known that waters high in organic matter and low in calcium and magnesium are corrosive, though the exact nature and action of the organic bodies are not understood. Acids freed in the boiler during the steam-making process by the deposition of basic radicles as hydrates are the most important cause of corrosive action. Iron, aluminum, and magnesium are precipitated as hydrates that are later partly or completely converted into oxides. According to the chemical composition of the water the acid radicles that were in equilib-

[a] Boardman, A. J., Proper treatment of boiler feed water: Power and Engineer, vol. 30, 1909, p. 552.

rium with these bases may do one or all of three things: They may pass into equilibrium with other bases, displacing equivalent proportions of carbonates and bicarbonates; or they may decompose carbonates that have been precipitated as scale; or they may combine with the iron of the boiler, thus causing corrosion. If these acids exceed the amount required to decompose the carbonate and bicarbonate radicles present the iron of the boiler is attacked, and the results are pits or tuberculations of the interior surface, leaks, particularly around rivets, and consequent deterioration of the boiler.

FOAMING.

Foaming is the formation of masses of bubbles on the surface of the water in the boiler and in the steam space above the water, and it is intimately connected with priming, which is the passage of water mixed with steam from the boiler. Foaming results when anything prevents the free escape of steam from the water. It may be due to particles of suspended matter, but usually the principal cause is an excess of dissolved substances that increases the surface tension of the liquid, and thereby reduces the readiness with which the steam bubbles break. Therefore the tendency of a water to foam varies inversely with the concentration it will undergo before developing an excessive surface tension. As the sodium and potassium salts remain dissolved in the boiler water while the greater portion of the other substances is precipitated, the foaming tendency is commonly measured by the degree of concentration of the alkaline salts in solution, because this figure considered in connection with the type of boiler determines the length of time that a boiler may run without danger of foaming.

REMEDIES FOR BOILER TROUBLES.

The best remedy for troubles caused by substances in feed waters is treatment of supplies before they enter boilers; this subject is considered under "Purification of water" (p. 251). When such treatment can not be given there are various ways of reducing potential injury. Low-pressure, large-flue boilers are frequently used in stationary plants in the Central States with hard waters, and it is said that the scale formed in them is softer and more flocculent and can therefore be more readily removed than that in high-pressure boilers. Blowing off is about the only practical means of preventing foaming, because this trouble is due principally to concentration of soluble salts in the residual water of the boilers. Accumulated sludge, or soft scale, can be removed by blowing, particularly in locomotive practice. In condensing systems much of the trouble due to mineral matter in the feed water is obviated because the quantity of raw water supplied is proportionately small. The problem is not completely solved in such systems, because the incrusting or corrosive action is transferred from the boiler to the condenser, which requires more or less cleaning and repairing in proportion to the undesirable qualities of the water supply.

BOILER COMPOUNDS.

Boiler compounds are widely used in regions where hard waters abound, but treatment within the boiler should be given only when it is impossible to purify the supply before it enters the boiler. If previous purification is not practicable the feed water frequently can be improved by judicious addition of chemicals. Many substances, ranging from flour, oatmeal, and sliced potatoes to barium and chromium salts, have been recommended for such use, but only two or three have proved to be truly economical. Cary[a] has classified these substances according to their action within the boiler. Those that attack chemically the scaling and corroding constituents precipitate the incrusting matter and neutralize acids. Soda ash, the commercial form of sodium carbonate, containing about 95 per cent Na_2CO_3, is the most valuable substance of this character, because it is comparatively cheap and its use is attended with the least objectionable results. Tannin and tannin compounds are also frequently used for the same purpose. Palmer[b] mentions the use of limewater to prevent corrosion and to obviate foaming, and it is probable that lime used with waters high in organic matter and very low in incrustants would improve them. The chemical reactions occurring when soda ash is used to remove the mineral constituents of water have been discussed at length in previous publications,[c] and it is not necessary to enter into details here. The proper amount to be used is a question to be decided for each water from its chemical composition and the style of boiler. The use of soda ash results in neutralizing of acids, precipitating the incrusting ingredients in a softer, more flocculent form, which is more easily removed from the boiler, and increasing the foaming tendency of the water by increasing its content of dissolved matter. Cary's second class of boiler compounds comprises those that act mechanically on the precipitated crystals of scale-making matter soon

[a] Cary, A. A., The use of boiler compounds: Am. Machinist, vol. 22, pt. 2, 1899, p. 1153.

[b] Palmer, Chase, Quality of the underground waters in the Blue Grass region of Kentucky: In Water-Supply Paper U. S. Geol. Survey No. 233, 1909, p. 187.

[c] Stabler, Herman, The mineral analysis of water for industrial purposes and its interpretation by the engineer: Eng. News, vol. 60, 1908, p. 355.

Cary, A. A., The use of boiler compounds: Am. Machinist, vol. 22, pt. 2, 1899, p. 1153.

Handy, J. O., Water-softening: Eng. News, May 26, 1904, p. 499.

Davidson, G. M., The C. & N. W. method of water treatment: Proc. Western Ry. Club, vol. 15, No. 6, Feb. 17, 1903.

Booth, W. H., Water softening and treatment, London, 1906.

Collett, Harold, Water softening and purification, London, 1896.

Christie, W. W., Boiler waters, New York, 1906.

after they are formed, surrounding them and robbing them of their cement-like action. Glutinous, starchy, and oily substances belong to this class, but they are not now used to any considerable extent because they frequently thicken and foul the water more than they prevent the formation of hard scale. The third class comprises those that act mechanically, like those of the second class, and also partly dissolve deposited scale, thus loosening it and aiding in its ready removal. Kerosene is the most effective of such materials.

Many boiler compounds possessing or supposed to possess one or more of the functions just described are on the market, and the sale of them is very great. Some are effective and some are positively injurious. Most of them depend for their chief action on soda ash, petroleum, or a vegetable extract, but all are costly compared with lime and soda ash. Every engineer should bear in mind that a steam boiler is an expensive piece of apparatus and that fuel and boiler repairs are also expensive. Therefore he should hesitate to add substances to his feed water without competent advice regarding their effect. It is far more economical to have the water supply analyzed and to treat it effectively by certain well-known chemicals in proper proportion, either within or without the boiler, than to experiment with compounds of unknown composition.

NUMERICAL STANDARDS.

Stabler[a] in his excellent mathematical discussion of the quality of waters with reference to industrial uses gives several formulas by which waters may be classified. His methods of calculating the amount and the character of scale likely to result from use of a water are given as follows:

$$A = .00833Sm + .00833Cm + .0107Fe + .0157Al + .0138Mg + .0246Ca.$$

$$B = Sm + Cm + 1.3Fe + 1.9Al + 1.66Mg + 2.95Ca.$$

A represents pounds of scale per 1,000 gallons of water and B (computed from the preceding formula) represents parts per million of scale. Sm, Cm, Fe, Al, Mg, and Ca represent, respectively, the amounts in parts per million of suspended matter, colloidal matter (silica plus oxides of iron and alumium), iron, aluminum, magnesium, and calcium in the water. In this formula Ca should not exceed $.668CO_3 + .328HCO_3 + .417SO_4$, in which CO_3, HCO_3, and SO_4 represent, respectively, the amounts in parts per million of the carbonate, bicarbonate, and sulphate radicles present in the water. It is sometimes uncertain whether iron and aluminum are in solution or in colloidal state, but in applying these formulas to Indiana ground waters little error is introduced by assuming that Cm equals silica only. If it is desired to compute the scale-forming ingredients of waters whose analyses in this report give no values for silica, iron,

[a] Eng. News, vol. 60, 1908, p. 355.

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or aluminum, Cm may be taken as 20 and Fe and Al as zero, without introducing great error. In clear waters Sm would of course be zero; consequently for most Indiana ground waters the amount of scale may be estimated practically from the figures representing silica, calcium, and magnesium.

In the following Stabler formula C represents the amount of hard scale in pounds per 1,000 gallons of water and D the same in parts per million recomputed from the C formula; SiO_2, Mg, Cl, SO_4, Na, and K represent the respective amounts in parts per million of silica, magnesium, chlorides, sulphates, sodium, and potassium. If the alkalies are not separated, the figure representing sodium and potassium together and computed as sodium may be used with the Na coefficient in place of the last two terms of these formulas.

$$C = .00833\ SiO_2 + .0138\ Mg + (.016Cl + .0118\ SO_4 - .0246Na - .0145\ K).$$

$$D = SiO_2 + 1.66\ Mg + (1.92Cl + 1.42SO_4 - 2.95Na - 1.74\ K).$$

The ratio (b) between the amount of hard scale and the total amount of scale is an index of the probable hardness of the scale, expressed thus:

$$b = \frac{C}{A} = \frac{D}{B}$$

If b is not more than 0.25 the scale may be classified as soft; if between 0.25 and 0.5, as medium; and if more than 0.5, as hard. For other formulas and comments on those quoted the original article should be consulted.

The committee on water service of the American Railway Engineers and Maintenance of Way Association have offered[a] a classification of waters in their raw state that may be employed for approximate purposes, but, as the report states, "it is difficult to define by analysis sharply the line between good and bad water for steam-making purposes." The following table gives this classification with the amounts transformed to parts per million. In many Indiana waters the total incrusting and corrosive constituents are equivalent approximately to total solids.

Approximate classification of waters for boiler use according to proportion of incrusting and corroding constituents.

Parts per million.		Classification.
More than—	Not more than—	
....	90	Good.
90	200	Fair.
200	430	Poor.
430	680	Bad.
680	....	Very bad.

[a] Proc. Am. Ry. Eng. and Maintenance of Way Assoc., vol. 5, 1904, p. 595.

These limits must be interpreted liberally in practice, because they are modified by the comparative hardness of the incrustation and the different extent of corrosion effected by waters of the same mineral content but of different chemical composition. Waters of the worst class may be improved by treatment in softening plants. The question how bad a water may be used without treatment can be decided by comparing the cost of artificially softening the water with the saving effected by the use of softened water. A report [a] of the committee on water service, just quoted, describes the principles on which such calculations should be based. In general, it is economical in locomotive service to treat waters containing 250 to 850 parts per million of incrustants and those containing less than the lower amount if the scale formed contains much sulphates.[b] As the incrusting solids may commonly be reduced to 80 or 90 parts per million, the economy of treating boiler waters deserves consideration in a region where most of the supplies contain 300 to 500 parts per million of incrusting and corrosive matter. The amount of mineral matter that makes a water unfit for boiler use depends on the combined effect in boilers of the softening reagents used with such waters and of the constituents not removed by softening. Substances added to a supply to remove incrustants or to prevent corrosion increase the foaming tendency, and this increase may be great enough to render a water useless for steaming purposes. It is not of much benefit to soften a water containing more than 850 parts per million of nonincrusting material and much incrusting sulphates.[b] Waters containing over 400 parts per million of alkali salts may be classed as bad for boiler use.[c] Though waters containing as high as 1,700 parts per million of foaming constituents have been used, it is usually more economical to incur considerable expense in replacing such supplies by better ones.

WATER FOR OTHER INDUSTRIAL USES.

GENERAL STATEMENT.

The manufacture of many articles is affected by the ingredients of natural waters. The quality of water for boiler service has already been discussed; with reference to factories it need only be added that increase of boiler efficiency often justifies purification of bad water when increased value of the manufactured product alone may not be considered to do so. This observation applies particularly to paper, pulp, and strawboard mills, laundries, and other establishments where large quantities of water are evaporated to furnish steam for drying, and to ice factories and similar plants where distilled water is

[a] Proc. Am. Ry. Eng. and Maintenance of Way Assoc., vol. 8, 1907, p. 601.
[b] Idem, vol. 6, 1905, p. 610.
[c] Idem, vol. 9, 1908, p. 134.

produced. But besides its use for steam making water plays a specific part in many manufacturing processes. In paper mills, strawboard mills, bleacheries, dye works, canning factories, pickle factories, creameries, slaughterhouses, packing houses, nitroglycerin factories, distilleries, breweries, woolen mills, starch works, sugar works, canneries, glue factories, soap factories, and chemical works water becomes a part of the product or is essential in its manufacture. As the principal function of water in most of these establishments is that of a cleansing agent or a vehicle for other substances, a supply free from color, odor, suspended matter, microscopic organisms, and especially bacteria of fecal origin, and fairly low in dissolved substances, especially iron, generally is satisfactory; but there are some exceptions. Water hygienically acceptable is necessary where it comes in contact with or forms part of food materials, as in the making of beverages, starch, and dairy or meat products. As all these ideal conditions are infrequently encountered in natural supplies, the manufacturer is confronted with the problems of ascertaining what degree of freedom from these substances is necessary to prevent injury to his machinery or to his output and whether the cost of obtaining such purity is counterbalanced by decreased cost of production and increased value of product. Competitive business methods and increased facilities of transportation have standardized the values of manufactured articles so thoroughly that makers are now obliged to scrutinize carefully every item of production cost in order to obtain reasonable profits. Therefore any appreciable saving effected by improvement of the water supply is one of the easiest sources of profit for the manufacturer.

The effects in some industries of the substances most commonly found in water are here outlined. The treatment is not exhaustive, the object being to offer approximate standards to aid in classification.

EFFECT OF FREE ACIDS.

Free mineral acids, such as sulphuric acid in drainage from coal mines or hydrochloric acid in the effluents of some industrial establishments, are especially injurious and nearly always necessitate purification. In paper mills, cotton mills, bleacheries, and dye works acids decompose chemicals and streak the fabrics, besides rotting them. They also corrode metal work, rapidly destroying screens, strainers, and pipes. Such effects are likely to follow the use of water that contains a measurable amount of free mineral acid.

EFFECT OF SUSPENDED MATTER.

Suspended matter in surface waters may be of vegetable, mineral, or animal origin, as it consists of particles of sewage, bits of leaves, sawdust, sticks, or sand and clay. The silt so common in rivers of the

West is largely derived from sand and clay. Few well waters contain suspended animal or vegetable matter, but many carry finely divided sand and clay, and they frequently become turbid by precipitation of dissolved ingredients. Suspended matter is objectionable in all processes in which water is used for washing or comes into contact with food materials, because it is likely to stain or spot the product. For this reason even a small amount of suspended matter due to precipitated iron is especially injurious. Small amounts (10 to 20 parts per million) of suspended vegetable or animal matter liable to decomposition or to partial solution are much more objectionable than equal quantities of mineral matter. For these reasons water should be freed from suspended matter before being used for laundering, bleaching, wool scouring, paper making, dyeing, starch and sugar making, brewing, distilling, and similar processes. In making the coarser grades of paper, such as strawboard, a small amount of suspended matter is not especially injurious, but for the finer white and colored varieties clear water is essential.

EFFECT OF COLOR.

Color in water is due principally to solution of vegetable matter, and materials bleached, washed, or dyed with light shades in colored water are likely to become tinged. Highly colored waters can be used in making wrapping or dark-tinted papers, but not the white grades, and paper manufacturers are put to great expense for water purification on that account. The lower waters are in color, therefore, the more desirable they are for use in bleacheries, dye works, paper mills, and other factories where fabrics are likely to acquire undesirable brown tints.

EFFECT OF IRON.

Iron is the most undesirable dissolved constituent and its presence in comparatively small quantities necessitates purification. Many ground waters contain 1 to 20 parts per million of iron, which may be precipitated by exposure to the air and by release of hydrostatic pressure, causing the waters to become turbid; such waters often develop growths of *Crenothrix* (see p. 235) that interfere in many industrial operations. In all cleansing processes, especially if soap or alkali is used, precipitated iron is likely to cause rusty or dull spots. In contact with materials containing tannin compounds iron forms greenish or black substances that discolor the product. Therefore many waters containing amounts even as small as 1 or 2 parts per million of iron have to be purified before they can be used industrially. In water for dye works iron is especially objectionable and it commonly prevents the use of the water without purification.[a]

[a] Sadtler, S. P., A handbook of industrial organic chemistry, Philadelphia, 1900, p. 483.

Iron in the water supply of paper mills may be precipitated on the pulp, giving it a brown color, or during sizing or tinting, giving spotty effects. Water containing much iron can not be used in bleaching fabrics, because salts that spot the goods are formed. The dark-colored compounds that iron forms with tannin discolor hides in tanning and barley in malting, and also give beer bad color, odor, and taste.[a]

EFFECT OF CALCIUM AND MAGNESIUM.

Calcium and magnesium are similar in their industrial effects and they usually vary together in amount, waters carrying 10 to 50 per cent as much magnesium as calcium. In most Indiana waters calcium and magnesium are the predominating bases. In boiling processes some calcium and magnesium are precipitated on whatever is boiled in the water, and this deposit may interfere with later operations because it covers the material. As these two basic substances decompose equivalent amounts of many chemicals employed in technical operations they are a cause of waste, and the alkaline-earth compounds thus formed on fabrics also interfere with later treatment. This is the chief trouble with calcareous waters and the greatest argument in favor of preliminary softening. Some of the chemicals used to disintegrate the fibers in making pulp are consumed by the calcium and magnesium in the water supply, but the loss from this source is not nearly so great as that occurring later when the resin soap used in sizing the paper is decomposed by the calcium and magnesium. The insoluble soaps thus created do not fix themselves on the fibers, but form clots and streaks. Similar decomposition of valuable cleansing materials and subsequent deposition of insoluble compounds take place in laundering, wool scouring, and similar processes. In the manufacture of soap calcium and magnesium form with the fatty acids curdy precipitates that are insoluble in water and therefore have no cleansing value. Many dyeing operations are interfered with by calcium and magnesium, which neutralize chemicals and change the reaction of the baths, besides forming insoluble compounds with many dyes. Highly calcareous waters can not be used for boiling the grain in distilleries because proper action is hindered by deposition of alkaline-earth salts on the particles of grain, nor for diluting spirits because they cause turbidity.[b] Very soft water, on the other hand, is said to be undesirable in paper mills for loading papers with any form of calcium sulphate because such waters dissolve part of the loading materials.[c] Probably waters high in chlorides would also be bad for this purpose because chlorides increase the solubility of calcium sulphate.

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[a] De la Coux, M. A. J., L'eau dans l'industrie, Paris, 1900, pp. 187 and 232.
[b] Idem, p. 251.
[c] Cross, C. F., and Bevan, E. J., A text-book of paper making, New York, 1900, p. 294.

EFFECT OF CARBONATES.

The effects of carbonates and bicarbonates in waters used in industrial processes are not differentiated in this paragraph. It is not uncommon to estimate the combined carbonic acid and to state it as the carbonate (CO_3) without distinguishing between the carbonate (CO_3) and bicarbonate (HCO_3), though in many natural waters the carbonate radicle is absent, the combined carbonic acid being present in the form of bicarbonates. If hard waters proportionately high in carbonates and low in sulphates are boiled the bicarbonate radicle is decomposed, free carbonic acid is given off, and the greater part of the calcium and magnesium is precipitated. For this reason waters of that character are generally more desirable for industrial operations than waters high in sulphates and low in carbonates, as boiling does not greatly reduce the amount of the hardening constituents under the latter conditions. In beer making waters high in carbonates are said to produce dark-colored beers with a pronounced malt flavor because the carbonates increase the solubility of the nitrogenous bodies, whereas waters high in sulphates yield pale beers with a definite hop flavor because the sulphates reduce the solubility of the malt and the coloring matters.[a]

EFFECT OF SULPHATES.

The influence of sulphates in beer making has been noted. Hard waters with sulphates predominating are desirable in tanning heavy hides because they swell the skins, exposing more surface for the action of the tan liquors.[b] Sulphates interfere with crystallization in sugar making so that the amount of sugar retained in the mother liquor is increased.

EFFECT OF CHLORIDES.

High chlorides in most Indiana waters are accompanied by high alkalies. Appreciable amounts of chlorides are injurious in many industrial processes. Beverages and food products, of course, can not be treated with waters very high in chlorides without becoming salty. In tanning, chlorides cause the hides to become thin and flabby.[b] Animal charcoal used in clarifying sugar is robbed of its bleaching power by absorption of salt, and chloride-bearing waters also affect the quality of sugars because saline salts are incorporated in the crystals.[c] In the preparation of alcoholic beverages chlorides in large amount prevent the growth of the yeast and interfere with the germination of the grain. The only way of removing chlorides from water that has been commercially developed is by distillation. The

[a] Brewing water, its defects and remedies, New York, 1909, p. 19. Also De la Coux, op cit., p. 169.

[b] Parker, H. N., Stream pollution [in Potomac River basin]: Water-Supply Paper U. S. Geol. Survey No. 192, 1907, p. 194.

[c] De la Coux, op. cit., p. 152.

cost of this process has been greatly reduced by use of multiple-effect evaporators, and this method of purification is worth consideration where chloride-bearing waters must be used.

EFFECT OF ORGANIC MATTER.

Organic matter of fecal origin is of course dangerous in any water supply that comes into contact with food products, and water so polluted should be purified before being used. Care in this respect is particularly necessary in creameries, slaughterhouses, canneries, pickle factories, distilleries, breweries, sugar factories, and starch works. Organic matter not necessarily capable of producing disease is undesirable in industrial supplies because it induces decomposition in other organic materials—like cloth, yarn, sugar, starch, meat, or paper—rotting and discoloring them.

EFFECT OF HYDROGEN SULPHIDE.

Hydrogen sulphide (H_2S) is a gas with an odor like that of rotten eggs, and it occurs dissolved in some underground waters. It is corrosive even in small quantities, and it also injures materials by discoloring and rotting them. This substance is associated with so much dissolved salts in many waters that they are unfit for industrial use for reasons other than their gaseous content.

EFFECT OF OTHER SUBSTANCES.

Silica and aluminum are usually not present in sufficient quantity to have any appreciable effect in industrial processes, except when water is evaporated. Large quantities of sodium and potassium, by adding to the amount of dissolved matter, are objectionable in some manufacturing operations. Phosphates, nitrates, and some other substances not noted in this outline interfere with industrial chemical reactions, but they are seldom present in natural waters in sufficient quantity to have noticeable effect.

WATER FOR MEDICINAL USE.

The relation between the constituents of natural waters and their physiologic action has been discussed at length in the works of Cohen,[a] Crook,[b] and others. An excellent article by Hessler[c] refers especially to the mineral waters of Indiana. Blatchley[d] has

[a] Cohen, S. S., System of physiologic therapeutics, vol. 9, Philadelphia, 1902.

[b] Crook, J. K., The mineral waters of the United States and their therapeutic uses, New York, 1899.

[c] Hessler, Robert, The medicinal properties and uses of Indiana waters: Twenty-sixth Ann. Rept., Indiana Dept. Geology and Nat. Res., 1903, p. 159; also The mineral waters of Indiana, with indications for their therapeutic application: Trans. Indiana State Med. Soc., 1902.

[d] Blatchley, W. S., The mineral waters of Indiana: Twenty-sixth Ann. Rept. Indiana Dept. Geology and Nat. Res., 1903, p. 11.

described 16 mineral waters in the 19 counties included in this report. To note a few features that are often forgotten or disregarded in considering the application of mineral waters may not be out of place.

The term "mineral" may reasonably be applied to all natural waters, as all contain dissolved mineral matter, but in general practice it is restricted to those that are exploited on account of their supposedly specific physiologic action. The term "medicinal" is sometimes used to distinguish highly mineralized waters from those that are low in mineral constituents and are especially acceptable as table waters by reason of their physical characteristics. The most logical classification of waters for discussing their chemical constituents in relation to therapeutics is that of Peale[a] as modified by Haywood[b] for the ionic form of stating analyses of water, though Haywood's system is somewhat misleading in a few minor details. It is a strictly chemical classification, by which waters are grouped according to their reaction and their predominating basic and acid radicles, so that the name conveys a statement of the principal active substances.

The therapeutic application of water, or its use for the correction of diseased conditions of the human body, has always been recognized in scientific writings, and the continued and increasing patronage of mineral-spring resorts and the undoubted improvement of many patients treated there clearly indicate that natural waters have curative properties. Yet the frequent claims of miraculous recovery by the use of mineral waters, together with the extravagant statements regarding the waters, can but rouse skepticism as investigation reveals how meagerly such claims are supported by evidence. Statement of analyses in hypothetical combination adds to the confusion, because the identity and the number of the compounds calculated depend on the judgment of the analyst and not on his laboratory data. Therefore comparison of the analyses of different waters is rendered difficult and misleading. Lithium, for instance, is said to be a particularly valuable ingredient; yet many analysts report lithium carbonate, sulphate, or chloride in waters in spite of the fact that the physiologic action is due mainly to the lithium itself and not to lithium carbonate in distinction from the chloride or the sulphate or, in other words, that the action takes place only when the salt is dissociated. If different lithium compounds are reported, it is impossible to measure the effect of the lithium, unless it is recognized that 5.3 parts per million of lithium carbonate, 6.1 parts of lithium chloride, 7.9 of the sulphate, and 9.7 of the bicarbonate contain

[a] Peale, A. C., The natural mineral waters of the United States: Fourteenth Ann. Rept. U. S. Geol. Survey, 1894, pt. 2, p. 53; also, The classification of American mineral waters: Trans. Am. Climatological Assoc., May 31, 1907; also, introductory chapter on the classification of mineral waters in Cohen's System of physiologic therapeutics, vol. 9, 1902, p. 299.

[b] Haywood, J. K., and Smith, B. H., Mineral waters of the United States: U. S. Dept. Agr., Bur. Chemistry, Bull. 91, 1905, p. 9.

each exactly 1 part of lithium. The curative properties of some waters are attributed to minor ingredients that are present in comparatively insignificant quantities, and many waters containing much less than 1 part per million of lithium are widely advertised as lithia waters. Though it is true that many drugs are as efficient when given in very small but frequent doses as when given in one large dose, the therapeutic value of 1 part per million of lithium may well be questioned, because a physician would have to prescribe 200 tumblerfuls of the water in order to administer an ordinary minimum dose of lithium. The physiologic effect of these minor ingredients is usually overshadowed by that of other substances present in much larger quantities. Many strong brines, for example, contain considerable amounts of lithium, but, as Hessler states,[a] the effect of 10 parts of lithium in the presence of 1,000 or more parts of chlorides would probably be insignificant as compared with the effect of the saline constituents. Many mineral springs are found to possess radioactivity, and this characteristic has been advanced as explaining their curative qualities. So far as the writer is informed, however, no acceptable proof of this theory has been advanced. On the other hand, the beneficial effect on the human body of water itself, both hot and cold, used internally or externally, is thoroughly recognized in therapeutics, and the curative qualities of waters not containing appreciable amounts of physiologically active substances may be attributed as reasonably to the action of water itself, combined with a normal regimen of diet, exercise, and other hygienic restrictions, as to some mysterious quality or substance yet undiscovered.

PURIFICATION OF WATER.

GENERAL DISCUSSION.

Purification of water is removal or reduction in amount of substances that render waters in their raw state unsuitable for use. It is practiced on a large scale with one or more of three objects in view: First, to render a supply safe and unobjectionable for drinking; second, to reduce the amount of the mineral ingredients injurious to boilers; third, to remove substances injurious to the machinery or to the manufactured product in industrial processes. The largest purification plants in this country have been constructed in order to produce potable waters without special attention to other possible uses, and some waters need no further treatment before being suitable for steaming and for general industrial purposes. But many other waters are hard, and increased appreciation of the value of good water has resulted in demand for the removal of the hardening con-

[a] Hessler, Robert, The mineral waters of Indiana, with indications for their therapeutic application: Trans. Indiana State Med. Soc., 1902.

stituents also. An excellent example of the result of such insistence is the recently installed plant at New Orleans, where hard, colored, turbid, sewage-polluted river water is brought up to practically all industrial and domestic standards of purity.

Removal of bacteria, especially those causing disease, and removal of turbidity, odor, taste, and iron are the principal requirements in purification of a municipal supply, elimination of bacteria and suspended matter being the most important. The most common methods of effecting such purification are slow filtration through sand and rapid filtration after coagulation, both methods usually being combined with sedimentation. The first process is known as slow sand filtration and the second as mechanical filtration. The efficiency of such filters is measured primarily by the ratio between the number of bacteria in the applied water and the number in the effluent. This figure, stated in percentage of removal, should be as high as 98 and often reaches 99.8 per cent with a filter of either kind operated carefully under normal conditions.

Removal of scale-forming and neutralization of corrosive constituents are the chief aims in preparing water for steam making. Two general methods are employed, namely, cold chemical precipitation followed by sedimentation, and application of heat with or without chemicals, usually followed by rapid filtration. The first process is carried on in cold-water softening plants and the second in feed-water heaters.

The requirements of the water supplies for industries are so varied that classification of purification methods is difficult. Water properly prepared for domestic and for boiler use is suitable for most industrial establishments, and it is more economical for small manufacturers in large cities to buy such water from water companies than to maintain private supplies and purification apparatus. It is usually cheaper, however, for large factories to be supplied from separate sources, not only because of saving in actual cost of water but also because of the opportunity thus afforded of procuring water specially adapted to the needs of the factory. The common methods of industrial water purification are those already mentioned, or combinations of them, modified to meet particular needs. In a few industrial processes, notably the manufacture of ice by the can system, water practically free from all dissolved and suspended substances is necessary, and distilled water must be manufactured. Distillation is expensive, though the employment of multiple-effect evaporators has greatly reduced the cost of operation.

Besides the four common systems of purification many minor processes are used, sometimes alone but more frequently as adjuncts to filters or softeners. Surface waters are screened through wooden or iron grids or through revolving wire screens to remove sticks and leaves before other treatment. Coarse suspended matter can be removed by rapid filtration through ground quartz or similar material in units of convenient size provided with arrangements for washing the filtering medium, similar to those used in mechanical filters. Very turbid river waters are first allowed to stand in large sedimentation basins to reduce the cost of operating the filters. Supplies objectionable only because of their iron content are aerated by being sprayed into the air or by being allowed to trickle over rocks, or by other methods causing evaporation of carbonic acid and absorption of oxygen. Such a process precipitates and oxidizes the iron in solution so that it can readily be removed by rapid filtration. Similar aeration is often employed to evaporate and oxidize dissolved gases that cause objectionable tastes and odors.

Disinfection by ozone, copper sulphate, calcium hypochlorite, and many other substances kills organisms that may cause disease or impart bad odors and tastes. Purification of this character must be done with substances that will destroy the objectionable organisms without making the water poisonous to animals. Such treatment is especially adapted for sewage[a] but it is also employed in connection with filtration of municipal supplies. Natural purification of water is accomplished largely through the biological processes mentioned by Hazen,[b] in which the organic matter is oxidized by serving as food for bacteria and objectionable organisms are destroyed by the production of conditions unfavorable to their existence. Action of this kind takes place in reservoirs and lakes, and it is also relied upon in many processes for the artificial purification of sewage.[c]

SLOW SAND FILTRATION.

Slow sand filtration consists in causing the water to pass slowly downward through a layer of sand of such thickness and fineness that the requisite removal of suspended substances is accomplished. The filter is also called the continuous and the English filter. On the bottom of a water-tight basin commonly constructed of concrete perforated tiles or pipes laid in the form of a grid are covered with a foot of gravel graded in size from 25 to 3 millimeters in diameter from bottom to top, and a layer of fine sand 3 to 4 feet in depth is put over the gravel, which serves only to support the sand. When water is applied on the surface it passes through the sand and the gravel and flows away through the underdrain. The suspended materials, including bacteria, are removed by the sand, the action of which is rendered more efficient by the rapid formation of a mat of finely

[a] Phelps, E. B., The disinfection of sewage and sewage filter effluents; Water-Supply Paper U. S. Geol. Survey No. 229, 1909.

[b] Hazen, Allen, Clean water and how to get it, New York, 1907, p. 83.

[c] Winslow, C.-E. A., and Phelps, E. B., Investigations on the purification of Boston sewage, with a history of the sewage-disposal problem: Water-Supply Paper U. S. Geol. Survey No. 185, 1906.

divided sediment on the surface. When this film has become so thick that filtration is unduly retarded, the water is allowed to subside below the surface and about half an inch of sand is removed, after which filtration is resumed. The sand thus taken off is washed to free it from the collected impurities, and it is replaced on the beds after they have been reduced by successive scrapings to a thickness of about 20 inches. As cleaning necessitates temporary withdrawal of filters from service, they are divided into units of convenient size, usually half an acre each, so that the operation of the system may not be interrupted. Filters may be roofed and sodded; this facilitates cleaning by preventing the formation of ice, permits work on the filter beds in all kinds of weather, and inhibits algæ growths.

The foregoing are the essential features of a slow sand filter, but several adjuncts render this system more efficient. A clear-water basin for the filtered supply, covered to prevent deterioration of the water, is provided in order that the varying rate of consumption may not affect the rate of filtration. Clarification of turbid water is rendered more economical by allowing it to stand for one to three days, during which a large portion of the suspended matter is deposited, so that the time between sand scrapings is lengthened. Another form of pretreatment is passage through roughing, or preliminary, filters consisting of beds of slag, sponge, or stone, the water flowing at 15 to 20 times the rate in sand filters. A very large proportion of the suspended matter is thus removed. Objectionable odors and tastes may be obviated by aeration before or after filtration. Killing the bacteria before filtration by use of ozone or other germicides has also been proposed.

Slow sand filtration removes practically all the suspended matter and the bacteria. Color is only slightly reduced, and the hardness is not changed. The process is especially adapted to waters low in color, suspended matter, and animal pollution. Very small particles of clay are not removed by these filters and for waters containing them only for limited periods the addition of a coagulant before filtration has been proposed.[a] It can readily be seen that the efficiency of this kind of filter depends largely on the character of the sand, as the ability to prevent the passage of suspended matter is governed by the size of the spaces between the sand particles. The rate of filtration depends on the average size of the sand particles, the thickness of the sand bed, the head of water, and the turbidity. Under ordinary conditions of operation in the United States the rate in slow sand filters preceded by sedimentation is 2,000,000 to 4,000,000 gallons per acre per day.

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[a] Report of Hering, Fuller, and Hazen on the methods of purifying the water supply of the District of Columbia: Senate Rept. 2380, 56th Cong., 2d sess.

MECHANICAL FILTRATION.

The distinctive features of the mechanical process are the use of a coagulant and the high rate of filtration. The term "mechanical" is applied because of the contrivances for washing the filtering medium; the filter is also known as the American filter. The raw water during its entrance into the sedimentation basin, which is smaller than that used with slow sand filters, is treated with a definite proportion of some coagulant, which forms by its decomposition a gelatinous precipitate that unites and incloses the suspended material, including the bacteria, and absorbs the organic coloring matter. This combined action destroys color and makes suspended particles larger and therefore more readily removable. When aluminum sulphate, the coagulant most commonly used, is decomposed aluminum hydrate is precipitated and the sulphate radicle remains in solution, replacing an equivalent amount of carbonate, bicarbonate, or hydroxyl radicles. The natural alkalinity of many waters is sufficient to effect this reaction. According to Hazen [a] 1 part per million of ordinary aluminum sulphate should be allowed 0.6 part of alkalinity expressed as $CaCO_3$ to insure complete decomposition. If the alkalinity is not high enough, part of the aluminum sulphate remains in solution and good coagulation does not take place. Therefore lime or soda ash is added if the alkalinity is too low. The proper amount of aluminum sulphate to be used is determined by the amounts of color, organic matter, and suspended matter, and by the fineness of the suspended matter, and it is best ascertained by direct experimentation with the water to be purified. Ferrous sulphate is sometimes used instead of aluminum sulphate; lime must always be added with it in order to bring about proper coagulation.

The water with the coagulant is allowed to stand three or four hours in the sedimentation basin, where a large proportion of suspended particles is deposited. It is then passed rapidly through beds of sand or ground stone to remove the rest of the suspended matter. Many filters now in use are built of wood or iron in cylindrical form 10 to 20 feet in diameter, and some are designed so that filtration can be hastened by pressure. The sand, 30 to 50 inches deep, rests on a metallic floor containing perforations large enough to allow ready issue of the water but small enough to prevent passage of sand grains. When the filter has become clogged the flow of water is reversed, filtered water being forced upward through the sand to wash it and to remove the impurities, which pass over the top of the filter with the wasted water. A revolving rake with long prongs projecting downward into the sand mixes it during washing and prevents it from becoming graded into spots of coarse or fine particles. In recently constructed

[a] Hazen, Allen, Report of filtration commission of the city of Pittsburg, 1899, p. 57.

works rectangular filters 300 to 1,300 square feet in area have been built, and compressed air forced through the sand at intervals is used instead of a revolving rake for agitating the sand during washing. Larger orifices in the strainers are also being used and the introduction of sand is prevented by fine gravel over the strainer pipes. The rate of filtration is from 80,000,000, to 180,000,000 gallons per acre per day.[1] The time between washings is six to twelve hours, depending principally on the turbidity of the water applied to the filter, and 4 to 8 per cent of the water filtered is consumed in washing.

Mechanical filtration removes practically all suspended matter, reduces the color to an amount that is unobjectionable, and part of the dissolved iron is removed under some conditions. The permanent hardness of the water is increased in proportion to the amount of sulphate radicle added as aluminum sulphate, and if only enough lime to decompose the coagulant is added, the total hardness is increased. If larger amounts of lime are added, however, the hardness is reduced. If soda ash is used in place of lime the foaming constituents of the water are increased. The chemicals are always added in solution. As this method of filtration is used almost entirely for river waters, with fluctuating contents of suspended and dissolved matter, proper operation requires constant and intelligent attention.

COLD-WATER SOFTENING.

The principal object of water softening is to remove the substances that cause incrustations in boilers, particularly calcium and magnesium, and to neutralize those that cause corrosion. Chemicals of known strength properly dissolved in water are added to the raw supply in such proportion as to precipitate all the dissolved constituents that can be economically removed by such treatment. The water is then allowed to stand long enough to permit the precipitate to settle, after which the clear effluent is drawn off; or, if more rapid operation is desired, filters of the rapid type may be used after sedimentation. The water softeners on the market differ only in the precipitant, in the filtering medium if one is used, and in the mechanism regulating the incorporation of the chemicals with the water.

Among the substances that have been proposed as precipitants are sodium carbonate, silicate, hydrate, fluoride, and phosphate, barium carbonate, oxide, and hydrate, and calcium oxide, but of these substances lime and soda ash are almost exclusively used on account of their excellent action and comparative cheapness. When soda ash (Na_2CO_3) and lime dissolved in water to form a solution of calcium hydrate [$Ca(OH)_2$] are added to a water in proper proportion, free acids are neutralized, free carbon dioxide is removed, the bicarbonate radicle is decomposed, and iron, aluminum, and magnesium hydrates and calcium carbonate are precipitated. These four basic substances are removed to the extent of the solubility of these compounds in water, and the calcium added as lime is also precipitated, but the sodium from the soda ash remains in solution in the softened water. The precipitate in settling takes down with it a large proportion of the suspended matter. The filters are thin beds of coke, sponge, excelsior, wool, or similar material, through which the water is passed at a very rapid rate to remove particles that have not subsided in the tanks.

Such treatment with lime and soda ash removes a large percentage of the iron, aluminum, calcium, magnesium, carbonates, bicarbonates, and free carbon dioxide and suspended matter, and part of the silica and the organic matter; in other words, the incrusting constituents are removed. Sodium, potassium, sulphates, and chlorides are left in solution, and the alkalies are increased in proportion to the quantity of soda ash that is added; that is, the foaming constituents are increased, and this fixes the maximum amount of incrustants that can be treated. The minimum amount of incrustants in a treated water is determined by the solubility of the precipitated substances and by the completeness of the reaction between the added chemicals and the dissolved matter. It is about 90 parts per million. The sulphate radicle can be removed by using barium compounds, which precipitate barium sulphate, but the poisonous effect of even small amounts of barium is a great objection to its use. The chlorides are not changed in amount by water softening. The chemicals should be very thoroughly mixed with the raw water and sufficient time should be allowed for complete reaction, which proceeds rather slowly, for otherwise precipitation will occur later in pipe lines or in boilers.

FEED-WATER HEATING.

Water heaters are designed primarily to utilize waste heat in stationary boiler plants by raising the temperature of the feed water and thereby lessening the work of the boilers themselves. This is their primary function, but some purification of water occurs in them and many heaters have been specially constructed to take advantage of that effect. The heat is derived from exhaust steam or from flue gases, and the heaters utilizing steam are either open—that is, operated at atmospheric pressure—or closed and operated at or near boiler pressure. In accordance with these three conditions, which result in distinct purifying effects, feed-water heaters are classified as open or closed or economizers, the last being those using flue gases. Open heaters are best adapted for removing large quantities of scale-forming material. In most forms the steam enters at the bottom and the water at the top, and intimate contact between the two is obtained by spraying the water or by allowing it to trickle over or to splash against plates. In this manner the water is quickly heated nearly to boiling temperature. Dissolved gases are expelled, the bicarbonate radicle is decomposed, and iron, aluminum, part of the magnesium, and calcium equivalent to the carbonates after decomposition of the bicarbonates are precipitated as hydrates, oxides, or carbonates under varying conditions of temperature, pressure, and time. The precipitate agglomerates the particles of suspended matter and makes them more readily removable by sedimentation and filtration. The slowness with which the reactions take place and the presence of acid radicles other than carbonates to hold the bases in solution prevent complete removal of calcium and magnesium. The addition of soda ash in proper proportion, however, effects fairly complete precipitation of the alkaline earths, and apparatus for constant introduction of this chemical in solution may be provided. After the precipitate has been formed the water passes through filters of burlap, excelsior, straw, hay, wool, coke, or similar material, arranged in units that can be readily cleaned. Open heaters operated without a chemical precipitant remove substances that are soft and bulky and leave in the water the constituents that form hard scale; therefore scale from water treated in such heaters is not so great in amount but is harder than that formed by the raw water.

In closed heaters the water is passed either through metal tubes surrounded by steam or around steam pipes, and manholes or other openings are provided for cleaning the scale from the tubes. As the water is heated under pressure some precipitation takes place, but closed heaters are not nearly so efficient in this respect as open heaters because there is no provision for the escape of the gases liberated from the water.

Economizers consist essentially of water tubes set in the flues leading from the furnaces. Facilities are provided for cleaning scale from the inside and soot from the outside of the tubes. As economizers are heated by flue gases, the water in the tubes under boiler pressure can be heated to a much higher temperature than in open or closed heaters, and boiler conditions as described on pages 238–244 are approximated. The precipitation of incrustants varies greatly with the normally fluctuating temperature of the flue gases.

CHEMICAL COMPOSITION OF THE WATERS.

WATER FROM THE UNCONSOLIDATED DEPOSITS.

In the tables in the body of the report 169 analyses are given of waters from wells drawing their supplies from the unconsolidated deposits of sand, clay, gravel, and alluvium overlying the solid rock.

The sources of water range in depth from 10 to 230 feet. They can not be differentiated, except in respect to depth of the well and geographic position, not only because it was impossible to procure information regarding the depth and character of the water-bearing strata of each well, but chiefly because most of the deeper wells yield mixed waters from two or more beds. Indeed, sharp distinction between the different water-bearing sands and gravels, though interesting, would hardly be profitable, on account of the heterogeneous nature of the unconsolidated deposits and the extremely local value of such detailed study in comparison with its importance in revealing the chemical composition of the waters.

The quality of the waters from the unconsolidated deposits, as indicated by averaging all the analyses, is shown in line A of the following table. Many of the analyses are incomplete, because the alkalies were not determined; and the figure for sodium and potassium is therefore the one most likely to be in error in all the averages. In order to ascertain whether drift waters from different parts of the region are similar it was divided into four parts by east and west lines and the analyses for each part were averaged as a group. The figures in lines B, C, D, and E represent the average quality of the waters from the unconsolidated deposits in the north, north middle, south middle, and south tiers of counties respectively. Bicarbonates, sulphates, and total solids show definite increase from north to south; the other figures are either similar or inconclusive on account of the small number of quantities averaged. In total mineral content the average for wells in the north tier is 72 parts lower and in the south tier 108 parts higher than the average for all in line A; yet inspection of the individual analyses in each group proves that waters from wells in different parts of the same township may diverge from one another far more widely in essential characteristics than waters from different tiers of counties. Many waters in the northern part of the region carry more than 600 parts of total solids and many in the southern part less than 400 parts. Therefore it must be concluded that the quality of water from the unconsolidated deposits has no relation to geographic position in this region, except that possibly the waters in the southern part may be slightly more highly mineralized than those in the northern part.

Quality of waters from the unconsolidated deposits.

[Parts per million except as otherwise stated.]

	Number of analyses.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
A....	169	18	0.8	91	31	18	0.0	306	76	2.8	47	467
B....	71	17	.7	83	29	13	.0	290	57	3.7	76	395
C.....	37	21	1.0	95	29	11	.0	292	76	2.0	18	464
D....	37	24	.8	98	33	9	.0	319	98	2.2	23	520
E....	24	17	.9	96	35	44	.0	359	100	2.5	45	575
F....	45	....	.3	110	36	21	.0	310	136	3.3	50	619
G....	....	4.1	[a].3	20.9	7.1	4.1	34.6	....	17.5	.6	10.8	....

[a] Fe_2O_3.

A. Average of all analyses of water from unconsolidated deposits.
B, C, D, and E. Average of all analyses arranged in four groups from north to south geographically.
F. Average of analyses of water from wells less than 30 feet deep. Na+K calculated.
G. Percentage composition of anhydrous residue computed from A.

Consideration of quality in reference to depth reveals no striking relation except that many shallow wells are more highly mineralized than deeper ones. Forty-five of the 169 waters are from wells less than 30 feet deep, and the average of their analyses is given in line F of the foregoing table, the alkali figure being computed from the other estimates. All the constituents are higher than in line A, and calcium and sulphates are especially high. The difference is more marked in the southern than in the northern half of the territory, for the total solids of all waters from shallow wells reported from the two southern tiers of counties exceed 1,000 parts. The small number of analyses available for discussion, however, makes it uncertain whether this difference is general, and it is therefore unwise to indulge in speculation on this topic.

Though the individual waters in the drift differ from each other in their concentration and to a less extent in the relative amounts of mineral matter that they contain, they are all of the same general type. They contain from 250 to 1,000 parts per million of total solids and they range from fair to bad for boiler use. Some of them contain so much iron that they are undesirable for laundry use, and most of them carry calcium and magnesium enough to make it necessary to soften them with chemicals before using them for washing. Generally the waters are acceptable for drinking. The average total hardness expressed as $CaCO_3$ is 360 parts per million, and the average total incrustants are 340 parts per million, or 2.82 pounds per 1,000 gallons. The average chemical composition of the anhydrous residue, given in line G, indicates that the waters are of the alkaline class, with bicarbonates largely predominating and with sulphates, chlorides, and alkalies usually present only in nominal amounts. The ratio of calcium to magnesium averages 3 and ranges normally from 2 to 5.

WATER FROM THE ROCK.

Two distinct types of water are contained in the formations underlying the drift in this area, and the relative position of the rocks that bear them can readily be understood from the generalized section on page 36. The lower limestones and sandstones yield hard, salt waters, generally carrying hydrogen sulphide; the upper limestones yield waters that are hard but not salty and are not impregnated with hydrogen sulphide except by intrusion from below. In the tables in the body of this report 88 analyses are given of waters coming wholly or mainly from the rock, and five of the analyses evidently represent the supply from the lower formations. Though these five waters differ considerably from each other in concentration, their average, as shown in lines A and B of the following table, gives a fair idea of their character:

Quality of waters from the rocks.

[Parts per million except as otherwise stated.]

	Number of analyses.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3)	Chlorine (Cl).	Total solids.
A....	5	14	0.7	205	104	820	0.0	400	170	....	1,570	3,890
B....	5	.4	[a].0	6.7	3.4	26.6	6.4	....	5.5	0.0	51.0	....
C....	83	18	1.8	82	31	27	.0	341	70	1.0	19	466
D....	169	18	.8	91	31	18	.0	306	76	2.8	47	467
E....	83	4.4	[a].4	19.6	7.4	6.5	40.2	....	16.8	.2	4.5	....
F....	169	4.1	[a].3	20.9	7.1	4.1	34.6	....	17.5	.6	10.8	....

[a] Fe_2O_3.

A. Average of analyses of water from lower limestones.
B. Percentage composition of anhydrous residue, computed from A.
C. Average of analyses of water from upper, or fresh-water, limestones.
D. Average of analyses of water from unconsolidated deposits.
E. Percentage composition of anhydrous residue, computed from C.
F. Percentage composition of anhydrous residue, computed from D.

The waters from the lower formations are very high in mineral content, and especially in chlorides, sulphates, alkalies, and calcium, being unfit for domestic or industrial use. These and other waters strongly polluted by them can readily be recognized by their chemical composition. The total solids exceed 700, the chlorides exceed 100, generally being 400 or 500, and there is commonly an odor of hydrogen sulphide. The large amount of magnesium in proportion to calcium is also distinctive. Such waters are encountered in drilling for gas and oil. The mixture of petroleum and salt water pumped from oil wells is run into tanks and allowed to settle, after which the water is drawn off and wasted, as a very highly mineralized liquid containing some petroleum and having a yellow to black color and an odor like a mixture of kerosene and rotten eggs. Part of it soaks into the ground near the pumping station, polluting the fresh-water supplies, and part runs into the streams, materially altering their composition. The problem of disposing of these oil-well wastes has been discussed by Bowman,[a] and it resolves itself into the practical question whether the ground waters or the streams shall be polluted. When wells drilled for oil are unproductive or when they cease to yield paying quantities of oil, the casings are often drawn out. Sometimes the casings are plugged above the salt water and split or partly withdrawn to permit entrance of water from the fresh-water limestones, so that the wells may yield potable supplies. In either case unless the well holes are carefully plugged above the "Trenton" limestone the salt water rises, mixes with the fresh water in the upper strata, and destroys sources of good supply, not only at that point, but also over an extensive area by infiltration. The danger of polluting fresh waters in this manner has repeatedly been referred to in the annual reports of the Indiana natural gas inspector, and state laws require proper plugging of abandoned holes.[b]

The mean composition of the water from the upper limestones, as computed from 83 analyses, is given in lines C and E of the foregoing table. Comparison with lines D and F draws attention to the great similarity between these waters and those of the drift. The limestone waters average lower in chlorides and higher in bicarbonates, a feature that makes them better for boiler use; many carry large amounts of iron, and the average iron content is more than twice that of the drift waters. Inspection of the individual analyses shows that the waters of the upper limestones differ locally from one another as much as the drift waters do, but that there is no tendency to increased mineral content toward the south. All these facts indicate that no general distinctions can be made between the quality of the waters from the drift and the quality of those from the fresh-water limestones, but that marked local differences may occur.

SURFACE WATER.

From August, 1906, to September, 1907, daily samples of water were collected from streams in or near the region under discussion and united in sets of ten consecutive samples, and analyses of the composites thus obtained permit computation of maximum, minimum, and average conditions. The results in detail have been published in Water-Supply Paper 236.[c] Samples of water from Wabash River at Logansport were collected by Mr. John Bender in midstream above the entrance of Eel River; lines A, B, and C in the following table give the mean, maximum, and minimum values, respectively, of the estimates. Wabash River was examined also at Vincennes, where Mr. L. J. Weisenberger collected samples from the waterworks

[a] Bowman, Isaiah, Disposal of oil-well wastes at Marion, Ind.: Water-Supply Paper U. S. Geol. Survey No. 113, 1905, p. 36.

[b] Thirty-second Ann. Rept. Indiana Dept. Geology and Nat. Res., 1907, pp. 590 et seq.

[c] Dole, R. B., The quality of surface waters in the United States, pt. 1: Water-Supply Paper U. S. Geol. Survey No. 236, 1910.

intake. The mean, maximum, and minimum values for the water at Vincennes are given in lines D, E, and F. At Indianapolis samples of water from West Fork of White River were taken in midstream under the direction of Mr. H. E. Jordan. Lines G, H, and I show the mean and the limits during the year for White River at Indianapolis. East Fork of White River was tested at Azalia, where samples were collected by Mr. L. E. Davis, and the summarized results are reported in lines J, K, and L. For comparison the average quality of the water of Lake Huron is given in line M, as computed from analyses of 12 monthly samples taken at Port Huron, Mich. The percentage composition of the anhydrous residues, computed from the mean quality of the same waters, is reported in lines N, O, P, Q, and R thus: Line N, percentage composition of the anhydrous residue of water from Wabash River at Logansport; line O, the same from Wabash River at Vincennes; P, West Fork of White River at Indianapolis; Q, East Fork of White River at Azalia; R, Lake Huron at Port Huron, Mich.

Quality of the surface waters.

[Parts per million, except as otherwise stated.]

	Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrare radicle (NO_3).	Chlorine (Cl).	Total solids.
A	132	117	14	0.23	82	35	142	0.0	234	79	5.9	292	807
B	900	802	38	1.2	133	77	478	7.9	317	138	18	960	1,940
C	Tr.	Tr.	5.0	Tr.	43	15	22	.0	116	42	.0	35	309
D	172	193	13	.24	61	22	25	.0	230	55	6.4	36	336
E	625	656	36	1.8	75	30	60	.0	264	73	18	104	504
F	15	18	3.0	Tr.	45	15	8.1	.0	147	37	1.1	8.3	209
G	39	38	14	.15	74	29	48	.0	291	58	6.1	78	450
H	235	124	27	.8	95	43	138	6.5	353	125	14	262	798
I	Tr.	Tr.	8.4	Tr.	48	17	14	.0	205	36	.5	13	245
J	52	48	15	.14	61	23	9.5	.0	276	30	5.6	3.1	279
K	245	240	29	1.2	70	29	16	12	320	40	12	8.0	334
L	3	Tr.	6.6	Tr.	42	15	5.2	.0	176	18	.5	1.3	196
M	Tr.	Tr.	12	.04	24	7.0	4.4	1.8	100	6.2	.4	2.6	108

PERCENTAGE COMPOSITION OF THE ANHYDROUS RESIDUES.

N	....	....	1.8	*a* .0	10.7	4.6	18.5	15.1	....	10.3	.8	38.2	....
O	....	....	3.9	*a* .1	18.4	6.6	7.5	34.1	....	16.6	2.0	10.8	....
P	....	....	3.1	*a* .0	16.4	6.4	10.7	31.8	....	12.9	1.4	17.3	....
Q	....	....	5.3	*a* .1	21.5	8.1	3.3	48.0	....	10.6	2.0	1.1	....
R	....	....	11.1	*a* .0	22.3	6.5	4.1	47.4	....	5.8	.4	2.4	....

a Fe_2O_3.

A, B, C. Wabash River at Logansport; analyses by W. M. Barr, H. S. Spaulding, and Walton Van Winkle.
D, E, F. Wabash River at Vincennes; analyses by W. M. Barr, H. S. Spaulding, and Walton Van Winkle.
G, H, I. West Fork of White River at Indianapolis; analyses by W. M. Barr, H. S. Spaulding, and Walton Van Winkle.
J, K, L. East Fork of White River at Azalia; analyses by W. M. Barr, H. S. Spaulding, Walton Van Winkle, R. B. Dole, Chase Palmer, and W. D. Collins.
M. Lake Huron at Port Huron, Mich.; analyses by R. B. Dole and M. G. Roberts.
N, O, P, Q, R. Percentage composition of the anhydrous residues computed from A, D, G, J, and M, respectively

The most noticeable feature in the foregoing table is the unusually high mineral content of Wabash River at Logansport, which averages 807 parts per million, as compared with 466 and 467 for the ground waters of the same region; another noticeable feature is the great fluctuation in mineral content, which ranges from 309 to 1,940 parts per million. From line N it can be seen that the water is particularly high in alkalies and chlorides, and inspection of the individual analyses shows that high chlorides and alkalies are always coincident with high total solids. The chief reason for these phenomena is undoubtedly varying pollution by salt water from oil wells, as noted on page 261, because surface waters from regions similar to this in rainfall and rock formations have not this peculiar compostion. Wabash River and its southern tributaries above Logansport, the Mississinewa and the Salamonie (see Pl. I), receive a large amount of drainage from the oil belt, and physical evidence of this pollution, such as oil-stained and blackened vegetation, is encountered in the beds of streams. The scale formed in boilers using such water would be hard, and the water would also foam and corrode the boilers; at times of highest mineralization the water is unfit for boiler use. Though Vincennes is not in the region under discussion, analyses of the river water at that city have been introduced in order to show the improvement effected by dilution. The great change in concentration can be appreciated by comparing lines A and D. West Fork of White River at Indianapolis gives evidence of some oil-well drainage, but not to so great extent as Wabash River. (See lines G, H, and I.) The mean quality of this water is strikingly similar to that of the underground water. It differs principally in being higher in chlorides and alkalies and correspondingly lower in bicarbonates. As a source of industrial supply it is far superior to Wabash River at Logansport. East Fork of White River, sampled at Azalia, is not contaminated by oil wells, and its water is more or less typical of what the other rivers would be in their normal or unpolluted state and of streams in this section that do not receive oil-well drainage.

SUMMARY.

Figures representing the average chemical composition of the principal sources of water supply in this region are given in the following table. Line A shows the average of five analyses of waters from the lower limestones; line B, the average of 83 analyses of waters from the upper limestones; line C, the average of 169 analyses of waters from the unconsolidated deposits. The average mineral contents of the waters of the Wabash at Logansport and the White at Indianapolis are given in lines D and E, respectively.

Average quality of waters in north-central Indiana.

[Parts per million.]

	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
A	14	0.7	205	104	820	0.0	400	170	....	1,570	3,890
B	18	1.8	82	31	27	.0	341	70	1.0	19	466
C	18	.8	91	31	18	.0	306	76	2.8	47	467
D	14	.2	82	35	142	.0	234	79	5.9	292	807
E	14	.2	74	29	48	.0	291	58	6.1	78	450

The chief points of interest in this table are the high mineralization of the waters from the lower limestones and from Wabash River and the great similarity in composition of the waters from the upper limestones, the drift, and White River. As stated in the previous paragraphs, however, it should be recognized that the river waters fluctuate a great deal in composition and that the waters of local wells differ greatly from one another.

FIELD ASSAYS.

The following table gives some field assays of water made in 1904 during a survey of industrial water conditions in Wabash River valley. The methods of assay and computation are outlined on pages 230 et seq. The tests at Greenfield were made by Herman Stabler; the others were made by R. B. Dole. These results, though necessarily cruder and less reliable than laboratory analyses, serve to amplify and to corroborate the statements and conclusions noted in the preceding pages and indicate a field of practical usefulness for assays of this nature.

Field assays of waters in north-central Indiana.

[Parts per million.]

SURFACE WATERS.

No.	Location.	Date (1904).	Color.	Odor.	Turbidity.	Iron (Fe).	Chlorine (Cl).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Total hardness as $CaCO_3$.	Estimated incrustants.	Classification for boiler use.
....	Blue River at Columbia City	June 15	60	3 v	*a* 12	0.5	9	293	60	205	265	Fair.
....	Brandywine Creek at Greenfield	Apr. 15	25	2 v	*a* 10	1.0	5	284	*a* 10	275	264	Do.
....	Center Lake at Warsaw	June 17	40	2 v	*a* 5	Tr.	16	174	60	261	245	Good.
....	Deer Creek at Delphi	July 2	40	3 v	*a* 15	1.0	4	259	*a* 10	234	232	Do.
....	Eel River at Logansport	June 29	25	2 v	*a* 10	0.5	7	278	*a* 25	194	229	Do.
....	Manitou Lake at Rochester	June 23	56	4 v	*a* 14	....	22	140	*a* 20	161	152	Do.
....	Mississinewa River at Peru	..do....	96	2 M+2o	*a* 20	1.5	130	178	55	208	216	Fair.
....	Salamonie River at Lagro	June 20	25	3 M	50	4	930	213	115	395	366	Bad.
....	Tippecanoe River at Rochester	June 23	56	3 M	0	3	17	229	*a* 10	141	174	Good.
....	Tippecanoe River at Winamac	July 3	40	2 v	0	2.5	4	235	*a* 20	194	207	Do.
....	Tippecanoe River at Monticello	July 2	40	2 e	*a* 20	1.5	4	210	*a* 10	154	172	Do.
....	Wabash River at Lagro	June 20	40	2 e	80	2.8	172	202	90	261	278	Poor.
....	Wabash River at Logansport	June 30	60	4 v	55	2.5	186	213	75	234	260	Do.
....	Wabash River at Delphi	July 1	60	3 e	50	4	115	221	65	234	254	Do.
....	Wildcat Creek at Kokomo	July 7	56	4 e+2 M	390	Tr.	4	142	*a* 5	114	120	Good.
....	Winona Lake at Warsaw	June 17	56	2 v	*a* 5	Tr.	14	175	35	215	206	Do.

GROUND WATERS.

No.	Location.	Date (1904).	Color.	Odor.	Turbidity.	Iron (Fe).	Chlorine (Cl).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Total hardness as $CaCO_3$.	Estimated incrustants.	Classification for boiler use.
1	Delphi	July 1	0	0	0	3	4	295	*a* 10	234	248	Good.
2	....do	..do....	0	0	0	3	70	449	330	(*b*)	835	Bad.
3	....do	..do....	40	5 H_2S +5o	*a* 10	3	....	822	Tr.	....	679	Do.
4	....do	July 2	0	0	0	2.5	156	480	220	....	711	Do.
5	Greenfield	Apr. 15	....	0	0	2.5	4	363	Tr.	332	316	Fair.
6	....do	..do....	....	0	0	Tr.	39	384	45	416	399	Poor.
7	....do	..do....	0	0	0	3.5	12	379	45	402	389	Do.
8	Kokomo	July 7	0	2 e	0	3	12	330	85	261	326	Fair.
9	....do	..do....	....	5 H_2S	0	Tr.	50	357	Tr.	275	285	Poor.
10	....do	..do....	0	0	0	4	4	373	Tr.	248	278	Fair.
11	....do	July 8	0	2 e	0	11	17	260	980	529	1,069	Bad.
12	....do	..do....	0	2 e	*a* 10	3	9	384	Tr.	315	316	Fair.
13	Logansport	June 29	0	2 H_2S	0	0.5	17	352	40	275	312	Poor.
14	....do	June 30	0	5 H_2S	0	1.5	514	375	90	355	394	Bad.

15	Peru	June 23	0	0	0	1.0	67	323	70	234	300	Fair.
16	do	do	0	0	0	Tr.	50	369	40	315	339	Do.
17	do	do	0	0	0	Tr.	24	339	45	315	329	Do.
18	Rich Valley	July 21	40	2 o	a 20	2.5	582	253	95	422	384	Bad.
19	Rochester	July 24	0	0	0	.5	19	316	a 20	288	288	Fair.
20	do	do	0	0	0	2.5	9	323	Tr.	248	258	Do.
21	Wabash	July 21	0	1 H_2S	a 5	3	2	356	a 5	301	302	Do.
22	do	do	0	0	0	1.5	9	300	a 10	....	265	Good.
23	do	do	0	0	0	2.5	111	358	75	328	366	Poor.
24	do	do	0	0	a 5	1.0	42	346	120	315	386	Do.
25	do	do	0	0	0	2.5	127	402	185	440	518	Bad.
26	Warsaw	July 17	0	0	a 10	3	4	307	Tr.	261	258	Good.
27	do	do	0	0	0	Tr.	6	269	a 10	221	230	Do.
28	do	July 18	0	3 H_2S	a 5	3	4	323	Tr.	234	250	Poor.

a Estimated.

b More than 500.

1. Springs 3 miles from city used for city supply; water from gravel.
2. Well of Matthew Julius in North street. Dug and bored 54 feet deep; water from gravel.
3. Flowing well in rock about 900 feet deep at city pumping station; chlorine high.
4. Well of Mr. Swigman, 16 feet deep in gravel.
5. City water supply from deep wells in gravel.
6. Well at corner of East Main and North Pratt streets, 14 feet deep in gravel.
7. Well at corner of East Main and North Pratt streets, 22 feet deep in gravel.
8. One of city wells in limestone about 130 feet deep.
9. Flowing well in the city park; water from the rock.
10. Well in city park, penetrating limestone.
11. Gravel well 48 feet deep in Crown Point cemetery.
12. Well of L. E. Collier near city limits; 89 feet deep; water from limestone.
13. Gravel well in Spencer Park; 35 feet deep.
14. Well about 600 feet deep at city waterworks and electric-ligh tplant.
15. City well No. 17; water from limestone.
16. Spring in edge of bluff at plant of Peru Brewing Company.
17. Well at plant of Peru Brewing Company; well 206 feet in rock.
18. Large dug well in river bottom at power house of Union Traction Company. It is understood that part of this water came by a tile pipe from Wabash River.
19. Well on Pearl street near Lake Erie and Western Railroad tracks; 30 feet deep in gravel.
20. Well 405 feet deep at the court-house corner; enters limestone.
21. One of city wells in valley of Treaty Creek; 50 feet deep in gravel.
22. Well 11 feet deep in gravel used to furnish water for Cleveland, Cincinnati, Chicago and St. Louis Railway locomotives.
23. Wells sunk 24 to 30 feet in river bottom of alluvium at plant of United Boxboard and Paper Company.
24. Well in rock about 180 feet deep in court-house square.
25. Dug well in gravel 24 feet deep at 122 East Maple street.
26. Well in sand 46 feet deep at Winona Park.
27. Flowing well in sand 22 feet deep at Winona Park.
28. Well in rock on east shore of Pike Lake; depth unknown.

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